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(72) Inventeurs/Inventors:
SAHOO, MAHI, CA;
MURRAY, MICHAEL, US
(73) Propriétaire/Owner:
SLOAN VALVE COMPANY, US
(74) Agent: FINLAYSON & SINGLEHURST

(54) Titre : ALLIAGE DE CUIVRE A FAIBLE TENUEUR EN PLOMB MODIFIE A L'ANTIMOINE
(54) Title: ANTIMONY-MODIFIED LOW-LEAD COPPER ALLOY

	Cu	Sn	Pb	Zn	Fe	Sb	Ni	S	P	Al	Si	Mn	Zr	B	C	Ti
Lead-Free Semi-Red Brass - Sand Cast																
C84030	82.0-89.0	2.0-4.0	0.09	5.0-14.0	0.4	0.1-1.5	0.5-2.0	0.01-0.65	0.05	0.005	0.005	0.20	0.20	0.20	0.1	0.30
Lead-Free Tin Bronze - Sand Cast																
C90430	86.0-89.0	7.5-8.5	0.09	1.0-5.0	0.4	0.1-1.5	1.0	0.01-0.65	0.05	0.010	0.010	0.2	0.20	0.20	0.1	0.30
Lead-Free Yellow Brass - Permanent Mold Cast																
C85930	58.0-62.0	1.5	0.09	31.0-41.0	0.50	0.1-1.5	1.5	0.01-0.65	0.01	0.1-0.6	0.25	0.2	0.20	0.20	0.1	0.30
Lead-Free Yellow Brass Wrought																
C28330	58.0-62.0	--	0.09	31.0-41.0	0.35	0.1-1.5	--	0.01-0.65	--	--	--	0.2	0.20	0.20	0.1	0.3 0

(57) **Abrégé/Abstract:**

Alloys and methods for forming alloys of copper, including red brass, and yellow brass, having sulfur and antimony.

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- (71) **Applicant:** SLOAN VALVE COMPANY [US/US];
10500 Seymour Avenue, Franklin Park, Illinois 60131-
1259 (US).
- (72) **Inventors:** SAHOO, Mahi; 38 Bateman Dr., Ottawa,
Ontario K2G 5H4 (CA). MURRAY, Michael; 6121 N.
Sheridan Road, 4J, Chicago, Illinois 60660 (US).
- (74) **Agents:** MARTIN, Matthew E. et al.; Foley & Lardner
LLP, 3000 K St. N.W., Washington, District of Columbia
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(54) **Title:** ANTIMONY-MODIFIED LOW-LEAD COPPER ALLOY

FIGURE 2

	Cu	Sn	Pb	Zn	Fe	Sb	Ni	S	P	Al	Si	Mn	Zr	B	C	Ti
Lead-Free Semi-Red Brass - Sand Cast																
C84030	82.0-89.0	2.0-4.0	0.09	5.0-14.0	0.4	0.1-1.5	0.5-2.0	0.01-0.65	0.05	0.005	0.005	0.20	0.20	0.20	0.1	0.30
Lead-Free Tin Bronze - Sand Cast																
C90430	86.0-89.0	7.5-8.5	0.09	1.0-5.0	0.4	0.1-1.5	1.0	0.01-0.65	0.05	0.010	0.010	0.2	0.20	0.20	0.1	0.30
Lead-Free Yellow Brass - Permanent Mold Cast																
C83930	58.0-62.0	1.5	0.09	31.0-41.0	0.50	0.1-1.5	1.5	0.01-0.65	0.01	0.1-0.6	0.25	0.2	0.20	0.20	0.1	0.30
Lead-Free Yellow Brass Wrought																
C28330	58.0-62.0	--	0.09	31.0-41.0	0.35	0.1-1.5	--	0.01-0.65	--	--	--	0.2	0.20	0.20	0.1	0.30

(57) **Abstract:** Alloys and methods for forming alloys of copper, including red brass, and yellow brass, having sulfur and antimony.

WO 2013/166454 A1

ANTIMONY-MODIFIED LOW-LEAD COPPER ALLOY

Cross-reference to related applications

[0001] This application claims priority from United States Provisional Patent Application 61/642,260 filed May 3, 2012.

BACKGROUND OF THE INVENTION

[0002] Current plumbing materials are typically made from lead containing copper alloys. One standard brass alloy formulation is referred to in the art as C84400 or the "81,3,7,9" alloy (consisting of 81% copper, 3% tin, 7% lead, and 9% zinc) (hereinafter the "81 alloy"). While there has been a need, due to health and environmental issues [as dictated, in part, by the U.S. Environmental Protection Agency (EPA) on maximum lead content in copper alloys for drinking water applications] and also for cost reasons, to reduce lead contained in plumbing fitting, the presence of lead has continued to be necessary to achieve the desired properties of the alloy. For example, the presence of lead in a brass alloy provides for desirable mechanical characteristics and to assist in machining and finishing the casting. Simple removal of lead or reduction below certain levels substantially degrades the machinability as well as the structural integrity of the casting and is not practicable.

[0003] Removal or reduction of lead from brass alloys has been attempted previously. Such previous attempts in the art of substituting other elements in place of lead has resulted in major machining and finishing issues in the manufacturing process, which includes primary casting, primary machining, secondary machining, polishing, plating, and mechanical assembly.

[0004] Several low or no lead formulations have previously been described. See, for example, products sold under the trade names SeBiLOY[®] or EnviroBrass[®], Federalloy[®], Biwalite[™], Eco Brass[®], Bismuth Red brass (C89833), and Bismuth

Bronze (C89836), as well as U.S. patents 7,056,396 and 6,413,330. Figure 1 is a table that includes the formulation of several known alloys based upon their registration with the Copper Development Association (CDA). The existing art for low lead or no lead copper based castings consists of two major categories: silicon based materials and bismuth/selenium materials.

[0005] However, there is a need for a low-lead alloy casting solution providing a low-cost alloy with similar properties to current copper/lead alloys without degradation of mechanical properties or chemical properties, as well as significant disruption to the manufacturing process because of lead substitution in the material causing cutting tool and finishing problems.

SUMMARY OF THE INVENTION

[0006] One embodiment of the invention relates to a composition of matter comprising 82% to about 89% copper, about 0.01% to about 0.65% sulfur, greater than 0.1 to about 1.5% antimony, about 2.0% to about 4.0% tin, less than about 0.09% lead, about 5.0% to about 14.0% zinc, and about 0.5% to about 2.0% nickel.

[0007] In one embodiment of the invention, the composition comprises 86% to about 89% copper, about 0.01% to about 0.65% sulfur, greater than 0.1 to about 1.5% antimony, about 7.5% to about 8.5% tin, less than about 0.09% lead, about 1.0% to about 5.0% zinc, and about 1.0% % nickel.

[0008] In one embodiment of the invention, the composition comprises 58% to about 62% copper, about 0.01% to about 0.65% sulfur, greater than 0.1 to about 1.5% antimony, about 1.5% tin, less than about 0.09% lead, about 31.0% to about 41.0% zinc, and about 1.5% nickel.

[0009] In one embodiment of the invention, the composition comprises 58% to about 62% copper, about 0.01% to about 0.65% sulfur, greater than 0.1 to about 1.5% antimony, less than about 0.09% lead, and about 31.0% to about 41.0% zinc.

[0010] Another embodiment of the invention relates to a method for adding sulfur to a brass alloy. A base ingot is heated to a temperature of about 2,100 degrees Fahrenheit to form a melt. In one embodiment, Zn, Ni, and Sn are added to the copper the melt at about 2,124 F°, stibnite is added at about 2,164 F°, and phosphorous is added at about 2,164 F°. Stibnite wrapped in copper foil is added and the temperature maintained at about 2164F. In one embodiment, phosphorus deoxidation is also done at this temperature. Heating of the melt is ceased and additives, including tin, zinc, nickel, and carbon, are added at about 2124 F. At least a partial amount of slag is skimmed from the melt. Temperature of the melt is maintained at 2100 F. Slag is removed from the melt.

[0011] Additional features, advantages, and embodiments of the present disclosure may be set forth from consideration of the following detailed description, drawings, and claims. Moreover, it is to be understood that both the foregoing summary of the present disclosure and the following detailed description are exemplary and intended to provide further explanation without further limiting the scope of the present disclosure claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The foregoing and other objects, aspects, features, and advantages of the disclosure will become more apparent and better understood by referring to the following description taken in conjunction with the accompanying drawings, in which:

[0013] Figure 1 provides a table listing formulations for several known low-lead commercial copper alloys.

[0014] Figure 2 provides a table listing formulations of alloys in accordance with select embodiments of the invention.

[0015] Figure 3A and 3B is a table of chemical analysis of semi-red brass with copper coated graphite, MnS, and sulfur.

[0016] Figure 4A and 4B is a table of chemical analysis of semi-red brass with copper coated graphite and Stibnite in accordance with certain embodiments of the invention.

[0017] Figure 5A – 5c is a table indicating composition and mechanical properties of certain semi-red brass with copper coated graphite, MnS, and Sulfur.

[0018] Figure 6A -6C is a table indicating composition and mechanical properties of semi-red brass with copper coated graphite and antimony in accordance with certain embodiments of the invention.

[0019] Figure 7 is a table of chemical analysis of yellow brass having antimony in accordance with certain embodiments of the invention.

[0020] Figure 8 is a table indicating composition and mechanical properties of certain embodiments of yellow brass.

[0021] Figure 9 is an analysis of typical and minimum mechanical properties for certain embodiments of the invention and selected prior art alloys.

[0022] Figures 10A illustrates machining chip morphology of a semi-red brass with copper coated graphite (1.5%). Figures 10B illustrates machining chip morphology of a semi-red brass with copper coated graphite (“CCG”) (1.5%) and 1.3% MnS. Figures 10C illustrates machining chip morphology of a semi-red brass with 0.44% sulfur. Figures 10D illustrates machining chip morphology of a semi-red brass with 1.3% MnS. Figures 10E illustrates machining chip morphology of a semi-red brass 1.64% stibnite and 1.5% calcinated petroleum coke (“CPC”). Figures 10F illustrates machining chip morphology of a semi-red brass with 1.64% stibnite and 1.5% CPC. Figures 10G illustrates machining chip morphology of a semi-red brass with 1.64% stibnite. Figures 10H illustrates machining chip morphology of a semi-red brass with 1% stibnite. Figures 10I illustrates machining chip morphology of a semi-red brass with 0.8% stibnite. Figures 10J illustrates machining chip morphology of a semi-red brass with 1.2% stibnite, 1% copper coated graphite, and 0.08% boron.

[0023] Figures 11 illustrates machining chip morphology of a yellow brass with 1.5% copper coated graphite and 0.8% stibnite.

[0024] Figure 12 illustrates the machinability of the C84030 red brass and C28330 yellow brass in comparison to the commercially available C36000 leaded red brass.

[0025] Figure 13A is a graph depicting the relationship of amount of stibnite addition to three mechanical properties (UTS, YS, and % Elongation); Figure 13B is a graph depicting the relationship of antimony concentration to three mechanical properties (UTS, YS, and % Elongation); Figure 13C is a graph depicting the relationship of sulfur concentration to three mechanical properties (UTS, YS, and % Elongation).

[0026] Figure 14 is a table of the chemistries for the test samples indicated in the metallographic images of Figures 15A-17J.

[0027] Figure 15A: Photomicrograph showing inclusion size of sample 1109319. Figure 15B: SEM backscatter image of sample 1109319 at low magnification. Figure 15C: SEM backscatter image of sample 1109319 at higher magnification. Figure 15D: Element map of sample 1109319. Figure 15E: BE image of sample 1109319 showing annotated locations. Figure 15F: EDS spectrum of sample 1109319 - location 1. Figure 15G: EDS spectrum of sample 1109319 - location 2. Figure 15H: EDS spectrum of sample 1109319 - location 3. Figure 15I: EDS spectrum of sample 1109319 - location 4. Figure 15J Sample 1109319 element map.

[0028] Figure 16A: Photomicrograph showing inclusion size of sample 84XX42-022812-H20P2-9A. Figure 16B: SEM backscatter image of sample 84XX42-022812-H20P2-9A at low magnification. Figure 16C: SEM backscatter image of sample 84XX42-022812-H20P2-9A at higher magnification. Figure 16D: Element map of sample 84XX42-022812-H20P2-9A. Figure 16E: BE image of sample 84XX42-022812-H20P2-9A showing annotated locations. Figure 16F: EDS spectrum of sample 84XX42-022812-H20P2-9A - location 1. Figure 16G: EDS spectrum of sample 84XX42-022812-H20P2-9A - location 2. Figure 16H: EDS spectrum of sample 84XX42-022812-H20P2-9A - location 3. Figure 16I: EDS spectrum of

sample 84XX42-022812-H20P2-9A - location 4. Figure 16J: Sample 84XX42-022812-H20P2-9A element map.

[0029] Figure 17A: Photomicrograph showing inclusion size of sample 84XX9-013112-H18P2-10A. Figure 17B: SEM backscatter image of sample 84XX9-013112-H18P2-10A at low magnification. Figure 17C: SEM backscatter image of sample 84XX9-013112-H18P2-10A at higher magnification. Figure 17D: Element map of sample 84XX9-013112-H18P2-10A. Figure 17E: BE image of sample 84XX9-013112-H18P2-10A showing annotated locations. Figure 17F: EDS spectrum of sample 84XX9-013112-H18P2-10A - location 1. Figure 17G EDS spectrum of sample 84XX9-013112-H18P2-10A - location 2. Figure 17H: EDS spectrum of sample 84XX9-013112-H18P2-10A - location 3. Figure 17I: EDS spectrum of sample 84XX9-013112-H18P2-10A - location 4. Figure 17J: Sample 84XX9-013112-H18P2-10A element map.

[0030] Figure 18A: BE image of Perm Mold sample at low magnification. Figure 18B: BE image of Perm Mold sample at high magnification. Figure 18C: EDS spectrum of Perm Mold sample - location 1. Figure 18D: EDS spectrum of Perm Mold sample - location 2. Figure 18E: EDS spectrum of Perm Mold sample - location 3. Figure 18F: EDS spectrum of Perm Mold sample - location 4. Figure 18G: EDS spectrum of Perm Mold sample - location 5. Figure 18H: EDS spectrum of Perm Mold sample - location 6. Figure 18I: Element map of Perm Mold sample.

[0031] Figure 19A: BE image of Annealed sample at low magnification. Figure 19B: BE image of Annealed sample at high magnification. Figure 19C: EDS spectrum of Annealed sample - location 1. Figure 19D: EDS spectrum of Annealed sample - location 2. Figure 19E: EDS spectrum of Annealed sample - location 3. Figure 19F: EDS spectrum of Annealed sample - location 4. Figure 19G: EDS spectrum of Annealed sample - location 5. Figure 19H: EDS spectrum of Annealed sample - location 6. Figure 19I: EDS spectrum of Annealed sample - location 7. Figure 19J: Element map of Annealed sample.

[0032] Figure 20A: BE image of Cold Rolled sample at low magnification. Figure 20B: BE image of Cold Rolled sample at high magnification. Figure 20C: EDS spectrum of Cold Rolled sample - location 1. Figure 20D: EDS spectrum of Cold Rolled sample - location 2. Figure 20E: EDS spectrum of Cold Rolled sample - location 3. Figure 20F: EDS spectrum of Cold Rolled sample - location 4. Figure 20G: EDS spectrum of Cold Rolled sample - location 5. Figure 20H: Element map of Cold Rolled sample.

[0033] Figures 21A-C illustrate phase diagrams for semi-red brass and Alloy C84030. Figure 21A is a phase diagram for a red brass without antimony. Figure 21B is a phase diagram for semi-red brass with 0.8 wt% antimony. Figure 21C is a phase diagram for semi-red brass with 1.3 wt% antimony.

[0034] Figure 22A is a phase assemblage diagram of Semi-Red Brass with 0.8 Sb. Figure 22B is a magnified part of the phase assemblage diagram of Semi-Red Brass with 0.8 Sb. Figure 22C is a magnified part of the phase assemblage diagram of Semi-Red Brass with 1.3 Sb. Figure 22D is a magnified part of the phase assemblage diagram of Semi-Red Brass with 0.8 Sb – Scheil Cooling. Figure 22E is a magnified part of the phase assemblage diagram of Semi-Red Brass with 1.3 Sb – Scheil Cooling.

[0035] Figure 23 is phase diagram showing the location of the yellow brass alloy 61/38/0.3/0 Cu/Zn/Sn/Sb wt%.

[0036] Figure 24A is an equilibrium phase assemblage diagram of yellow brass with 0 wt% Sb. Figure 24B is an equilibrium phase assemblage diagram of yellow brass with 0.6 wt% Sb. Figure 24C is an equilibrium phase assemblage diagram of yellow brass with 1 wt% Sb. Figure 24D is a Scheil phase assemblage diagram of yellow brass with 0 wt% Sb. Figure 24E is a Scheil phase assemblage diagram of yellow brass with 0.6 wt% Sb. Figure 24F is a Scheil phase assemblage diagram of yellow brass with 1 wt% Sb.

[0037] Figure 25 is a free energy diagram.

[0038]Figure 26A shows dezincification corrosion (between lines) extends to a maximum depth of 0.0012" (31.2 microns) from the exposed surface (towards top) in the metallographic section prepared through the edge of the "MBAF 180" sample. Unetched. (494X). Figure 26B shows dezincification corrosion (between lines) extends to a maximum depth of 0.0113" (287.0 microns) from the exposed surface (towards top) in the metallographic section prepared through the core of the "MBAF 180" sample. Unetched. (201X).

[0039]Figure 27A shows dezincification corrosion (between lines) extends to a maximum depth of 0.04830" (1,228.1 microns) from the exposed surface (towards top) in the metallographic section prepared through the thin walled section of the "C36000 Ht# 1-Yeager" sample. Unetched. (50X). Figure 27B shows dezincification corrosion (between red lines) extends to a maximum depth of 0.05133" (1,303.8 microns) from the exposed surface (towards top) in the metallographic section prepared through the thick walled section of the "C36000 Ht# 1-Yeager" sample. Unetched. (50X).

[0040]Figure 28A shows no dezincification corrosion is present at the exposed surface (towards top) in the metallographic section prepared through the edge of the "28330-Lab# 358050 P4 H2a" sample. Unetched. (494X). Figure 28B shows dezincification corrosion (between lines) extends to a maximum depth of 0.0033" (82.8 microns) from the exposed surface (towards top) in the metallographic section prepared through the core of the "28330-Lab# 358050 P4 H2a" sample. Unetched. (494X).

[0041]Figure 29A shows no dezincification corrosion is present at the exposed surface (towards top) in the metallographic section prepared through the edge of the "84030-62412-H3P2-9" sample. Unetched. (494X). Figure 29B shows no dezincification corrosion is present at the exposed surface (towards top) in the metallographic section prepared through the edge of the "84030-62412-H3P2-9" sample. Unetched. (494X).

[0042] Figure 30 illustrates the chemical compositions of various alloys tested based on Design of Experiments (DOE).

[0043] Figure 31 illustrates the relation of alloy properties between C84030 red brass and two commercial brasses which were used as the base for the DOE.

[0044] Figure 32 illustrates the composition and mechanical properties of various tested alloys based on Design of Experiments (DOE).

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0045] In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented here. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the figures, can be arranged, substituted, combined, and designed in a wide variety of different configurations, all of which are explicitly contemplated and made part of this disclosure.

[0046] Brass alloys typically utilize lead as a chip breaker and to generally improve the qualities desirable in brass alloys for use in a wide range of situations, including plumbing. The use of sulfides as a replacement for lead has been previously taught in U.S. Patent Publication U.S. 2012/0121455 A1 March 17, 2012.

[0047] It has been observed that the addition of elemental sulfur in place of lead in a "standard" brass alloy may not result in the sulfur becoming integrated into the final alloy, but rather loss to the dross. As further described below, the brass alloys of the present invention utilize antimony for improved properties. In one embodiment, of the present invention a sulfur containing mineral, stibnite, is utilized as a source of sulfur and to provide antimony to the alloy.

[0048] Stibnite is a naturally occurring sulfide mineral in the form of Sb_2S_3 . Stibnite typically contains 26.7% sulfur, 69.2% antimony and 0.4% moisture. Apparent density is 1.19 g/cc. Particle size is 325 mesh or 44 microns. One embodiment, utilized in the examples noted below, contains 27% S and 69% Sb.

[0049] Figure 2 illustrates the nominal ranges for four alloy embodiments, each including antimony. C84030 is a red brass having sulfur and antimony. C90430 is a tin bronze having sulfur and antimony. C85930 is a yellow brass for permanent mold casting applications having sulfur and antimony. C28330 is a yellow brass for wrought applications having sulfur and antimony. For easy of reference, the respective embodiments will be referred to by these numbers throughout. The specific materials used for such formulations may be specified in certain embodiments.

Alloy components

[0050] The alloys of the present invention comprise copper, zinc, tin, sulfur, nickel, phosphorus, and antimony. In certain embodiments, one or more of manganese, zirconium, boron, titanium and/or carbon are included.

[0051] The alloys, comprise as a principal component, copper. Copper provides basic properties to the alloy, including antimicrobial properties and corrosion resistance. Pure copper has a relatively low yield strength, and tensile strength, and is not very hard relative to its common alloy classes of bronze and brass. Therefore, it is desirable to improve the properties of copper for use in many applications through alloying. The copper will typically be added as a base ingot. The base ingot's composition purity will vary depending on the source mine and post-mining processing. The copper may also be sourced from recycled materials, which can vary widely in composition. Therefore, it should be appreciated that ingot chemistry can vary, so, in one embodiment, the chemistry of the base ingot is taken into account. For example, the amount of zinc in the base ingot is taken into account when determining how much additional zinc to add to arrive at the desired final

composition for the alloy. The base ingot should be selected to provide the required copper for the alloy while considering the secondary elements in the base ingot and their intended presence in the final alloy since small amounts of various impurities, such as iron, are common and have no material effect on the desired properties.

[0052] Lead has typically been included as a component in copper alloys, particularly for applications such as plumbing where machinability is an important factor. Lead has a low melting point relative to many other elements common to copper alloys. As such, lead, in a copper alloy, tends to migrate to the interdendritic or grain boundary areas as the melt cools. The presence of lead at interdendritic or grain boundary areas can greatly improve machinability and pressure tightness. However, in recent decades the serious detrimental impacts of lead have made use of lead in many applications of copper alloys undesirable. In particular, the presence of the lead at the interdendritic or grain boundary areas, the feature that is generally accepted to improve machinability, is, in part, responsible for the unwanted ease with which lead can leach from a copper alloy.

[0053] Sulfur is added to the alloys of the present invention to overcome certain disadvantages of using leaded copper alloys. Sulfur present in the melt will typically react with transition metals also present in the melt to form transition metal sulphides. For example, copper sulfide and zinc sulfide may be formed, or, for embodiments where manganese is present, it can form manganese sulfide. Figure 25 illustrates a free-energy diagram for several transition metal sulphides that may form in embodiments of the present invention. The melting point for copper sulfide is 1130 Celsius, 1185 Celsius for zinc sulfide, 1610 Celsius for manganese sulfide, and 832 Celsius for tin sulfide. Thus, without limiting the scope of the invention, in light of the free energy of formation, it is believed that a significant amount of the sulfide formation will be zinc sulfide for those embodiments having no manganese. It is believed that sulphides that solidify after the copper has become to solidify, thus forming dendrites in the melt, aggregate at the interdendritic areas or grain boundaries.

[0054] Sulfur provides similar properties as lead would impart to a copper alloy, without the health concerns associated with lead. Sulfur forms sulphides which it is believed tend to aggregate at the interdendritic or grain boundary areas. The presence of the sulphides provides a break in the metallic structure and a point for the formation of a chip in the grain boundary region and improve machining lubricity, allowing for improved overall machinability. The sulphides predominate in the alloys of the present invention provide improved lubricity. Good distribution of sulphides improves pressure tightness, as well as, machinability.

[0055] It is believed that the presence of tin in some embodiments increases the strength and hardness but reduces ductility by solid solution strengthening and by forming Cu-Sn intermetallic phase such as Cu_3Sn . It also increases the solidification range. Casting fluidity increases with tin content. Tin also increases corrosion resistance. However, currently Sn is very expensive relative to other components.

[0056] With respect to zinc, it is believed that the presence of Zn is similar to that of Sn, but to a lesser degree, in certain embodiments approximately 2% Zn is roughly equivalent to 1 % Sn with respect to the above mentioned improvements to characteristics noted above. Zn increases strength and hardness by solid solution hardening. However, Cu-Zn alloys have a short freezing range. Zn is much less expensive than Sn.

[0057] With respect to certain embodiments, iron can be considered an impurity picked up from stirring rods, skimmers, etc during melting and pouring operations, or as an impurity in the base ingot. Such categories of impurity have no material effect on alloy properties.

[0058] [0059] In some embodiments, nickel is included to increase strength and hardness. Further, nickel aids in distribution of the sulphide particles in the alloy. In one embodiment, adding nickel helps the sulfide precipitate during the cooling process of the casting. The precipitation of the sulfide is desirable as the suspended sulfides act as a substitute to the lead for chip breaking and machining lubricity

during the post casting machining operations. With the lower lead content, it is believed that the sulfide precipitate will minimize the effects of lowered machinability.

[0060] Phosphorus may be added to provide deoxidation. The addition of phosphorus reduces the gas content in the liquid alloy. Removal of gas generally provides higher quality castings by reducing gas content in the melt and reducing porosity in the finished alloy. However, excess phosphorus can contribute to metal-mold reaction giving rise to low mechanical properties and porous castings.

[0061] Aluminum is, in some embodiments, such as semi-red brasses and tin bronzes, treated as an impurity. In such embodiments, aluminum has harmful effects on pressure tightness and mechanical properties. However, aluminum in yellow brass castings can selectively improve casting fluidity. It is believed that aluminum encourages a fine feathery dendritic structure in such embodiments which allows for easy flow of liquid metal.

[0062] Silicon is also considered an impurity. In foundries with multiple alloys, silicon based materials can lead to silicon contamination in non silicon containing alloys. A small amount of residual silicon can contaminate semi red brass alloys, making production of multiple alloys near impossible. In addition, the presence of silicon can reduce the mechanical properties of semi-red brass alloys.

[0063] Manganese may be added in certain embodiments. The manganese is believed to aid in the distribution of sulphides. In particular, the presence of manganese is believed to aid in the formation of and retention of zinc sulfide in the melt. In one embodiment, a small amount of manganese is added to improve pressure tightness. In one embodiment, manganese is added as MnS.

[0064] Either zirconium or boron may be added individually (not necessarily in combination) to produce a fine grained structure which improves surface finish of castings during polishing.

[0065] Carbon may be added in certain embodiments to improve pressure tightness, reduce porosity, and improve machinability. In one embodiment, carbon may be added to the alloy as copper coated graphite ("CCG"). One type of copper coated graphite product is available from Superior Graphite and sold under the name DesulcoMC™. One embodiment of the copper coated graphite utilizes graphite that contains 99.5% min carbon, 0.5% max ash, and 0.5% max moisture. US mesh size of particles is 200 or 125 microns. This graphite is coated with 60% Cu by weight and has very low S.

[0066] In another embodiment, carbon may be added to the alloy as calcinated petroleum coke ("CPC") also known as thermally purified coke. CPC may be screened to size. In one aspect, 1% sulfur is added and the CPC is coated with 60% Cu by weight. CPC, because of its relatively higher and coarser S content compared to copper coated graphite, imparts slightly higher S to the alloy and hence, better machinability.

[0067] It is believed that a majority of the carbon is not present in the final alloy. Rather, it is believed that carbon particles are formed that float to the surface as dross or reacting to form carbon dioxide (around 2100 F) that is released from the melt as a gas. It has been observed that final carbon content of alloy is about 0.005% with a low density of 2.2 g/cc. Carbon particles float and form CO₂ at 2100F (like a carbon boil) and purify the melt. Thus, the alloys utilizing carbon may be more homogeneous and pure compared with other additions such as S, MnS, stibnite etc. Further, the atomic radius of carbon is 0.91×10^{-10} M, which is smaller than that of copper (1.57×10^{-10} M). Without limiting the scope of the invention, it is believed that carbon because of its low atomic volume remains in the face centered cubic crystal lattice of copper, thus contributing to strength and ductility.

[0068] Titanium may be added in combination with carbon, such as in graphite form. Without limiting the scope of the invention, it is believed that the titanium aids in bonding the carbon particles with the copper matrix, particularly for raw graphite. For

embodiments utilizing copper coated with carbon, titanium may not be useful to distribute the carbon.

[0069] Brass alloys having antimony have been shown to exhibit dezincification resistance. In addition, antimony may aid in chip breaking by segregating to the grain boundaries. This provides for improved machinability. Sb forms compounds with Cu (Cu_2Sb) and Zn (ZnSb). As discussed further below in regard to the back scattered electron images (18B-F and 20B-F) in the alloy materials, Sb, if added as Stibnite, separates from the S and interacts with Sn and Cu. Antimony may be provided in the form of Stibnite, which has the benefit of also providing sulfur and avoiding certain issues that arise with the use of elemental sulfur.

Alloy Formulations

[0070] Figure 2 illustrates a table listing four embodiment corresponding to semi-red brass, tin bronze, yellow brass (permanent mold cast) and yellow brass (sand cast). Figure 3 is a table comparing the content of various alloy heats, with the components noted in the comments. Figure 3 provides a comparison, for example, of the sulfur content of alloys having various components. Figure 4 provides chemical compositions of embodiments of a semi-red brass having antimony and copper coated graphite. Figure 7 provides chemical compositions of embodiments of a yellow brass having antimony.

[0071] It can be observed that the use of stibnite provides sulfur to the finished alloy in a similar amount as some other components, such as the much more expensive MnS. As has been noted above, the use of sulfur in the alloy formation provides several problems, including environmental concerns due to the amount of sulfur dust and sulfur dioxide released, often violently, into the environment rather than integrated into the alloy melt. The use of sources of sulfur that provide for a better “yield” with regard to the amount of sulfur added and that retained in the finished alloy has been observed to be beneficial. Further, various sulfur sources could be utilized, but any non-sulfur component may have a negative impact on the properties

of the finished alloy. Further, cost and availability are a consideration for selecting a sulfide for use as a sulfur source in the alloy. It has been observed that stibnite in the range of 0.4 to 1.6% provides sulfur in the amount desired and the antimony that remains in the alloy does not have an unacceptable impact on the properties of the finished alloys. A discussion of the impact of the antimony on the alloy mechanical properties is discussed further below.

[0072] One embodiment of the invention relates to a composition of matter comprising 82% to about 89% copper, about 0.01% to about 0.65% sulfur, greater than 0 to about 1.5% antimony, about 2.0% to about 4.0% tin, less than about 0.09% lead, about 5.0% to about 14.0% zinc, and about 0.5 to about 2.0% nickel. In one embodiment, less than 0.65% sulfur is utilized to minimize the formation of gases such as sulfur dioxide, which negatively impact the mechanical properties of the finished product made from the alloy.

[0073] In one embodiment of the invention, the composition comprises 86% to about 89% copper, about 0.1% to about 0.65% sulfur, greater than 0 to about 1.5% antimony, about 7.5% to about 8.5% tin, less than about 0.09% lead, about 1.0% to about 5.0% zinc, and about 1.0% % nickel.

[0074] In one embodiment of the invention, the composition comprises 58% to about 62% copper, about 0.01% to about 0.65% sulfur, greater than 0 to about 1.5% antimony, about 1.5% tin, less than about 0.09% lead, about 31.0% to about 41.0% zinc, and about 1.5% % nickel.

[0075] In one embodiment of the invention, the composition comprises 58% to about 62% copper, about 0.01% to about 0.65% sulfur, greater than 0 to about 1.5% antimony, less than about 0.09% lead, and about 31.0% to about 41.0% zinc.

[0076] Figure 3 is a chemical analysis table showing examples of various semi-red brasses with copper coated graphite, MnS, and Sulfur. Figure 4 is a chemical analysis table showing examples of various semi-red brass with copper coated graphite and antimony in accordance with certain embodiments of the invention.

Figure 7 is a chemical analysis table showing embodiments of yellow brass with antimony in accordance with certain embodiments of the invention.

[0077] In one embodiment, the brass alloy includes stibnite. The stibnite may be added in the range of greater than zero but less than 1.2%. In one embodiment, the preferred range is about 0.4 to about 1.2%. In one embodiment, the stibnite is 1.64%. In an alternative embodiment, the stibnite is 0.6%. In an alternative embodiment, the stibnite is 0.4%. The preferred embodiment utilizes about 1% stibnite. Addition of elemental S contributes to environmental problems due to release of sulfur dust and SO_2 to the atmosphere. The use of stibnite provides a source of antimony and a source of sulfur, without the drawbacks associated with working with elemental sulfur in alloy melts. The preferred range for Sb, S and stibnite, in the final alloy, are 0.3 to 0.8%, 0.1 to 0.35% and 0.4 to 1% respectively. (This is evident from Figures 13B and 13C)

[0078] In certain embodiments, the brass alloy may include stibnite in combination with carbon. In one embodiment, the alloy includes 1.0% CCG or CPC and 1% stibnite. In a further embodiment, an additional 0.2% sulphur is provided for better machinability. In one embodiment, 1% carbon and 1% stibnite is utilized. In one embodiment, the stibnite is 0.6% and the carbon is 1. In an alternative embodiment, the stibnite is 1.64% and the carbon is 1.5%. In one embodiment, the carbon is copper coated graphite. In an alternative embodiment, the carbon is CPC.

[0079] It should be appreciated that the total amount of stibnite utilized in the melt can be varied to alter the amount of sulfur and the amount of antimony in the final alloy. For example, using a 27% S/69% Sb: 0.4 % Stibnite gives 0.071% S and 0.27% Sb; 0.6% Stibnite gives 0.12% S and 0.4 % Sb; 0.8% stibnite gives 0.2% S and 0.64% Sb; 1% stibnite gives 0.25% S and 0.77% Sb; 1.2% stibnite gives 0.278 % S and 0.859% Sb, and 1.64% Stibnite gives 0.4% S and 1.35 % Sb.

[0080] In one embodiment, about 0.5 to about 1.0 CCG (or CPC) together with about 0.8 to about 1.0 Stibnite provides desirable mechanical properties and machinability.

The use of the stibnite provides benefits of sulfur while avoiding many of the issues with using pure sulfur in an alloy melt, including flaring and excess dross. As shown in the SEM (Figures 15J, 16J, 17J, 18I, 19J, and 20H) the stibnite breaks down to Sb and S. Sb reacts with Cu and Sn to form intermetallic compounds; whereas S reacts with Cu and Zn to form their sulfides.

[0081] The addition of stibnite to provide sulfur and antimony provides several advantages over the use of elemental sulfur. The use of sulfur results in undesired consequences, including environmental impact. For example, sulfur addition to the melt may cause flaring that results in the loss of sulfur as well as dangerous conditions during the addition. Further, the use of sulfur directly results in a lower yield with respect to the percentage of added sulfur that enters the melt and the final alloy, as much of the sulfur is lost to dross. The increase in dross can cause other problems with the alloying.

[0082] In one embodiment, the stibnite is wrapped in copper foil prior to addition to the melt. The wrapped stibnite may be added after melting the ingots and bringing temperature to about 2000F.

[0083] In one embodiment, about 0.5 to about 1.0 CCG (or CPC) is utilized with about 0.8 to about 1.0 Stibnite to provide the best combination of mechanical properties and machinability. In a further embodiment, additional sulfur may be added to further increase the amount of sulfur in the alloy.

Alloy Characteristics

[0084] In one embodiment, an alloy of the present invention solidifies in a manner such that a multitude of discrete particles of sulfur/sulfide are distributed throughout in a generally uniform manner throughout the casting. These nonmetallic sulfur particles serve to improve lubricity and break chips developed during the machining of parts cast in this new alloy, thereby improving machinability with a significant or complete reduction in the amount of lead. Without limiting the scope of the invention, the sulfides are believed to improve lubricity. The presence of antimony further

improves properties of the C84030 red brass as described below. Embodiments utilizing stibnite provide for a source of antimony and sulfur while also delivering the sulfur in a form more readily compatible with the alloy melt process.

[0085] The preferred embodiments of the described alloy retain machinability advantages of the current leaded alloys. Further, it is believed that due to the relative scarcity of certain materials involved, the preferred embodiments of the ingot alloy will cost considerably less than that of the bismuth and/or selenium alloyed brasses that are currently advocated for replacement of leaded brass alloys. The sulfur is present in certain embodiments described herein as a sulfide which is soluble in the melt, but is precipitated as a sulfide during solidification and subsequent cooling of the alloy in a piece part. This precipitated sulfur enables improved machinability by serving as a chip breaker similar to the function of lead in alloys and in bismuth and selenium alloys. In the case of bismuth and/or selenium alloys the formation of bismuthides or selenides, along with some metallic bismuth, accomplishes a similar objective as this new sulfur containing alloy. The improvement in machinability may show up as increased tool life, improved machining surfaces, reduced tool forces, etc. This new idea also supplies the industry with a low lead brass/bronze which in today's environment is seeing any number of regulatory authorities limit by law the amount of lead that can be contained in plumbing fittings.

Melt Process

[0086] In one embodiment, graphite is placed on the bottom of the crucible prior to heating. In one embodiment, silicon carbide or clay graphite crucibles may be used in the melts. It is believed that the use of graphite reduces the loss of zinc during the heat without substantially becoming incorporated into the final alloy. In one embodiment, approximately two cups of graphite are used for a 90 to 95 lbs capacity crucible. For the examples used herein, a B-30 crucible was used for the melts, which has a capacity of 90 to 95 lbs of alloy. For embodiments using CPC or CCG, the carbon is wrapped in copper foil, preheated in oven at 150 C to drive off moisture and plunged into the melt followed by stirring.

[0087] Based upon the desired end alloy's formulation, the required base ingot is placed in the crucible and the furnace started. The base ingot, is brought to a temperature of about 1,149 degrees Celsius to form a melt. In one embodiment a conventional gas-fired furnace is used, and in another an induction furnace is used. The furnace is then turned off, i.e. the melt is no longer heated. Then the additives, except, in one embodiment, for sulfur and phosphorus, are then plunged into the melt between 15 to 20 seconds to achieve desired levels of Zn, Ni and Sn. The additives comprise the materials needed to achieve the final desired alloy composition for a given base ingot. In one embodiment, the additives comprise elemental forms of the elements to be present in the final alloy. Then a partial amount of slag is skimmed from the top of the melt.

[0088] The furnace is then brought to a temperature of about 1,171 Celsius. The furnace is then shut off and the sulfur additive is plunged in, such as in the form of stibnite. For certain embodiments having phosphorus added, such as for degassing/deoxidizing of the melt, the furnace is then reheated to a temperature of about 1,177 degrees Celsius and phosphorous is plunged into the melt as a Cu-P master alloy. Next, preferably all of the slag is skimmed from the top of the crucible. Tail castings for pressure testing and evaluation of machinability and plating, buttons, wedges and mini ingots for chemical analysis, and web bars for tensile testing are poured at about 1,149, about 1,116, and about 1,093 degrees Celsius respectively.

Mechanical Properties

[0089] Mechanical properties of various embodiments of the present alloys were tested as well as those for red brass without antimony added (as stibnite or otherwise). Sample heats, prepared in accordance with the process above and the resultant alloys were tested for ultimate tensile strength ("UTS"), yield strength ("YS"), percent elongation ("E%"), Brinnell hardness ("BHN"), and Modulus of Elasticity ("MoE").

[0090] Figure 5 shows composition and mechanical properties of a with one or more of copper coated graphite, MnS, and Sulfur. Table 1 (below in the section regarding machinability) provides an analysis of select properties of certain embodiments of the alloys of semi-red brass with copper coated graphite, MnS, and Sulfur, including machinability, mechanical properties, cost, etc. Figure 6 shows Composition and Mechanical Properties of Semi-red Brass C84030, illustrating semi-red brass with stibnite added and with various other combinations of MnS and copper coated graphite. As can be seen in Figures 5-6, the mechanical properties of semi-red Brass (SRB) with low amounts of Stibnite are generally around 40.5 ksi UTS, 18.3 ksi Ys and 41.0% elongation. The addition of stibnite in a yellow brass alloy, either for wrought or permanent mold casting, with all variations of antimony of Stibnite are generally around 49.83 ksi UTS, 29.0 ksi Ys and 7% elongation. The 1% stibnite alloy of C84030 provided 42.9 ksi UTS, 20.3 ksi YS, and 32% Elongation.

[0091] It has been observed that the sulfur content of SRB increases when MnS is added along with 0.4 and 0.6 % Stibnite. When 1.64% stibnite is utilized, the sulfur level goes to 0.4%, but Sb level also increases to 1.35%.

[0092] Antimony is observed to improve or not be detrimental to certain desirable properties of the brass alloy at low levels. Above 1.5% the antimony's presence begins to negatively impact mechanical properties. However, sufficient antimony is necessary to provide the improved characteristics. Thus, one embodiment of C84030 includes 0.1% to 1.5% antimony.

[0093] The use of carbon in a brass alloy provides beneficial results. SRB with CCG or CPC have UTS around 43.5ksi, YS of 18.1 ksi, but elongation in the range 59% (49 -61%). However, adding MnS to CCG decreases UTS slightly to (42.9 ksi), YS remains almost unchanged (17.95 ksi), elongation decreases to 33-51% (47% avg). High levels of stibnite, 1.64%, in combination with CCG or CPC decreases UTS to 38.5 ksi, YS is around 19.8 ksi and elongation drops to 17-22% (20% Avg).

[0094] The use of MnS in a brass alloy gives 42.3 ksi UTS, 18.08 ksi YS and 45% elongation. Adding MnS to CCG and CPC does give good combination of UTS, YS and % elongation. However, sulfur level is not high enough to produce desirable machinability. Besides, addition of MnS increases ingot cost significantly. Adding S to SRB gives 39.7 ksi UTS, 18.67 YS and 29% elongation.

[0095] Figure 8 is a table indicating composition and mechanical properties of certain embodiments of C28330 a yellow brass. Properties of certain embodiments of yellow brass C28330 have been compared with known leaded yellow brass alloys C26000 and C35600. Zr and B were added to heat P4H2A to see if grain refinement would produce any beneficial effect. There appears to have some benefits. UTS and hardness of the grain refined one are relatively higher in the cold rolled condition. % elongation and UTS of cold rolled and annealed at 1290 F are also relatively higher. It is believed that the grain size of this annealed sample is finer than that of heat P4H1. Figure 8 also includes information regarding annealing and cold working.

[0096] Overall, the tested embodiments of yellow brass C28330 had comparable results to the two leaded alloys C26000 and C35600 mentioned above. It is believed that quarter hard, half hard, hard and extra hard correspond to different stages of cold rolling such as 10%, 30%, 45% cold reduction etc. The hardness depends on the work hardening behaviour of the alloy. Embodiments of C28330 were cold rolled from 0.150 to 0.040 inch. This corresponds to 73% cold reduction. This is equivalent to extra hard condition.

[0097] Figure 9 summarizes the properties for several commercially available alloy compounds and for embodiments tested of the C84030 red brass and the C85930 yellow brass.

Machinability

[0098] Machinability was tested for certain embodiments of semi-red brass C84030 and yellow brass C28330. Machinability testing described in the present application was performed using the following method. The piece parts were machined by a

coolant fed, 2 axis, CNC Turning Center. The cutting tool was a carbide insert. The machinability is based on a ratio of energy that was used during the turning on the above mentioned CNC Turning Center. The calculation formula can be written as follows:

$$C_F = (E_1 / E_2) \times 100$$

C_F = Cutting Force

E_1 = Energy used during the turning of a "known" alloy C 36000 (CDA).

E_2 = Energy used during the turning of the New Alloy.

Feed rate = .005 IPR

Spindle Speed = 1,500 RPM

Depth of Cut = Radial Depth of Cut = 0.038 inches

[0099] An electrical meter was used to measure the electrical pull while the cutting tool was under load. This pull was captured via milliamp measurement. Table 1 below lists the chemical composition and machinability rating for several tested samples. Table 2 below lists the chemical composition and machinability rating for several tested samples of a C84030 red brass in accordance with the present invention. Table 3 below lists the chemical composition and machinability rating for several tested samples of a C28330 yellow brass in accordance with the present invention.

Table 1 MACHINABILITY RATING FOR SEMI-RED BRASS

Heat No	Cu	Sn	Zn	S	Mn	Pb	Sb	C	Mach Ratin g (%)	Addition
C84XX1- 012412- H1P1-7C	86.80	2.92	9.00	0.012	.001	.019	.005	.00 2	37	Only CCG(1. 5%)
C84XX2- 012412- H3P3-7C	86.83	3.00	8.81	0.087	.046	.017	.004	.00 2	36	1.5 %CCG +1.3 %MnS
C84XX5- 012512- H8P4-7X	86.96	2.99	8.54	0.298	.000 5	.019	.011		48	0.44 %Sulfur
C84XX6- 012612- H10P2-7X	86.90	3.04	8.62	0.162	.023	.017	.006		49	1.3 %MnS

Table 2 MACHINABILITY RATING FOR SEMI-RED BRASS C84030

Heat No	Cu	Sn	Zn	S	Mn	Pb	Sb	C	Mach Rating (%)	Addition
1109319	82.47	2.94	12.98	.169	.004	.019	.266		63	0.4%Stibnite+0.6 %MnS
1109308	82.77	2.81	12.94	.071	.0003	.020	.269			0.4 %Stibnite
1109330	82.10	2.95	13.26	.121	.0005	.034	.395		60	0.6 %Stibnite
1109341	83.00	2.79	12.29	.251	.007	.022	.418		62	0.6 %Stibnite + 1 %MnS
1109352	82.57	2.92	12.57	.264	.007	.024	.423		61	0.6% Stibnite+ 1 %MnS
84XX9-013112-H17P1-7-X-C	85.28	3.07	8.76	.379	.001	.035	1.32	.005	53	1.64 % Stibnite+ 1.5% CPC
84XX9-013112-H18P2-7-X-C	85.13	3.06	8.91	.386	.001	.033	1.34	.005	53	1.64 % Stibnite+ 1.5% CPC
84XX41-022812-H19P1-7X	86.59	2.91	8.72	.212	.001	.019	.641	.002	57	0.8 % Stibnite
84XX42-022812-H20P2-7X	86.41	2.92	8.68	.249	.0008	.02	.77	.002	59	1.0 % Stibnite
84030-062912-H7P1-7-C- B	84.49	2.80	10.10	.373	.001	.019	1.01	.002	49	1.2% Stibnite, 1% CCG, 0.08 B
84XX4-012512-H6P2	85.39	2.87	8.81	.428	.001	.050	1.26		39	1.64% Stibnite

Table 3 Yellow Brass C28330 Machinability Properties

Heat No	Cu	Sn	Zn	S	Mn	Pb	Sb	C	Mach Rating (%)	Addition
28330-030813-P4H2b*	61.00	1.45	36.92	.016	.032	.005	.336	.002	61	1.5% CCG, 0.8% Stibnite

*0.036% B, 0.010% Zr

[0100] Figures 10A-J illustrates the machinability of the C84030 red brass and Figure 11 illustrates C28330 yellow brass in comparison to the commercially available C36000 leaded red brass.

[0101] Machinability testing of embodiments of C84030 red brass indicate the addition of CCG does not improve machinability. There is some improvement in machinability when CCG and MnS are added together. The addition of sulfur improves machinability; however, addition of sulfur creates a lot of fumes in the melting area which is not environmentally friendly. The addition of MnS improves machinability; however, MnS is very expensive and increases ingot cost significantly. The addition of antimony as stibnite improves machinability. However, the benefits to machinability of embodiments of the C84030 red brass are lessened above 1% stibnite (for example, providing 0.8% antimony) as machinability decreases when stibnite content exceeds 1%. Further, it has been observed that antimony, for example provided as stibnite, in combination with MnS or CCP improves machinability. In one embodiment, a red-brass alloy includes 0.4-1% stibnite. In one embodiment, 0.3-0.8% antimony is included.

[0102] Machinability index of wrought alloy C28330 was 61%, which compares with C84030 containing Sb under 1%. It was observed that tail castings produced by permanent mold casting were used for machinability evaluation. These have a fine grain structure compared with sand cast C84030 tail castings. Chip morphology of C28330 was not good in comparison with C84030. However, it should be noted that the machined surfaces looked good. It should be appreciated that the possibility

exists that the machinability rating could change if different speeds, feeds and tool geometry were to be used and samples can be machined well with proper use of tools and appropriate feed rate and speed.

Effect of Stibnite, Antimony, and Sulfur content on Mechanical Properties of Semi Red Brass

[0103] Initially, the impact of sulfur upon the alloy's mechanical properties can be studied. Table 4 shows the effect of sulfur addition on mechanical properties (UTS, YS, and %Elongation) of four alloys from Figure 5. Two different target sulfur contents were tested to compare the impact of sulfur. As can be seen, the lower sulfur content of alloys 84XX5-H8P4-9A-X and 84XX5-H9P1-9A-X exhibited lower YS, but higher UTS and substantially higher %Elongation over the higher sulfur content alloys 84XX51-H21P3-9A-X and 84XX52-H22P1-9A-X. High S levels make the alloy drossy and less clean leading to inclusions and porosity in the castings and hence, lower UTS and %elongation. YS, however, remains unaffected.

Table 4 Effect of Sulfur Addition on Mechanical Properties

Alloy Number	Sulfur, Wt%	UTS, ksi	YS, ksi	% Elongation
84XX5-H8P4-9A-X	0.298	39.0	18.87	26.5
84XX5-H9P1-9A-X	0.289	40.45	18.48	31
84XX51-H21P3-9A-X	0.473	37.4	20.2	18
84XX52-H22P1-9A-X	0.487	34.0	19.98	14

[0104] The impact of various components in the alloys of the present invention was tested. Table 5 lists the seven alloys of the present invention from Figure 6. The mechanical properties of these alloys were tested. Specifically, UTS, YS, and %elongation. Table 5 also lists the weight percent for each of the sample alloys of stibnite, antimony, and sulfur. The UTS and YS exhibit a trend of improving (increasing) with a maximum at alloy 84XX42-H20P2-7X, which has 1.0 % stibnite, (0.770 antimony, and 0.249 sulfur). %Elongation exhibits a trend of decreasing as

the weight percent of each of stibnite, antimony, and sulfur increase, with the decrease between more pronounced at the higher percentages.

[0105] The back scattered electron images (Figures 15B-D and 15J; 16 B-D and 16H-J; and 17 B-J) show that Sb is associated with Sn and Cu. It is possible that a ternary compound of Cu-Sn-Sb forms. These compounds together with Sb in solid solution with Cu contribute to strength and ductility and also machinability. However, excess amount of Sb can have adverse effect on strength and ductility which has been observed in this investigation, for example as in case of 1.64 Stibnite addition (1.3% Sb in the alloy)

Table 5 Effect of Stibnite Content, Antimony and Sulfur on Mechanical Properties of Semi-Red Brass

Alloy Number	Stibnite, Wt%	Antimony, Wt%	Sulfur, Wt%	UTS, ksi	YS, ksi	% Elongation
1109312 2A	0.4	0.269	0.071	40.2	16.1	43.5
1109332 1A	0.6	0.395	0.121	40.5	17.15	39.5
84XX41-H19P1-7X	0.8	0.661	0.212	41.75	20.82	31
84XX42-H20P2-7X	1.0	0.770	0.249	42.30	20.35	33
84XX4-032212-7X	1.20	0.859	0.278	40.4	19.20	29.5
84XX9-H17P1-7-X-C	1.64	1.260	0.428	34.85	19.44	15.5
84XX9-H18P2-7-X-C	1.64	1.320	0.424	39.3	19.86	25.5

Micrographical Analysis

[0106] Micrographical analysis was done on certain embodiments of C84030 red brass as indicated in Figure 14. Sample 1109319 was from a button. The other two were from grip area of the tensile test bar.

Metallographic Procedure

[0107] A portion of each sample was mounted, metallographically prepared and then examined optically using an inverted metallograph and a scanning electron microscope equipped with energy dispersive spectroscopy (SEM/EDS) in backscatter electron (BE) mode for semi-quantitative chemical content and elemental mapping. BE mode achieves greater contrast between elements of differing atomic weight percentages.

Results -Red Brass

[0108] The observed microstructures consist of dispersed particles throughout the copper-rich matrix. As polished metallograph photomicrographs were taken at 500X. Image analysis was then performed to determine the particle size. The minimum, maximum and average measurements are reported in the following table. As polished photomicrographs are provided in Figures 15A, 16A, and 17A for each of the three tested sample alloys respectively.

[0109] A micrographical analysis of certain embodiments was undertaken to characterize the alloy and provide information regarding the microstructure and positioning of various elements within the alloy's structure. Figure 14 lists the chemistries for the alloys whose micrographs are shown in Figures 15-17. It appears stibnite breaks down to Sb and S. S forms ZnS and Cu₂S. Sb is in solid solution with the copper matrix and also appears to form a compound with Sn. Looking at the Sb-Sn phase diagram, there is an intermetallic compound Sn₃Sb₂ which forms over a composition range of 43.6 to 61 % Sb.

[0110] Figures 15A, 16A, and 17A, are a photographs of Sample 1109337, Sample 84XX42-022812-H20P2-9A, and 84XX9-013112-H18P2-10A, respectively, showing inclusions. Figures 15B and 15C are a SEM images of Sample 1109337. Figures 16B and 16C are a SEM images of Sample 84XX42-022812-H20P2-9A. Figures 17B and 17C are a SEM images of Sample 84XX9-013112-H18P2-10A. The dark materials illustrate sulfur distribution within the alloy. As can be seen, the sulfur

distribution as copper sulfides and zinc sulfides are present in dendritic and interdendritic areas.

[0111] Figure 15D illustrates elemental mapping of Sample 1109337 for sulfur, manganese, iron, nickel, copper, zinc, tin, and antimony. Figure 15J illustrates elemental mapping of Sample 1109337 for sulfur, iron, nickel, copper, zinc, tin, and antimony. The distribution of elements is indicative of the stibnite breaking down into antimony and sulfur. In particular, the antimony distribution of 15D and the sulfur distribution of 15D indicate that the antimony is not isolated to the regions with sulfur, i.e. still present as a sulfide. As can be seen in Figure 25, at the temperatures involved in the alloy melt (2164 degrees Fahrenheit), the observed elemental distribution is in agreement with the expected formation based upon the free energies of the involved reactions.

[0112] Figure 16D illustrates elemental mapping of Sample 84XX42-022812-H20P2-9A for sulfur, manganese, iron, nickel, copper, zinc, tin, and antimony. Figures 16J illustrates elemental mapping of Sample 84XX42-022812-H20P2-9A for sulfur, iron, nickel, copper, zinc, tin, antimony, phosphorous, and lead. The distribution of elements is indicative of the stibnite breaking down into antimony and sulfur. In particular, the antimony distribution of 16F and the sulfur distribution of 16D indicate that the antimony is not isolated to the regions with sulfur, i.e. still present as a sulfide. As can be seen in Figure 25, at the temperatures involved in the alloy melt (2164 degrees Fahrenheit), the observed elemental distribution is in agreement with the expected formation based upon the free energies of the involved reactions.

[0113] Figure 17D illustrates elemental mapping of Sample 84XX9-013112-H18P2-10A for sulfur, manganese, iron, nickel, copper, zinc, tin, and antimony. Figure 17J illustrates elemental mapping of Sample 84XX9-013112-H18P2-10A for sulfur, iron, nickel, copper, zinc, tin, antimony, phosphorous, and lead. The distribution of elements is indicative of the stibnite breaking down into antimony and sulfur. In particular, the antimony distribution of 18F and the sulfur distribution of 18D indicate that the antimony is not isolated to the regions with sulfur, i.e. still present as a

sulfide. As can be seen in Figure 25, at the temperatures involved in the alloy melt (2164 degrees Fahrenheit), the observed elemental distribution is in agreement with the expected formation based upon the free energies of the involved reactions.

[0114] The micrograph information supports the improved mechanical properties discussed above. Because some antimony remains in solid solution, a good %elongation is observed. The intermetallic compound and the solid solution contribute to strength. However, if there is too much intermetallic compound, strength and % elongation could gradually decrease. A decrease in UTS and % elongation is observed at 1.64% Stibnite addition.

[0115] SEM /EDS element analysis reveals dispersed particles primarily consisting of sulfur, zinc, tin, or antimony. SEM backscatter images taken at 200X and 1000X along with element maps at 1500X showing the requested element intensities are provided in Figures 15E-J, 16E-J, and 17E-J. Table 6 sets forth the particle size information for the tested alloys. The average particle size increases with Sb and S contents, shown in Figure 14

TABLE 6 PARTICLE SIZES FOR THE THREE SAMPLES

Sample ID	Minimum (μm)	Maximum (μm)	Average (μm)
1109319	0.1	16.6	1.2
84XX9-013112-H18P2-10A	0.1	22.8	1.8
84XX42-022812-H20P2-9A	0.2	18.1	3.8

[0116] SEM EDS spectra results of the base material from sample 1109320 consist of significant amounts of copper with lesser amounts of tin, nickel, and zinc (see location 1, Figure 15F). The light colored phase reveals significant amounts of copper, tin, and antimony with lesser amounts of nickel zinc (see location 2 and 4, Figure 15G and 15I). The dark colored phase reveals significant amounts of zinc and

sulfur with lesser amounts of nickel (see location 3, Figure 15H). Although the EDS spectra did not show any peaks for Sb, presence of Sb in the microstructure (matrix as well as some intermetallic compounds) is evident from the elemental maps (see Fig. 15D). Note, because Mn content of this sample is very low there was Mn detected in the area tested for Figure 15D but not in Figure 15J and the EDS spectra do now show a peak for Mn. This indicates a very non-uniform distribution of Mn. A semi-quantitative chemical analysis data is reported in Table 7 for the sample 1109320 locations indicated in Figure 15E.

TABLE 7 SEMI-QUANTITATIVE CHEMICAL ANALYSIS OF SAMPLE 1109319

Spectrum	S	Ni	Cu	Zn	Sn
Location 1	---	4.6	84.1	9.8	1.5
Location 2	---	2.1	65.6	4.6	27.6
Location 3	6.5	3.1	69.2	21.2	---
Location 4	---	2.3	65.9	4.1	27.8

[0117] SEM EDS spectra results of the base material from sample 84XX42-022812-H20P2-9A consist of significant amounts of copper with lesser amounts of tin, nickel, and zinc (see location 1, Figure 16E). The dark colored phase reveals significant amounts of zinc and sulfur with lesser amounts of copper (see location 2, Figure 16G). The light colored phase reveals significant amounts of copper, tin, and antimony with lesser amounts of phosphorous, lead, iron, nickel, and zinc (see location 3 and 4, Figures 16H, 16I).

[0118] Semi-quantitative chemical analysis data is reported in table 8 for the above locations. Sb is present in the matrix in solid solution and also in the intermetallic compounds.

TABLE 8 SEMI-QUANTITATIVE CHEMICAL ANALYSIS OF SAMPLE 84XX42-022812-H20P2-9A

Spectrum	P	S	Fe	Ni	Cu	Zn	Sn	Sb	Pb
Location 1	---	---	---	1.1	87.0	9.3	2.6	---	---
Location 2	---	29.2	---	---	2.3	68.4	---	---	---
Location 3	1.3	---	0.3	12.2	54.5	1.4	10.7	13.4	6.2
Location 4	---	---	0.1	4.5	80.3	5.4	6.0	2.4	1.2

[0119] SEM EDS spectra results of the base material from sample 84XX9-011312-H18P2-10A consist of significant amounts of copper with lesser amounts of tin, antimony, nickel and zinc (see location 1, Figure 17F). The light colored phase reveals significant amounts of copper, tin, and antimony with lesser amounts of nickel zinc (see location 2, Figure 17G). The dark colored phase reveals significant amounts of zinc and sulfur with lesser amounts of iron and copper (see location 3 and 4, Figures 17H, 17I). Location 4 (Figure 17J) reveals lesser amounts of nickel.

[0120] Semi-quantitative chemical analysis data is reported in Table 9 for the above locations. Sb is present in the matrix in solid solution and also in the intermetallic compounds.

TABLE 9 SEMI-QUANTITATIVE CHEMICAL ANALYSIS OF SAMPLE 84XX9-011312-H18P2-10A

Spectrum	S	K	Fe	Ni	Cu	Zn	Sn	Sb
Location 1	---	---	---	0.9	86.4	8.6	3.3	0.8
Location 2	---	---	---	4.4	57.7	1.5	16.2	20.1
Location 3	28.2	0.1	0.3	---	6.0	65.4	---	---
Location 4	17.7	---	0.3	0.6	29.6	50.6	1.1	---

RESULTS - Yellow Brass

[0121] Metallography work was also done on embodiments of yellow brass C28330. Chemistry of this alloy (28330-030613-P4H2A) is given in Figure 7. A section from each sample was hot mounted in conductive epoxy, metallographically prepared to a 0.04 micron final polish, and examined a SEM in backscatter mode to identify the observed particles. Backscatter mode achieves greater contrast between elements of different weight percentages. Evaluation consisted of backscatter electron (BE) beam images taken at low and high magnification, SEM/EDS spectra with semi-quantitative chemical content, and elemental mapping.

[0122] SEM/EDS spectra analysis was taken at several locations including the base material and dispersed inclusions throughout the base material on all three samples. Figures 18A-I show images and spectra results for the Perm Mold sample. Figures 19A-J show images and spectra results for the cold rolled and annealed sample. Figures 20A-H show images and spectra results for the Cold Rolled sample. Semi-quantitative data for each sample location are reported in the following table (Table 10).

Table 10

Sample ID	Location	S	Ti	Mn	Fe	Cu	Zn	Zr	Sn
Perm Mold Figure 18B	1					64.5	35.6		
	2					56.0	42.3		1.7
	3					56.7	36.2		7.1
	4	27.9		2.0		4.4	65.8		
	5					61.2	38.8		
	6		8.1	0.1	1.5	54.0	34.0	1.2	1.2
Annealed Figure 19B	1					57.9	39.8		2.4
	2					65.7	34.3		
	3				93.5	4.2	2.3		
	4					61.5	36.6		1.9

	5	25.6		3.5		10.8	60.1		
	6					59.6	36.5		3.9
	7		4.4	0.1	2.4	59.8	32.6		0.7
Cold Rolled Figure 20B	1					57.8	39.9		2.4
	2					63.3	36.1		0.6
	3					53.3	37.5		9.2
	4	25.4		2.8		13.5	58.4		
	5		4.4		0.6	55.7	36.9		2.5

[0123] Results are semi-quantitative, the spectra results are in weight percent unless otherwise indicated and the method used was SEM/EDS

[0124] The results indicate that grain size of permanent mold cast sample is about 50 microns (Fig.18A). Grains and second phase particles get elongated during cold rolling(Figs. 20A and 20B). Annealing at 1290 F has produced a recrystallized microstructure. Grains are equiaxed. (Fig.19B) Average grain size is about 70 microns. This is relatively coarser than the as-cast grain size. It is believed that for alloys of C28330 annealed at 1100 and 1200 F. there would be finer than 70 microns grains as evident from the elongation values. The large grain size of 1290 F annealing reduces the % elongation. Antimony content of the two alloys was in the range 0.3 to 0.4%. Although the tested regions did not show any antimony peaks it is believed to be due to the low levels. Antimony is believed to be in solid solution with Cu.

Analysis of Additives for Red Brass

[0125] As discussed above, copper may utilize a number of elements to alloy with. The use of stibnite as disclosed herein was tested in comparison to two forms of carbon, CCG and CPC, sulfur, manganese sulfide, and combinations thereof as indicated in Table 11.

Table 11 Analysis of mechanical properties and cost for red brass alloys

Additives	S	C	Sb	Mn	UTS	YS	% Elong	Machinability	Comments
CCG		0.002	-		43.3	18.1	57	37	1.5 CCG
CCG + MnS	.087-.108	0.002	-	0.046-0.053	42.3	17.8	48	36	1.5CCG+ 1.3 MnS
CCG + Stibnite	0.417	0.006	1.35	-	38.2	19.6	23	48	1.5CCG + 1.64 Stibnite.
Stibnite	0.428-0.424	-	1.32-1.26	-	38.3	19.7	23	39	1.64 Stibnite
Stibnite	0.249	-	0.77	-	42.3	20.35	33		1.0 Stibnite
Stibnite	0.212	-	0.64	-	41.75	20.82	31		0.8 Stibnite
Stibnite	0.071		0.269		40.5	16.25	45		0.4 Stibnite
Stibnite	0.121		0.395		40.0	17.08	36	60	0.6 Stibnite
Sulfur	0.298-0.289	-	-	-	39.7	18.7	29	48	0.4 S
MnS	0.162-0.123	-	-	0.023-0.033	42.1	18.1	45	49	1.3 MnS
CPC + MnS	0.121-0.122	0.005-0.007		0.047-0.052	41.4	17.9	46	51	1.5 CPC + 1.33 MnS
CPC	0.012-0.009	0.004-0.002	-	-	43.5	18.1	60	52	1.5 CPC
CPC + Stibnite	0.379-0.386	-	0.005	0.001	38.7	19.87	21	53	1.5 CPC+1.64 Stibnite

Phase Diagram

[0126] Phase information was gathered for red brass C84030 (Figures 21A-C, 22A-E) and yellow brass C28330 alloys (Figures 23 and 24A-F).

[0127] The base composition: 87 Cu, 9 Zn, 3 Sn, 1 Ni, 0.4 S for the red brass, plus the indicated amount of antimony. It is generally observed that Sb forms stable compounds with Cu (Cu_2Sb), with Mn (MnSb and Mn_2Sb) with Zn (ZnSb) and with S (Sb_2S_3). Among these, it is believed that only Cu_2Sb forms when Sb is added in the range of 0.4 to 1.3 wt%. The addition of Sb did not change the liquidus or the solidus temperatures. Figures 21A and 21B illustrate the phase diagrams of alloys having 0% antimony, 0.8%, and 1.3% antimony respectively.

[0128] Figure 22A is a phase assemblage diagram of Semi-Red Brass with 0.8 Sb. Less than 2 wt% Cu_2Sb formed, as can be seen in the magnified Figure 22B.

Magnified part of the phase assemblage diagram of Semi-Red Brass with 0.8 Sb. Figure 22C is a magnified part of a phase assemblage diagram of semi-red brass C84030 with 1.3% antimony. When the Sb content is increased to 1.3, the amount of Cu_2Sb increased to around 3 wt%. Similar amounts of Cu_2Sb form during Scheil cooling as well, as can be seen in Figures 19D (0.8% Sb) and 22E (1.3% Sb). Scheil cooling shows that one can expect the FCC solid solution phase (Cu containing Zn, Ni, some Sn and some Sb in solid solution), the beta (β') phase with Zn, Cu_3Sn intermetallic compound, Cu_2S and Cu_2Sb . Melting point is not affected by the addition of Sb and is about 1025 C which is close to equilibrium temp of 1030 C. Solidus temp under Scheil cooling is 825 C.

[0129] Microstructural analysis shows that there are Zn, Sn and Ni in solid solution with Cu. In view of the microstructure and the phase analysis, it is believed that stibnite breaks down to Sb and S. Some Sb is in solid solution with Cu and some forms Cu_2Sb compound. S combines with Zn and also Cu to form ZnS and Cu_2S . The high level of Sn and Cu in some phases indicates that it is Cu_3Sn phase.

Based on the observed phases described above, a 100 kg overall alloy will contain the following amounts of each phase in kg.

Table 12 Equilibrium phases

Composition	Equilibrium				Scheil Cooling					
	FCC	Cu_2Sb	Cu_3Sn	ZnS	FCC	Cu_2Sb	Cu_2S	Cu_3Sn	γ	$\beta(\text{BCC})$
Semi-red brass	91	0	7.7	1.2	87.4	0	2.0	1.4	0.4	8.5
+ 0.8 wt% Sb	89.5	1.6	7.7	1.2	85.7	1.6	2.0	1.5	0.4	8.6
+ 1.3 wt% Sb	88.4	2.5	7.7	1.2	84.8	2.7	1.8	1.5	0.4	8.6

Table 13 Liquidus and solidus temperatures:

Composition	Equilibrium		Scheil Cooling	
	Liquidus	Solidus	Liquidus	Solidus
Semi-red	1030°C	878°C	1026°C	825°C

brass				
+ 0.8 wt% Sb	1029°C	875°C	1025°C	825°C
+ 1.3 wt% Sb	1028°C	874°C	1025°C	825°C

[0130] Figure 23 illustrates a phase diagram showing the location of the yellow brass alloy C28330 (61/38/0.3/0 Cu/Zn/Sn/Sb wt%). Figures 24A illustrates Equilibrium phase assemblage diagram of yellow brass with 0 wt% Sb. Figure 24B illustrates Equilibrium phase assemblage diagram of yellow brass with 0.6 wt% Sb. The impact of the antimony can be seen in Figure 24B and is further seen in Figure 24C is an equilibrium phase assemblage diagram of yellow brass with 1 wt% Sb. Figure 24D is a Scheil phase assemblage diagram of yellow brass with 0 wt% Sb. Figure 24E is a Scheil phase assemblage diagram of yellow brass with 0.6 wt% Sb. Figure 24F is a Scheil phase assemblage diagram of yellow brass with 1 wt% Sb. The Scheil cooling shows that expected phases the beta (β) phase with Zn, some ZnS and Cu₂Sb. Observed melting point with Sb is about 900 C and solidus temp is 894 C.

A 100 kg overall alloy will contain the following amounts of each phase in kg.

Table 14 Relative amount of the phases present at room temperature:

Composition	Equilibrium				Scheil Cooling				
	FCC	Cu ₂ S _b	Zn _S	β' (BCC ₂)	FC _C	Cu ₂ S _b	Zn _S	β (BCC ₁)	β' (BCC ₂)
Yellow brass	51.9	0	0.9	47.2	4.9	0	0.9	94.2	0
+ 0.6 wt% Sb	47.6	1.2	0.9	50.3	0	1.2	0.9	97.9	0
+ 1 wt% Sb	44.7	2.0	0.9	52.3	0	2	0.9	97.1	0

Table 15 Relative Liquidus and solidus temperatures:

Composition	Equilibrium		Scheil Cooling	
	Liquidus	Solidus	Liquidus	Solidus
Yellow brass	904°C	897°C	904°C	877°C
+ 0.6 wt% Sb	901°C	896°C	902°C	877°C
+ 1 wt% Sb	905°C	894°C	901°C	877°C

Liquidus and Solidus Temperatures

[0131] Thermal investigation of the systems was performed using a DSC-2400 Setaram Setsys Differential Scanning Calorimetry. Temperature calibration of the DSC was done using 7 pure metals: In, Sn, Pb, Zn, Al, Ag, and Au spanning the temperature range from 156 to 1065 °C. The samples were cut and mechanically polished to remove any possible contaminated surface layers. Afterwards, they were cleaned with ethanol and placed in a graphite crucible with a lid cover to limit possible evaporation and protect the apparatus. To avoid oxidation, the analysis chamber was evacuated to 10^{-2} mbar and then flooded with argon. The DSC measurements were carried out under flowing argon atmosphere. Three replicas of each sample were tested. The weight of the sample was 62~78 mg.

[0132] Two samples, one from the semi-red brass, C84030 and the other from the yellow brass, C28330 were used to measure the liquidus and solidus temperatures. Their compositions are given in Table 16

Table 16 Samples for Liquidus and Solidus Study

Alloy	Cu	Ni	Zn	Mn	S	Sb	Sn	Fe	Al	P	Pb	Si	C
84XX42-022812-H20P2-7X	86.41	.762	8.68	.0008	.249	0.77	2.92	.159	.001	.014	.02	.002	.002
28330-030613-P4H2a-2*	61.50	.019	36.76	.012	.009	.324	1.22	.092	.002	.001	.007	.001	.002

*0.013% B, 0.020% Zr

[0133] To find out the solidus and liquidus temperature the samples were heated from room temperature up to 1100 C, then cooled to 800 C, then heated to 1100 C and cooled to 800 C again. Finally the apparatus was brought down to room temperature. These experiments were conducted under an Argon atmosphere which was preceded by vacuum pump evacuation of the DSC chamber. Thus data from two cycles were collected. The heating was done at 10 C/min and the cooling at 15 C/min, as agreed. The solidus and the liquidus temperatures, obtained from both cycles are provided in the table below. Data from the first cycle is more representative of the alloys because of the Zn loss that occurs in the second cycle

which was 7.3% for C84030 (low-Zn alloy) and 35.4% for the C28330 (high Zn) alloy. The measured values are shown in Table 17.

Table 17 Solidus and Liquidus Temperatures

Sample No.	1 st Cycle		2 nd Cycle	
	Solidus T, C	Liquidus T, C	Solidus T, C	Liquidus T, C
84XX42-022812-H20P2-7X	872	1034	903	1041
28330-030613-P4H2a-2	849	1050	980	1055

Dezincification Study

[0134] Four brass samples, two commercial brasses and embodiments of the C28330 yellow brass and C84030 red brass, were evaluated for the resistance to dezincification corrosion in accordance with ISO 6590, "Corrosion of Metals and Alloys – Determination of the Dezincification Resistance of Brass." In this test, ground cross sections are immersed in a 1% copper chloride solution at 75±5 °C for 24 hours. At the end of this immersion period, polished cross sections are prepared perpendicular to the exposed surfaces, and the depth of any dezincification corrosion is measured. This analysis was performed in both a thin area and a thick area of the casting per the ISO specification. Where possible the sections were prepared from thick and thin walled sections. The samples that exhibited a uniform cross section samples were taken from the edge and the core. More than 100 microns of dezincification penetration was considered to exceed the allowable dezincification.

Table 18 Alloys used for Dezincification Work

	Cu	Ni	Zn	Mn	S	Sb	Sn	Fe	Al	P	Pb	Si	C
84030-062712-H3P2-7-X	83.62	1.07	11.06	.003	.314	0.854	2.81	.210	.001	.028	.018	.004	
28330-030613-P4H2a-2*	61.50	.019	36.76	.012	.009	.324	1.22	.092	.002	.001	.007	.001	.002
MBAF 180, White Metal**	63	5.0	17.0	12.0	-	-	1.0	-	1.0	-	-	-	-
C36000	61.5		35.5								3.0		

*0.013% B, 0.020% Zr

** Nominal compositions, with 1.0% Bi

*** Nominal compositions

[0135] Figure 26A shows dezincification corrosion (between lines) extends to a maximum depth of 0.0012" (31.2 microns) from the exposed surface (towards top) in the metallographic section prepared through the edge of the "MBAF 180" sample Unetched. (494X). Figure 26B shows dezincification corrosion (between lines) extends to a maximum depth of 0.0113" (287.0 microns) from the exposed surface (towards top) in the metallographic section prepared through the core of the "MBAF 180" sample. Unetched. (201X).

[0136] Figure 27A shows dezincification corrosion (between lines) extends to a maximum depth of 0.04830" (1,228.1 microns) from the exposed surface (towards top) in the metallographic section prepared through the thin walled section of the "C36000 Ht# 1-Yeager" sample. Unetched. (50X). Figure 27B shows dezincification corrosion (between red lines) extends to a maximum depth of 0.05133" (1,303.8 microns) from the exposed surface (towards top) in the metallographic section prepared through the thick walled section of the "C36000 Ht# 1-Yeager" sample. Unetched. (50X).

[0137] Figure 28A shows no dezincification corrosion is present at the exposed surface (towards top) in the metallographic section prepared through the edge of the "28330-Lab# 358050 P4 H2a" sample of a C28330 yellow brass alloy Unetched. (494X)). Figure 28B shows dezincification corrosion (between lines) extends to a maximum depth of 0.0033" (82.8 microns) from the exposed surface (towards top) in the metallographic section prepared through the core of the "28330-Lab# 358050 P4 H2a" sample. Unetched. (494X).

[0138] Figure 29A shows no dezincification corrosion is present at the exposed surface (towards top) in the metallographic section prepared through the edge of the "84030-62412-H3P2-9" sample. Unetched. (494X). Figure 29B shows no dezincification corrosion is present at the exposed surface (towards top) in the

metallographic section prepared through the edge of the “84030-62412-H3P2-9” sample. Unetched. (494X).

[0139] This dezincification results show that embodiments of yellow brass C28330 of the present invention provide for superior resistance to dezincification in comparison with commercial alloys, including C36000 yellow brass. Specifically, the results indicate that the section from the core of the sample identified as “MBAF 180” and both the thick and thin walled sections from the sample identified as “C36000 Ht# 1-Yeager” exhibit significant dezincification corrosion when tested in accordance with ISO 6509, “Corrosion of Metals and Alloys – Determination of the Dezincification Resistance of Brass.” ISO 6509 does not include any acceptance criteria, however, the dezincification depth of these samples exceed the 100 micron maximum dezincification depth included in the similar Australian Standard AS 2345, “Dezincification Resistance of Copper Alloys.” These results indicate these samples are susceptible to dezincification corrosion. This investigation indicates that the section from the edge of the sample identified as “MBAF 180” and the sections from both the core and the edge of the samples identified as “28330-Lab# 358050 P4 H2a” and “84030-62412-H3P2-9” exhibit dezincification corrosion which is in conformance with the 100 micron maximum dezincification depth when tested in accordance with ISO 6509.

Parameters of Properties Experiments.

[0140] A series of alloys were created and tested to determine the properties of alloys having a composition outside of that set forth for the C84030 red brass alloy in Figure 2. Figure 30 illustrates the chemical compositions of these variances on C84030 with the component in variance shown in *italics*. The compositions were selected by software to be outside of the nominal C84030 composition such as Cu, Sn, Zn, Ni, and Sb except a few cases in case of sulfur.

[0141] In order to provide a “figure of merit” to quantify the properties of the variance alloys in comparison to C84030, UTS, YS and EL % properties were utilized.

Sufficient results for each of those three property values had to occur together for one of the pours to create further investigation. These three property values are:

- 1) The Ultimate Tensile Strength has to be greater than the maximum limit of C 84030 (> than 42.9)
- 2) The Yield Strength has to be greater than the maximum limit of C 84030 (> than 20.3)
- 3) The Elongation % has to be greater than the typical limit of C 84400 (> than 26)

[0142] Table 19 below provides a summary of the results of the variance testing. The design of experiment (DOE) was conceptually structured based on a statistical Taguchi method. The defining elements to the alloy were brought both above and below their defined limits. Table 19 below shows this logic always with the end result being 100%. The end goal being to see if better properties existed by going both above and below the defined limits to the nominal range for C84030. Figure 31 illustrates the relation of alloy properties between C84030 red brass and two commercial brasses which were used as the base for the DOE. Figure 32 includes composition information for several tested variance alloys along with the mechanical properties. None of the variance alloys provided superior results for the three properties. The mechanical properties of the eight alloys show that although there are some alloys outside the range for C84030 that can meet some of the minimum and typical mechanical properties shown in Figure 9 for C84030, there is no single alloy that can exceed the requirements set out above for UTS, YS and % elongation.

Table 19: Design of Experiment factor formulations based on Taguchi method

$L_8(2^7)$ = 2 Levels with 7 Factors							Total of Factors 1 thru 6	The Total of the 7 Factors	
	1 (C)	2 (S)	3 (Sb)	4 (Ni)	5 (Sn)	6 (Zn)	7 (Cu)		
1	1 0.05%	1 0.05%	1 0.05%	1 0.25%	1 1.00%	1 3.50%	95.10%	4.90%	100.00%
2	1 0.05%	1 0.05%	1 0.05%	2 3.00%	2 6.00%	2 16.00%	74.85%	25.15%	100.00%
3	1 0.05%	2 0.85%	2 2.00%	1 0.25%	1 1.00%	2 16.00%	79.85%	20.15%	100.00%
4	1 0.05%	2 0.85%	2 2.00%	2 3.00%	2 6.00%	1 3.50%	84.60%	15.40%	100.00%
5	2 1.70%	1 0.05%	2 2.00%	1 0.25%	2 6.00%	1 3.50%	86.50%	13.50%	100.00%
6	2 1.70%	1 0.05%	2 2.00%	2 3.00%	1 1.00%	2 16.00%	76.25%	23.75%	100.00%
7	2 1.70%	2 0.85%	1 0.05%	1 0.25%	2 6.00%	2 16.00%	76.85%	23.15%	100.00%
8	2 1.70%	2 0.85%	1 0.05%	2 3.00%	1 1.00%	1 3.50%	91.60%	8.40%	100.00%

[0143] The foregoing description of illustrative embodiments has been presented for purposes of illustration and of description. It is not intended to be exhaustive or limiting with respect to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired from practice of the disclosed embodiments. It is intended that the scope of the invention be defined by the claims appended hereto and their equivalents.

What is claimed is:

1. A composition of matter comprising:
a copper content of about 82 wt.% to about 89 wt.%;
a sulfur content of about 0.01 wt.% to about 0.65 wt.%;
an antimony content of about 0.1 wt.% to about 1.5 wt.%;
a tin content of about 2.0 wt.% to about 4.0 wt.%;
a lead content of less than 0.09 wt.%;
a zinc content of about 5.0 wt.% to about 14.0 wt.%; and
a nickel content of about 0.5 wt.% to about 2.0 wt.%.
2. The composition of matter of claim 1, further comprising an antimony content of 0.1 wt.% to 1.0 wt.%.
3. The composition of matter of claim 1, wherein at least a portion of the sulfur and antimony are derived from stibnite.
4. The composition of matter of claim 1, wherein at least a portion of the sulfur and antimony are derived from 1 wt.% stibnite.
5. The composition of claim 1, further comprising about 0.3 wt.% titanium.
6. The composition of claim 1, further comprising about 0.1 wt.% carbon.

FIGURE 1

Alloy Type	Cu	S	Sn	Pb	Zn	Fe	Sb	Ni	P	Al	Si	Mn	Bi	Se
Biwalite™ - C83470	90.0-96.0	0.20-0.60	3.0-5.0	0.09	1.0-3.0	0.50	0.20	0.1-1.0	0.05	0.01	0.01	-	-	-
Bismuth Brass														
SeBiLOY™ - C89520	85-87	0.08	5.0-6.0	0.25	4.0-6.0	0.20	0.25	1.0	-	0.005	-	-	1.6-2.2	0.8-1.1
C89836	87.0-91.0	0.08	4.0-7.0	0.25	2.0-4.0	0.35	0.25	0.90	0.06	0.005	0.005	-	1.5-3.5	-
C89833	86.0-91.0	0.08	4.0-6.0	.09	2.0-6.0	0.30	0.25	1.0	0.500	0.005	0.005	-	1.7-2.7	0
Silicon Brass														
C87500	>79.0	--	--	0.09	12.0-16.0	--	-	-	-	0.50	3.0-5.0	-	-	-
Eco Brass™ - C87850	74.0-78.0	--	0.30	0.09	Rem.	0.10	-	0.20	-	-	2.7-3.4	0.1	-	-
Leaded Semi-Red Brass/Tin Bronze														
C84400	78.0-82.0	0.08	2.3-3.5	6.0-8.0	7.0-10.0	0.40	0.25	1.0	0.02	0.005	0.005	-	-	-
C90300	86-89	0.05	7.5-9	0.3	3-5	0.2	0.2	1.0	0.05	0.005	0.005	-	-	-

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FIGURE 2

	Cu	Sn	Pb	Zn	Fe	Sb	Ni	S	P	Al	Si	Mn	Zr	B	C	Ti
Lead-Free Semi-Red Brass - Sand Cast																
C84030	82.0-89.0	2.0-4.0	0.09	5.0-14.0	0.4	0.1-1.5	0.5- 2.0	0.01-0.65	0.05	0.005	0.005	0.20	0.20	0.20	0.1	0.30
Lead-Free Tin Bronze - Sand Cast																
C90430	86.0-89.0	7.5-8.5	0.09	1.0-5.0	0.4	0.1-1.5	1.0	0.01-0.65	0.05	0.010	0.010	0.2	0.20	0.20	0.1	0.30
Lead-Free Yellow Brass - Permanent Mold Cast																
C85930	58.0-62.0	1.5	0.09	31.0- 41.0	0.50	0.1-1.5	1.5	0.01-0.65	0.01	0.1- 0.6	0.25	0.2	0.20	0.20	0.1	0.30
Lead-Free Yellow Brass Wrought																
C28330	58.0-62.0	--	0.09	31.0- 41.0	0.35	0.1-1.5	--	0.01-0.65	--	--	--	0.2	0.20	0.20	0.1	0.30

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FIGURE 3A

CHEMICAL ANALYSIS OF SEMI-RED BRASS WITH CCG, MNS, SULFUR ETC

Heat No	Cu	Sn	Zn	Ni	S	P	Mn	Pb	Fe	Sb	Al	Si	C	Comments
1109363	87.00	3.10	8.61	0.952	0.087	.012	0.024	.017	0.183	.003	.001	.003	0.001	1 CCG+0.6 MnS
1109374	86.34	3.18	8.96	0.992	0.270	.013	0.050	.016	0.16	.003	.002	.003	0.001	1 CCG +1.8 MnS
1109385	87.10	3.0	8.51	0.941	0.180	.011	0.026	.027	0.187	.002	.002	.003	0.001	1 CCG +1.2 MnS
1104232	89.33	2.70	6.89	0.842	0.130	.004	0.006	.005	0.075	.003	.002	.004	0.006	CCG +0.6 MnS
1104240	89.82	2.60	6.44	0.869	0.158	.003	0.006	.006	0.078	.003	.002	.003	0.006	CCG +0.6 MnS
1104262	86.63	2.75	9.31	0.979	0.137	.013	0.018	.028	0.115	.003	.002	.003	0.006	CCG +0.6 MnS+1 CCG
1104272	87.68	2.73	8.24	0.862	0.141	.014	0.020	.021	0.250	.016	.002	.004	0.009	CCG +0.6 MnS+ 1 Sup Gra
84XX1-H1P1-7C	86.80	2.92	9.00	1.060	0.012	.015	0.001	.019	0.155	.005	.001	.004	0.002	Only CCG (1.5%)
84XX1-H2P2-7C	87.04	2.99	8.72	1.040	0.007	.015	0.001	.018	0.151	.005	.002	.003	0.002	Only CCG (1.5%)
84XX2-H3P3-7C	86.83	3.00	8.81	1.040	0.087	.014	0.046	.017	0.138	.004	.001	.005	0.002	1.5 CCG +1.3 MnS
84XX2-H4P4-7C	86.67	3.03	8.86	1.030	0.108	.014	0.053	.017	0.198	.005	.002	.004	0.001	1.5 CCG +1.3 MnS
84XX5-H8P4-7X	86.96	2.99	8.54	1.020	0.298	.045	0.0005	.019	0.103	.011	.001	.002		0.44 Sulfur
84XX5-H9P1-7X	87.05	2.93	8.52	1.050	0.289	.030	0.0004	.016	0.092	.009	.001	.002		0.44Sulfur
84XX6-H10P2-7X	86.90	3.04	8.62	1.020	0.162	.033	0.023	.017	0.165	.006	.001	.003		1.3 MnS
84XX6-H11P3-7X	87.16	3.00	8.46	1.000	0.123	.039	0.033	.016	0.149	.007	.003	.004		1.3 MnS

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84XX7- H12P1-7CPC	87.66	2.95	8.06	0.983	0.121	.012	0.047	.018	0.126	.004	.001	.002	0.005	1.5 CPC + 1.3 MnS
84XX7- H13P2-7CPC	87.33	2.92	8.37	1.02	0.122	.015	0.052	.018	0.128	.004	.001	.002	0.007	1.5CPC + 1.3 MnS
84XX8- H14P3-7CPC	87.42	2.91	8.56	0.959	0.012	.017	0.003	.019	0.083	.004	.001	.002	0.004	1.5 CPC
84XX8- H15P1-7CPC	87.53	2.93	8.41	0.980	0.009	.017	0.002	.019	0.089	.003	.001	.002	0.002	1.5 CPC
84XX51- H21P3-7X	87.16	2.94	8.34	0.926	0.473	.013	0.0004	.017	0.108	.005	.001	.003	.003	0.6 Sulfur
84XX52- 022912-H22P- 7-X	86.41	3.0	8.97	0.955	0.487	.014	0.002	.013	0.130	.004	.002	.002		0.8 Sulfur
84XX101- H23P2-7-C	86.45	2.99	8.87	1.06	0.409	.013	0.001	.011	0.173	.003	.001	.001	0.007	1 CCG + 0.6 S
84XX102- H24P3-7-C	86.29	2.98	9.07	1.01	0.394	.013	0.001	.011	0.205	.004	.001	.002	0.010	0.5 CCG + 0.6 S

FIGURE 3B

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FIGURE 4A

CHEMICAL ANALYSIS OF SEMI-RED BRASS (C84030) WITH CCG AND STIBNITE

Heat No	Cu	Sn	Zn	Ni	S	P	Mn	Pb	Fe	Sb	Al	Si	C	Zr	B	Ti	Comments
Aim	82-89	2-4	5-14	.5-2	.1- .65	.05	.20	.09	.40	.1- 1.5	.005	.005	.10	0.10	.10	.10	
1109308	82.77	2.81	12.94	1.03	.071	.013	.0003	.020	.065	.269	.002	.001					0.4 Stibnite
1109319	82.47	2.94	12.98	1.02	.169	.013	.004	.019	.107	.266	.002	.001					0.4Stibnite+0.6MnS
1109330	82.10	2.95	13.26	1.04	.121	.015	.0005	.034	.074	.395	.001	.001					0.6 Stibnite
1109341	83.00	2.79	12.29	1.01	.251	.016	.007	.022	.181	.418	.002	.002					0.6 Stibnite+1MnS
1109352	82.57	2.92	12.57	1.02	.264	.016	.007	.024	.173	.423	.001	.001					0.6 Stibnite+1MnS
84XX3-012512-H5P1-7C	85.61	2.92	8.50	.963	.417	.014	.001	.050	.154	1.35	.001	.003	.006				1.5 CCG+1.64 Stibnite
84XX3-012812-H16-P2-7C	85.35	2.99	8.91	.961	.359	.018	.002	.034	.159	1.20	.001	.001	.005				1.5 CCG +1.64 Stibnite
84XX4-012512-H6P2-7X	85.39	2.87	8.81	1.00	.428	.014	.001	.050	.164	1.26	.001	.002					1.64 Stibnite
84XX4-012512-H7P3-7X	85.41	2.84	8.76	.989	.424	.013	.001	.044	.183	1.32	.001	.004					1.64 Stibnite
84XX9-013112-H17P1-7-X-C	85.28	3.07	8.76	.968	.379	.012	.001	.035	.156	1.32	.001	.002	.005				1.64 Stibnite+1.5 CPC
84XX9-013112-H18P2-7-X-C	85.13	3.06	8.91	.963	.386	.012	.001	.033	.148	1.34	.001	.003	.005				1.64 Stibnite+1.5 CPC
84XX41-022812-H19P1-7X	86.59	2.91	8.72	.769	.212	.014	.001	.019	.112	.641	.001	.002	.002				0.8 Stibnite
84XX42-022812-H20P2-7X	86.41	2.92	8.68	.762	.249	.014	.0008	.02	.159	.77	.001	.002	.002				1.0 Stibnite
84XX4-032212-H19P1-7-X	86.69	2.89	8.14	.964	.278	.014	.005	.029	.118	.859	.001	.002					1.2% Stibnite
84030-062712-	84.77	3.89	8.65	1.25	.340	.046	.012	.019	.098	.894	.002	.005					1 Stibnite

[illegible]

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FIGURE 5A

**COMPOSITION AND MECHANICAL PROPERTIES OF SEMI-RED
BRASS C84030- WITH CCG, MNS AND SULFUR**

Heat No	Cu	Sn	Zn	S	Ni	Mn	Sb	C	UTS ksi	YS ksi	% Elong	BHN	MoE Mpsi	Comments
1109365 1A	87.00	3.1	8.61	.087	0.952	0.024	.003	.001	42.1	17.93	47	68	12.8	1 CCG+0.6 MnS
1109367 2A	87.00	3.1	8.61	.087	0.952	0.024	.003	.001	40.6	18.01	35	67	12.9	1 CCG +0.6 MnS
1109376 1A	86.34	3.18	8.96	.270	0.992	0.05	.003	.001	39.9	18.59	37	67	12.8	1 CCG +1.8 MnS
1109378 2A	86.34	3.18	8.96	.270	0.992	0.05	.003	.001	40.2	19.03	33	69	13	1 CCG +1.8 MnS
1109387 1A	87.10	3.0	8.51	.180	0.941	0.026	.002	.001	42.6	18.33	51	65	12.8	1 CCG +1.2 MnS
1109389 2A	87.10	3.0	8.51	.180	0.941	0.026	.002	.001	42.9	18.25	51	65	12.8	1 CCG +1.2 MnS
1104234-A	89.33	2.70	6.89	.130	.842	.006	.003		39.6	16.4	43	55	14.9	CCG+0.6MnS
110234-B	89.33	2.70	6.89	.130	.842	.006	.003		39.9	16.8	42	57	14.8	CCG +0.6MnS
1104242-A	89.82	2.60	6.44	.158	.869	.006	.003		38.3	16.4	35	57	15.1	CCG +0.6MnS
1104242-B	89.82	2.60	6.44	.158	.869	.006	.003		38.1	16.45	30	53	14.7	CCG +0.6MnS
1104274-A	87.68	2.73	8.24	.141	.862	.020	.016	.009	39.6	18.51	39	65	14.4	0.6MnS+1% CCG
1104274-B	87.68	2.73	8.24	.141	.862	.020	.016	.009	39.5	18.84	37	61	14.1	0.6MnS+1% CCG
84XX1- H1P1-9A-C	86.80	2.92	9.00	0.012	1.060	0.001	0.005	.002	43.3	18.13	61	72	15.0	1.5% CCG
84XX1- H1P1-10A-C	86.80	2.92	9.00	0.012	1.060	0.001	0.005	.002	43.1	18.00	49	72	15.1	1.5% CCG
84XX1- H2P2-9A-C	87.04	2.99	8.72	0.007	1.040	0.001	0.005	.002	43.4	18.23	60	74	15.0	1.5% CCG
84XX1- H2P2-10A-C	87.04	2.99	8.72	0.007	1.040	0.001	0.005	.002	43.3	17.93	58	73	14.9	1.5% CCG
84XX2- H3P3-9A-C	86.83	3.00	8.81	0.087	1.040	0.046	.004	0.002	42.3	18.11	44	74	15.0	1.5 CCG +1.3 MnS
84XX2- H3P3-10A-C	86.83	3.00	8.81	0.087	1.040	0.046	.004	0.002	42.5	17.83	46	72	14.9	1.5 CCG +1.3 MnS
84XX2- H4P4-9A-C	86.67	3.03	8.86	0.108	1.030	0.053	.005	0.001	41.3	17.43	47	71	14.9	1.5 CCG +1.3 MnS

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84XX2-H4P4-10A-C	86.67	3.03	8.86	0.108	1.030	0.053	.005	0.001	43.1	17.64	58	74	15.0	1.5 CCG +1.3 MnS
C84XXX5-H8P4-9A-X	86.96	2.99	8.54	0.298	1.020	0.0005	.011		39.8	18.82	32	66	14.9	0.44 Sulfur
C84XXX5-H8P4-10A-X	86.96	2.99	8.54	0.298	1.020	0.0005	.011		38.1	18.92	21	72	14.9	0.44 Sulfur
C84XXX5-H9P1-9A-X	87.05	2.93	8.52	0.289	1.050	0.0004	.009		40.6	18.49	31	70	14.8	0.44 Sulfur
C84XXX5-H9P1-A-X	87.05	2.93	8.52	0.289	1.050	0.0004	.009		40.3	18.46	31	68	14.9	0.44 Sulfur
C84XXX6-H10P2-9A-X	86.90	3.04	8.62	0.162	1.020	0.023	0.006		41.8	17.63	41	65	14.8	1.3 MnS
C84XXX6-H10P2-10A-X	86.90	3.04	8.62	0.162	1.020	0.023	0.006		42.1	17.84	47	65	14.7	1.3 MnS
C84XXX6-H11P3-9A-X	87.16	3.00	8.46	0.123	1.000	0.033	0.007		42.0	18.28	43	68	14.9	1.3 MnS
C84XXX6-H11P3-10A-X	87.16	3.00	8.46	0.123	1.000	0.033	0.007		42.5	18.58	48	68	14.8	1.3 MnS
C84XXX7-H12P1-9A-CPC	87.66	2.95	8.06	0.121	0.983	0.047	0.004	0.005	41.2	17.89	46	66	14.8	1.5 CPC+ 1.3 MnS
C84XXX7-H12P1-10A-CPC	87.66	2.95	8.06	0.121	0.983	0.047	0.004	0.005	41.2	18.04	43	67	14.9	1.5 CPC+ 1.3 MnS
C84XXX7-H13P2-9A-CPC	87.33	2.92	8.37	0.122	1.02	0.052	0.004	0.007	41.1	17.86	45	66	14.8	1.5 CPC+ 1.3 MnS
84XX7-H13P2-10A-CPC	87.33	2.92	8.37	0.122	1.02	0.052	0.004	0.007	42.2	17.87	50	66	14.8	1.5 CPC+ 1.3 MnS

FIGURE 5B

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84XX8-H14P3-9A-CPC	87.42	2.91	8.56	0.012	0.959	0.003	0.004	0.004	43.5	18.14	64	68	15	1.5 CPC
84XX8-H14P3-10A-CPC	87.42	2.91	8.56	0.012	0.959	0.003	0.004	0.004	43.3	17.99	57	66	15.0	1.5 CPC
84XX8-H15P1-9A-CPC	87.53	2.93	8.41	0.009	0.980	0.002	0.003	0.002	43.4	18.06	58	65	14.9	1.5 CPC
84XX8-H15P1-10A-CPC	87.53	2.93	8.41	0.009	0.980	0.002	0.003	0.002	43.9	18.4	61	65	14.9	1.5 CPC
84XX51-H21P3-9A-X	87.16	2.94	8.34	0.473	0.926	0.0004	.005	.003	28.8	20.2	8	69	14.8	0.6 Sulfur
84XX51-H21P3-10A-X	87.16	2.94	8.34	0.473	0.926	0.0004	.005	.003	37.4	20.2	18	69	15.2	0.6 Sulfur
84X52-H22P1-9A-X	86.41	3.0	8.97	0.487	0.955	0.002	.004	.004	34.0	19.98	14	67	14.9	0.8 Sulfur
84XX52-H22P1-10A-X	86.41	3.0	8.97	0.487	0.955	0.002	.004	.004	29.3	19.75	7	66	14.7	0.8 Sulfur
84XX101-H23P2-9A-C	86.45	2.99	8.87	0.409	1.06	0.001	0.003	0.007	40.3	21.6	27	65	14.9	1 CCG + 0.6 S
84XX101-H23P2-10A-C	86.45	2.99	8.87	0.409	1.06	0.001	0.003	0.007	40.2	19.03	28	65	14.8	1 CCG + 0.6 S
84XX102-H24P3-9A-C	86.29	2.98	9.07	0.394	1.01	0.001	0.004	0.01	38.7	19.57	24	66	14.8	0.5 CCG + 0.6 S
84XX102-H24P3-10A-C	86.29	2.98	9.07	0.394	1.01	0.001	0.004	0.01	39.2	18.86	25	65	14.7	0.5 CCG + 0.6 S

FIGURE 5C

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FIGURE 6A

**COMPOSITION AND MECHANICAL PROPERTIES OF SEMI-RED
BRASS C84030 WITH CCG AND STIBNITE**

Heat No	Cu	Sn	Zn	S	Ni	Mn	Sb	C	UTS ksi	YS ksi	% Elong	BHN	MoE Mpsi	Comments
1109310 1A	82.77	2.81	12.94	.071	1.03	.0003	.269		40.5	16.25	45	65	12.6	15 Zn, 0.4 Stibnite
1109312 2A	82.77	2.81	12.94	.071	1.03	.0003	.269		39.8	15.95	42	62	12.4	15 Zn, 0.4 Stibnite
1109321 1A	82.47	2.94	12.98	.169	1.02	.004	.266		35.7	16.75	24	60	12.6	15 Zn, 0.4 Stibnite+0.6 MnS
1109323 2A	82.47	2.94	12.98	.169	1.02	.004	.266		38.8	17.92	33	62	12.7	15 Zn, 0.4 Stibnite+0.6 MnS
1109332 1A	82.10	2.95	13.26	.121	1.04	.0005	.395		41.1	17.22	43	65	12.6	15 Zn, 0.6 Stibnite
1109334 2A	82.10	2.95	13.26	.121	1.04	.0005	.395		40.0	17.08	36	62	12.6	15 Zn, 0.6 Stibnite
1109343 1A	83.00	2.79	12.29	.251	1.01	.007	.418		35.0	18.0	20	65	12.7	15 Zn, 0.6 Stibnite + 1 MnS
1109345 2A	83.00	2.79	12.29	.251	1.01	.007	.418		39.9	18.1	30	67	12.7	15 Zn, 0.6 Stibnite + 1 MnS
1109354 1A	82.57	2.92	12.57	.264	1.02	.007	.423		34.1	16.58	22	62	12.7	15 Zn, 0.6 Stibnite + 1 MnS
1109356 2A	82.57	2.92	12.57	.264	1.02	.007	.423		37.5	16.84	31	65	12.7	15 Zn, 0.6 Stibnite + 1 MnS
84XX3-012512- H5P1-9A-C	85.61	2.92	8.50	.417	.963	.001	1.35	.006	39.1	19.65	20	74	15.1	1.5 CCG+1.64 Stibnite
84XX3-012512- H5P1-10A-C	85.61	2.92	8.50	.417	.963	.001	1.35	.006	37.6	19.68	19	72	15.1	1.5 CCG+1.64 Stibnite
84XX3-012812- H16P2-9A-C	85.35	2.99	8.91	.359	.961	.002	1.20	.005	36.5	19.45	17	65	15.0	1.5 CCG+1.64 Stibnite
84XX3-012812- H16P2-10A-C	85.35	2.99	8.91	.359	.961	.002	1.20	.005	39.6	19.49	24	69	15.0	1.5 CCG+1.64 Stibnite
84XX4-012512- H6P2-9A-X	85.39	2.87	8.81	.428	1.00	.001	1.26		36.3	19.59	17	73	15.0	1.64% Stibnite
84XX4-012512-	85.41	2.84	8.76	.424	.989	.001	1.32		38.8	19.9	20	72	15.1	1.64% Stibnite

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H7P3-9A-X	85.41	2.84	8.76	.424	.989	.001	1.32	.005	39.8	19.82	31	74	15.2	1.64% Stibnite
84XX4-012512-H7P3-10A-X	85.28	3.07	8.76	.379	.968	.001	1.32	.005	37.8	19.75	18	69	15.3	1.5 CPC + 1.64 Stibnite
84XX9-013112-H17P1-9A-X-C	85.28	3.07	8.76	.379	.968	.001	1.32	.005	37.9	19.97	20	67	15.2	1.5 CPC + 1.64 Stibnite
84XX9-013112-H17P1-10A-X-C	85.13	3.06	8.91	.386	.963	.001	1.34	.005	39.8	20.00	22	69	15.1	1.5 CPC + 1.64 Stibnite
84XX9-013112-H18P2-9A-X-C	85.13	3.06	8.91	.386	.963	.001	1.34	.005	39.3	19.75	22	67	15.2	1.5 CPC + 1.64 Stibnite
84XX41-022812-H19P1-9A-X	86.59	2.91	8.72	.212	.769	.001	.641	.002	41.8	19.64	37	69	14.9	0.8 % Stibnite
84XX41-022812-H19P1-10A-X	86.59	2.91	8.72	.212	.769	.001	.641	.002	41.7	22.00	25	67	15.0	0.8 % Stibnite
84XX42-022812-H20P2-9A-X	86.41	2.92	8.68	.249	.762	.0008	.77	.002	42.9	20.3	32	69	15.0	1.0 % Stibnite
84XX42-022812-H20P2-10A-X	86.41	2.92	8.68	.249	.762	.0008	.77	.002	41.7	20.4	34	69	14.8	1.0 % Stibnite
84XX4-032212-H19P1-9A-X	86.69	2.89	8.14	.278	.964	.005	.859		40.4	19.22	30	69	14.7	1.2 % Stibnite
84XX4-032212-H19P1-10A-X	86.69	2.89	8.14	.278	.964	.005	.859		40.4	19.17	29	69	14.7	1.2 % Stibnite
84030-062712-H1P1-10A-X	84.77	3.89	8.65	.340	1.25	.012	.894		39.7	21.7	19	74	15.8	1 Stibnite
84030-062712-H3P2-9A-X	83.61	2.81	11.06	.314	1.07	.003	.854		36.7	19.37	17	69	15.6	1 Stibnite, 1 CCG, 0.1 Zr
84030-062712-H3P2-10A-X	83.61	2.81	11.06	.314	1.07	.003	.854		39.4	19.68	22	69	15.5	1 Stibnite, 1 CCG, 0.1 Zr
84030-062812-H4P1-9A-C-B	84.56	2.77	10.32	.337	1.02	.001	.825	.002	35.7	19.17	18	65	15.5	1 Stibnite, 1 CCG, 0.08 B

FIGURE 6B

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84030-062812-H4P1-10A-C-B	84.56	2.77	10.32	.337	1.02	.001	.825	.002	37.8	19.04	22	67	15.6	1 Stibnite, 1 CCG, 0.08 B
84030-062812-H6P3-9A-C-ZR	83.22	2.97	11.05	.342	1.04	.002	1.07	.002	37.0	18.88	19	69	15.5	1.2 Stibnite, 1 CCG, 0.1 Zr
84030-062812-H6P3-10A-C-ZR	83.22	2.97	11.05	.342	1.04	.002	1.07	.002	37.0	18.86	20	69	15.6	1.2 Stibnite, 1 CCG, 0.1 Zr
84030-062912-H7P1-10A-C-B	84.49	2.80	10.10	.373	1.08	.001	1.01	.002	38.5	19.55	20	69	15.6	1.2 Stibnite, 1 CCG, 0.08 B
84030-062912-H8P2-9A-C-TI	86.03	3.95	7.30	.171	1.34	.001	.953	.002	39.8	21.0	19	68	15.7	1.2 Stibnite, 1 CCG, 0.3 Ti
84030-062912-H8P2-10A-C-TI	86.03	3.95	7.30	.171	1.34	.001	.953	.002	42.0	20.6	27	70	15.7	1.2 Stibnite, 1 CCG, 0.3 Ti
84030-062912-H9P3-9A-C	85.22	3.50	9.26	.319	.674	.002	.827	.001	37.9	19.76	19	70	15.6	1 Stibnite, 0.5 CCG
84030-062912-H9P3-10A-C	85.22	3.50	9.26	.319	.674	.002	.827	.001	36.5	20.2	17	70	15.7	1 Stibnite, 0.5 CCG
84030-072312-H1P1-9A	84.48	3.55	9.48	.367	.977	.002	.881		35.4	18.0	19	67	15.4	1.2 Stibnite
84030-072512-H4P1-9A	84.63	3.48	9.49	.401	.986	.0006	.717	.0008	33.7	16.82	21	64	15.3	1 Stibnite
84030-072512-H4P1-9B	84.63	3.48	9.49	.401	.986	.0006	.717	.0008	34.5	17.35	20	65	15.4	1 Stibnite
84030-070312-H11P1-9A-C	85.25	3.28	9.66	.266	.805	.0007	.501	.001	37.9	18.7	23	70	15.4	0.8 Stibnite, 1 CCG
84030-070312-H11P1-10A-C	85.25	3.28	9.66	.266	.805	.0007	.501	.001	38.1	18.38	25	69	15.5	0.8 Stibnite, 1 CCG
84030-070312-H12P2-10A-X	85.00	3.35	9.16	.330	.963	.0005	.996		36.9	19.93	17	70	15.5	1.4 Stibnite

FIGURE 6C

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FIGURE 7
CHEMICAL ANALYSIS OF YELLOW BRASS

Heat No	Cu	Sn	Zn	Ni	S	P	Mn	Pb	Fe	Sb	Al	Si	C	Comments
28330-030613-P4H1	61.01	1.52	36.80	.023	.005	.001	.011	.006	.195	.401	.001	.001	.002	1.5% CCG wrought
28330-030613-P4H2A*	61.50	1.22	36.76	.019	.009	.001	.012	.007	.092	.324	.002	.001	.002	1.5% CCG wrought
85900 – 122011 H11P1-9-X	61.62	1.22	35.3	.917	0.004	0.056	0.206	0.017	0.211	0.160	0.255	0.023	-	2.4%MnS permanent mold
85910 122211 H11P3-9-X	61.82	1.25	35.01	1.0	0.002	0.058	0.151	0.017	0.270	0.2254	0.206	0.024	-	1.8% MnS permanent mold
85900 – 122211 H12P1-9-X	62.13	1.20	34.72	0.928	0.003	0.056	0.166	0.016	0.222	0.276	0.252	0.23	-	1% CCG + 1.8% MnS permanent mold
85910 122211 H12P2-9-X	61.96	1.28	34.77	1.01	0.004	0.058	0.135	0.018	0.270	0.294	0.167	0.024	-	1% CPC+ 1.8% Mns permanent mold

*B: 0.013; Zr: 0.020

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FIGURE 8

Heat No	Cu	Sn	Zn	Ni	S	Sb	UTS ksi	YS ksi	% Elong	BHN	Comments
28330-030613-P4H1	61.01	1.52	36.80	.023	.005	.401	107.60	96.60	1.0	99	Cold Rolled(CR)
							112.20	107.20	1.0	99	Cold Rolled(CR)
							61.70	28.40	19	67	CR+annealed, 1100F, 1hr
							58.70	27.70	13	66	CR+annealed, 1200F, 1hr
							60.40	26.60	16	65	CR+annealed, 1200F, 1hr
							42.30	26.10	5	66	CR+annealed, 1290F, 1hr
28330-030613-P4H2A	61.50	1.22	36.76	.019	.009	.324	104.30	91.50	1	38*	Cold Rolled (CR)
							117.10	112.00	1	39*	Cold Rolled (CR)
							56.90	26.10	19	62	CR+annealed, 1100F, 1hr
							55.30	24.90	17	59	CR+annealed, 1100F, 1hr
							56.30	24.80	17	62	CR+annealed, 1200F, 1hr
							53.80	24.60	16	61	CR+annealed, 1200F, 1hr
							53.90	22.40	8	57	CR+annealed, 1290F, 1hr
Alloy C26000**	68.5-71.5		Bal				76.00	63.00	8	82	Hard
							86.00	65.00	5	88	Extra Hard
							62.00	52.00	25	70	Half Hard
							54.00	40.00	43	55	Quarter Hard
Alloy C35600***	59-64.5		Bal				74.00	65.00	8	81	Hard
							88.00	66.00	5	85	Extra Hard
							61.00	50.00	20	70	Half Hard
							54.00	40.00	35	55	Quarter Hard
85900 - 122011 H11P1-9-X	61.62	1.22	35.3	0.917	0.004	0.160	49.5	28.55	7	89	2.4% Mns
85910 122211 H11P3-9-X	61.82	1.25	35.01	1.00	0.002	0.225	49.2	29.35	6	91.5	1.8% Mns
85900 - 122211 H12P1-9-X	62.13	1.20	34.72	0.928	0.003	0.276	52.15	31.2	8	87	1%CCG + 1.8% MnS
85910 122211 H12P2-9-X	61.96	1.28	34.77	1.01	0.004	0.294	48.45	26.85	7.5	85.5	1%CPC + 1.8% MnS

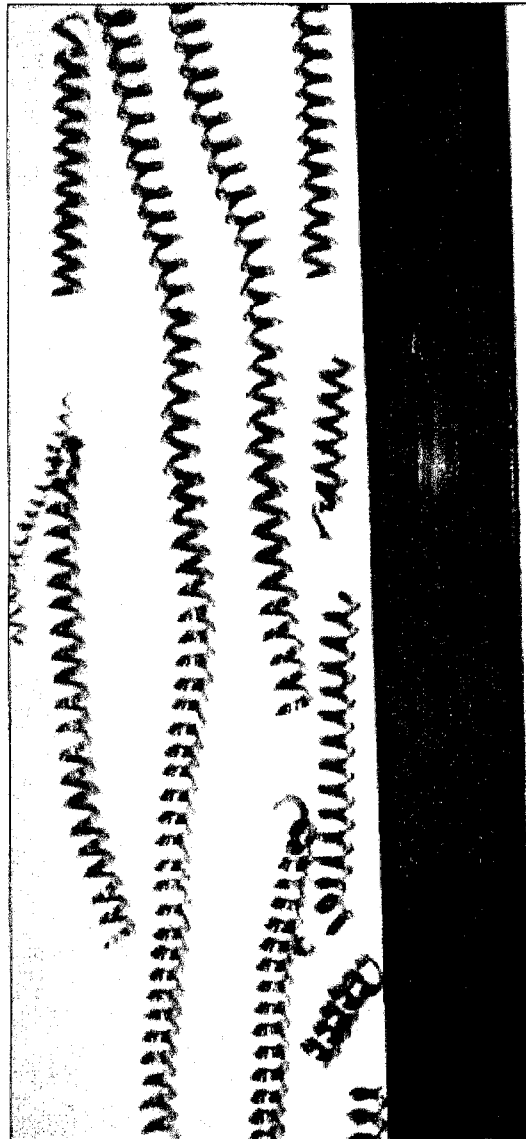
*HRD, **0.07 % Pb, ***2.0-3.0 % Pb

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FIGURE 9

<i>Alloy</i>	UTS, ksi		YS, ksi		% Elongation		<i>Brinell Hardnes</i>	<i>Modulus of Elasticity(ksi)</i>
	<i>Minimum</i>	<i>Typical</i>	<i>Minimum</i>	<i>Typica</i>	<i>Minimum</i>	<i>Typical</i>		
SeBiLOY - C89520	26.0	31.0	18.0	21.0	6	10	54	
Bismuth Red Brass, C89833		37		17		28	60	
Bismuth Bronze, C89836	33.0	37.0	15.0	19.0	20	30	65	
Biwalite -C83470	29.0	36.0			17	25		
Silicon Brass,C87500	60.0	67.0	24.0	30.0	16	21	115	15,400
Ecobrass - C87850		63		26		25	78	15,400
Semi-Red Brass, C84030	34.10	38.40	15.95	19.00	17.0	24.6	67.8	14,700
Yellow Brass C85930	48.45	49.83	26.85	28.99	6.0	7.13	88.3	16,013

CDA # 84XX1 Pour Date 012412 Heat #1 Pour #1.xlsm



Chips from:

84XX1 - 012412 - H 1 P 1 - 2

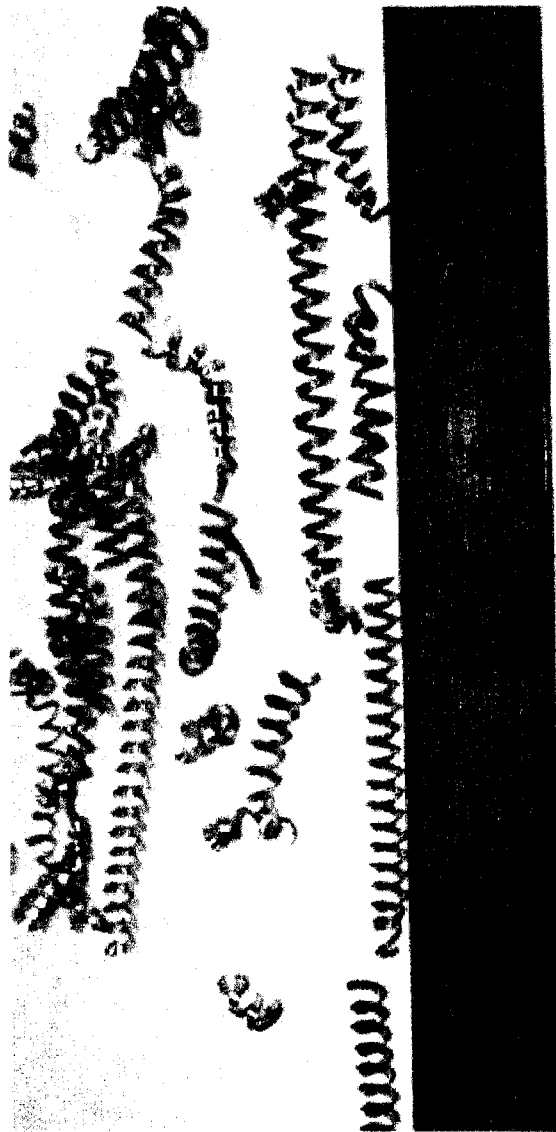
Thru

84XX1 - 012412 - H 1 P 1 - 5

FIGURE 10A

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CDA # 84XX2 Pour Date 012412 Heat #3 Pour #3.xlsm



Chips from:

84XX2 - 012412 - H 3 P 3 - 2

Thru

84XX2 - 012412 - H 3 P 3 - 5

FIGURE 10B

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CDA # 84XX5 Pour Date 012512 Heat #8 Pour #4.xlsm



Chips from:

84XX5 - 012512 - M 8 P 4 - 2

Thru

84XX5 - 012512 - M 8 P 4 - 5

Figure 10C

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PCT/US2013/039567

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CDA # 84XX6 Pour Date 012612 Heat #10 Pour #2.x/5m

Chips from:

84XX467	012612	- H	POP	2	- 2
---------	--------	-----	-----	---	-----

Thru

84XX466	012612	- H	POP	2	- 5
---------	--------	-----	-----	---	-----

FIGURE 10D

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CDA # 84XX9 Pour Date 013112 Heat #17 Pour #1.xlsm

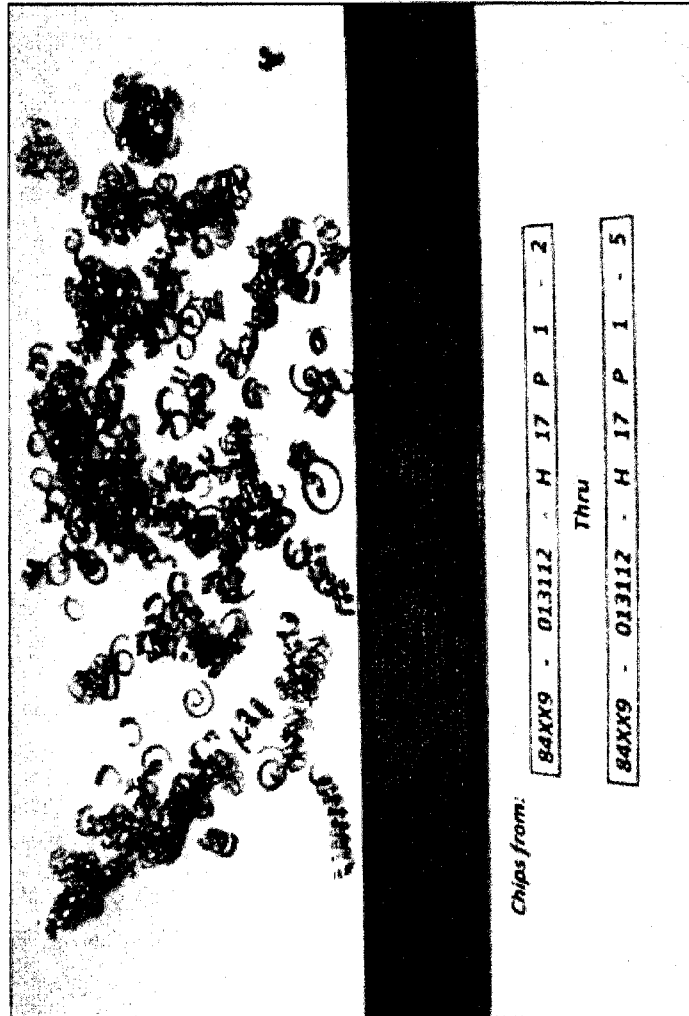


FIGURE 10E

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PCT/US2013/039567

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CDA # 84XX9 Pour Date 013112 Heat #18 Pour #2.xlsm

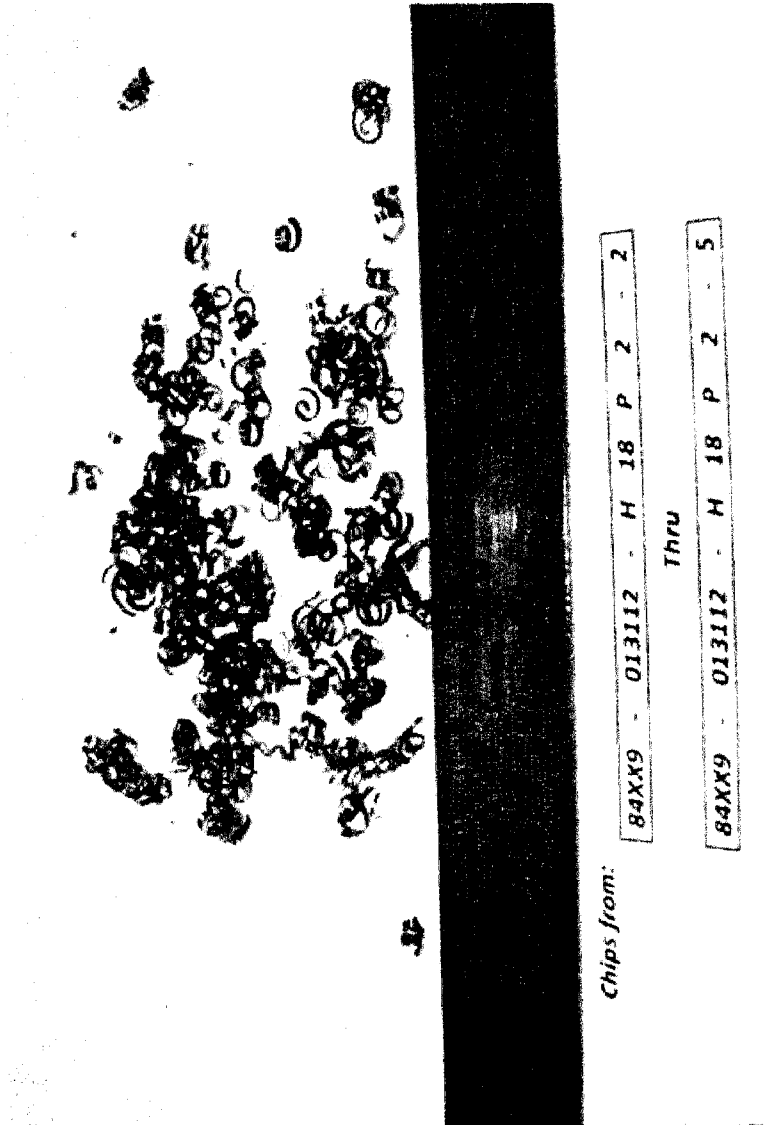


FIGURE 10F

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CDA # 84XX4 Pour Date 012512 Heat #6 Pour #2.xlsm



Chips from:

84XX4 - 012512 - H 6 P 2 - 2

Thru

84XX4 - 012512 - H 6 P 2 - 5

FIGURE 10G

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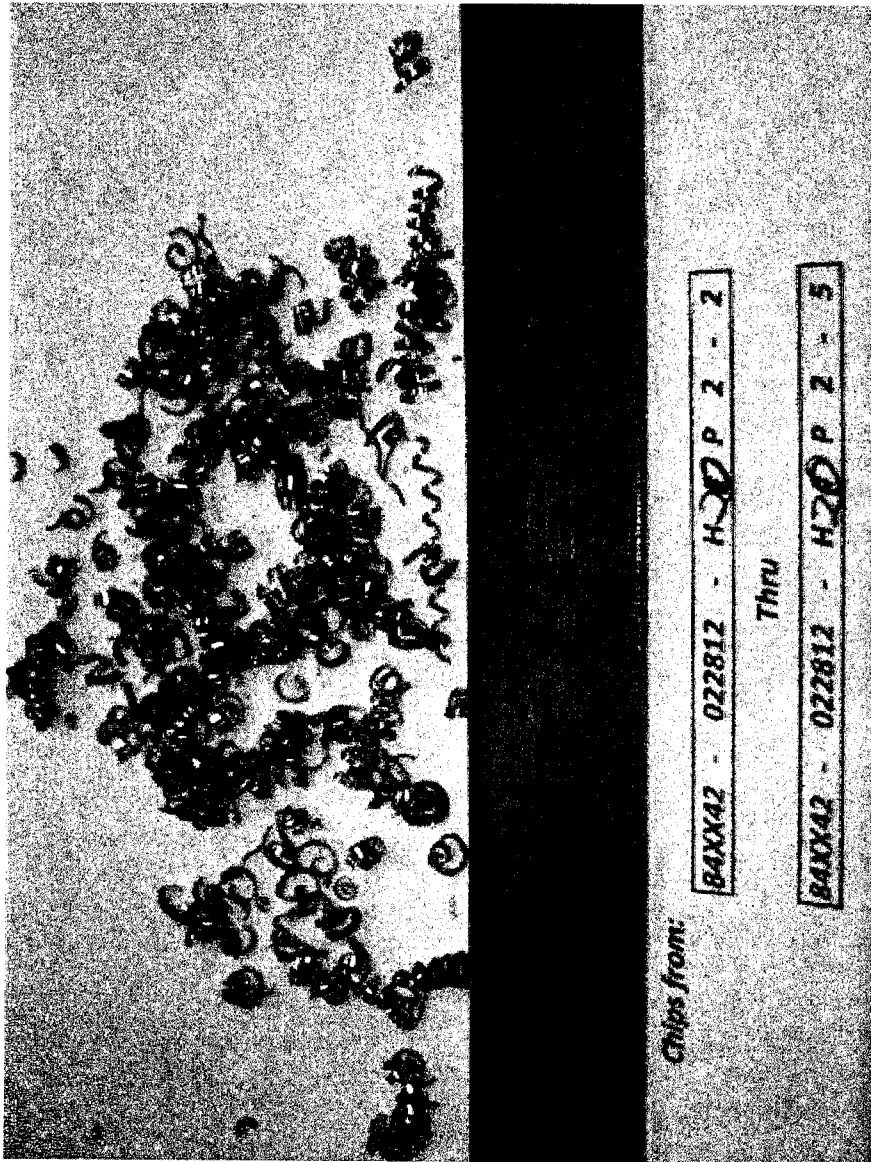


FIGURE 10H

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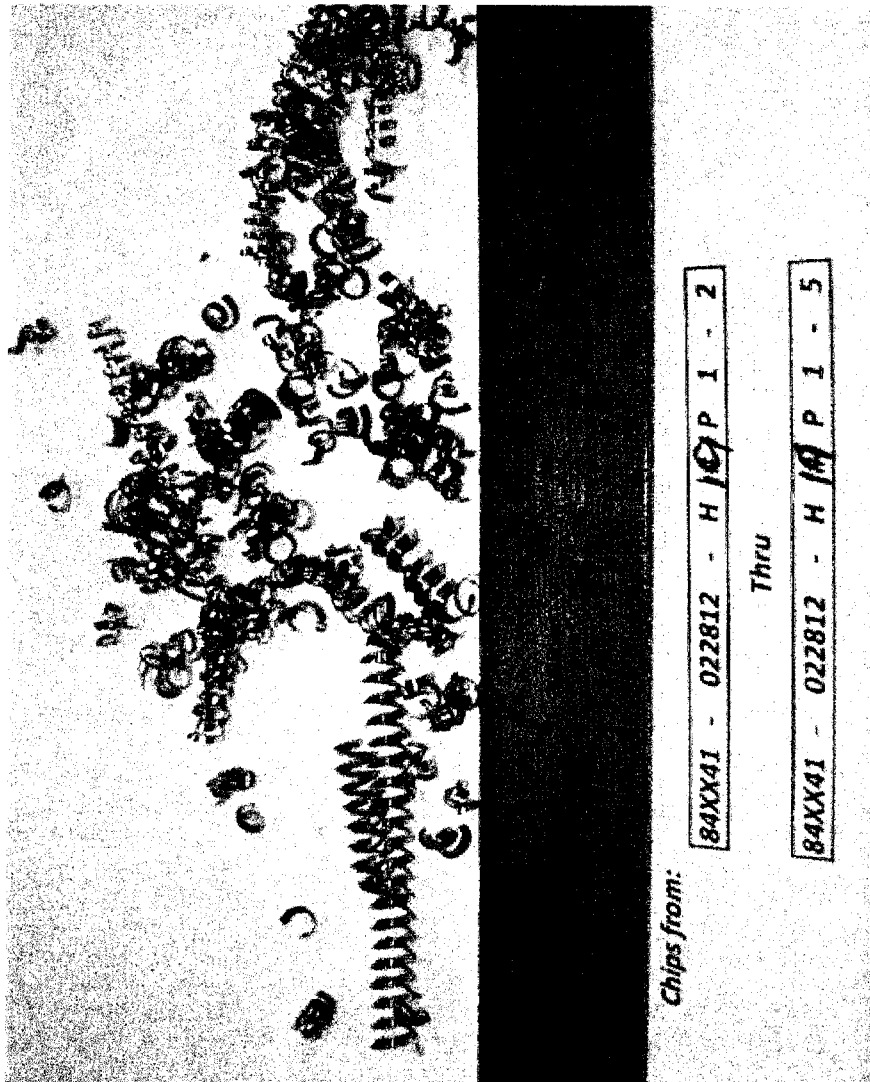


FIGURE 10I

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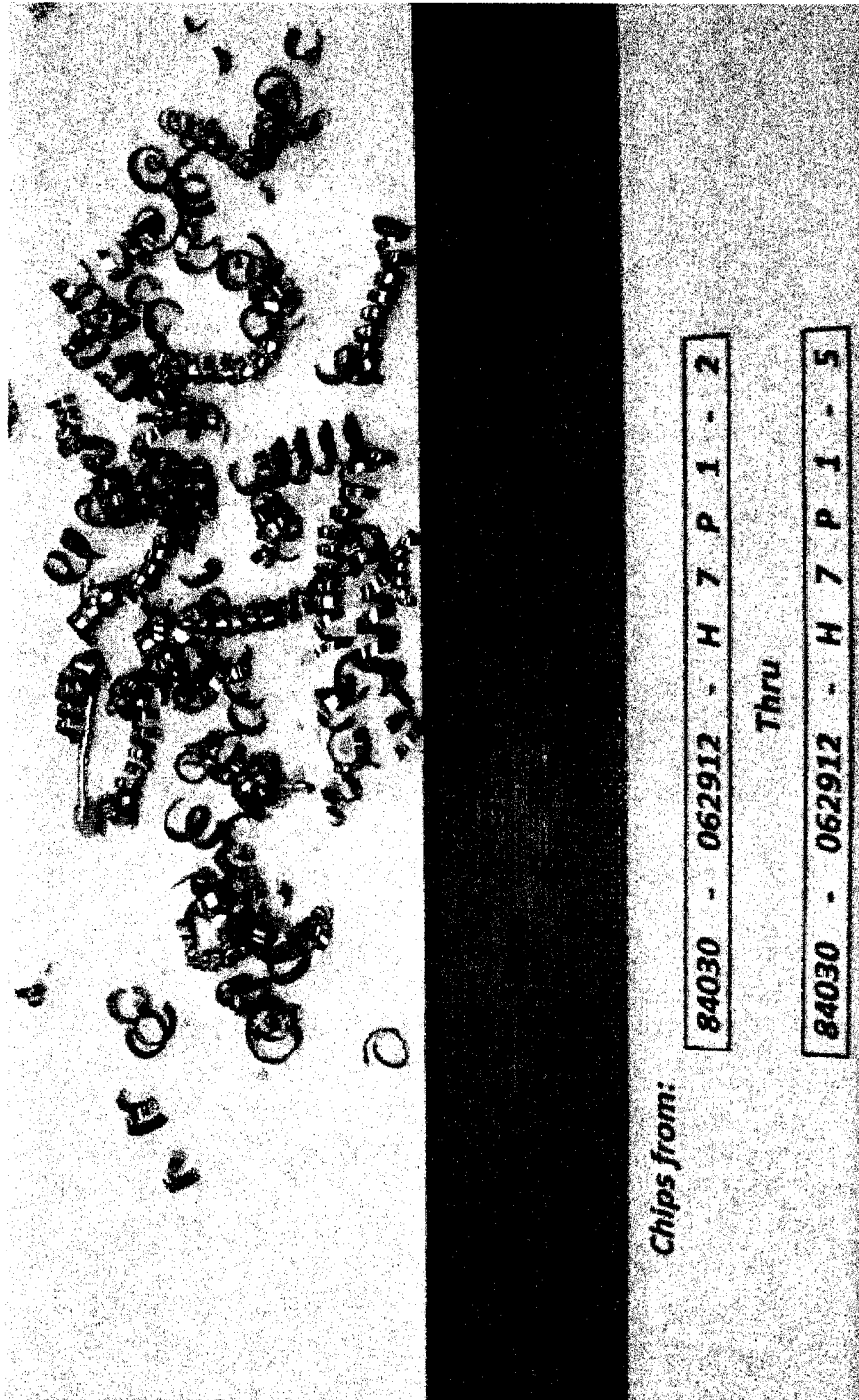


FIGURE 10J

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FIGURE 11

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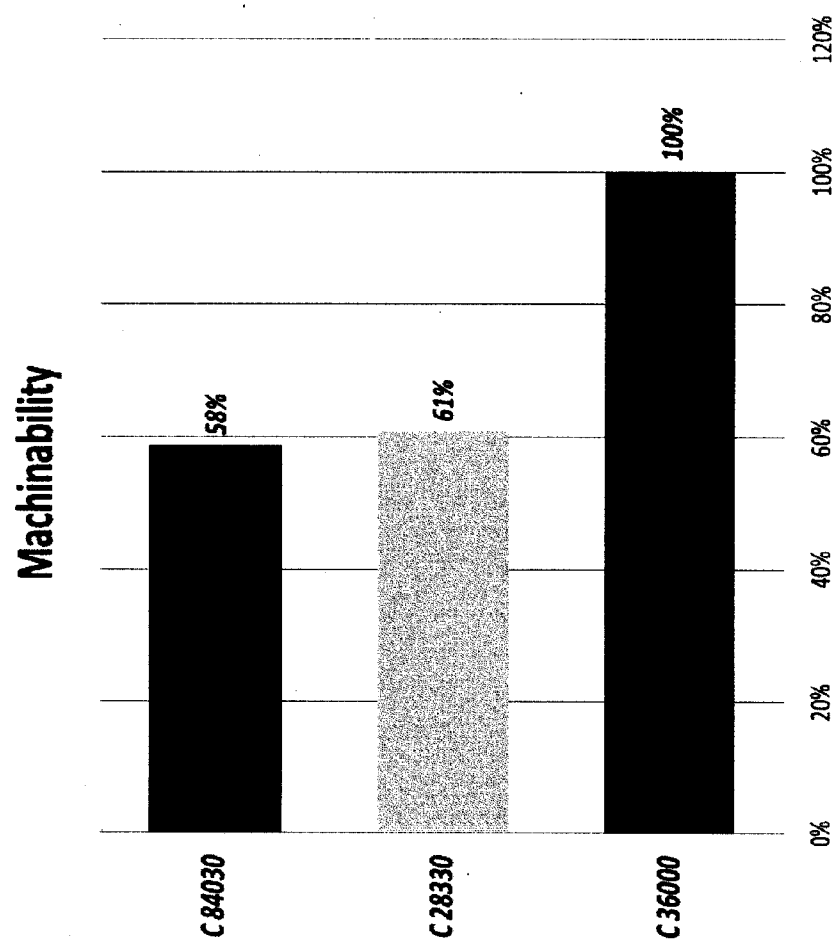


FIGURE 12

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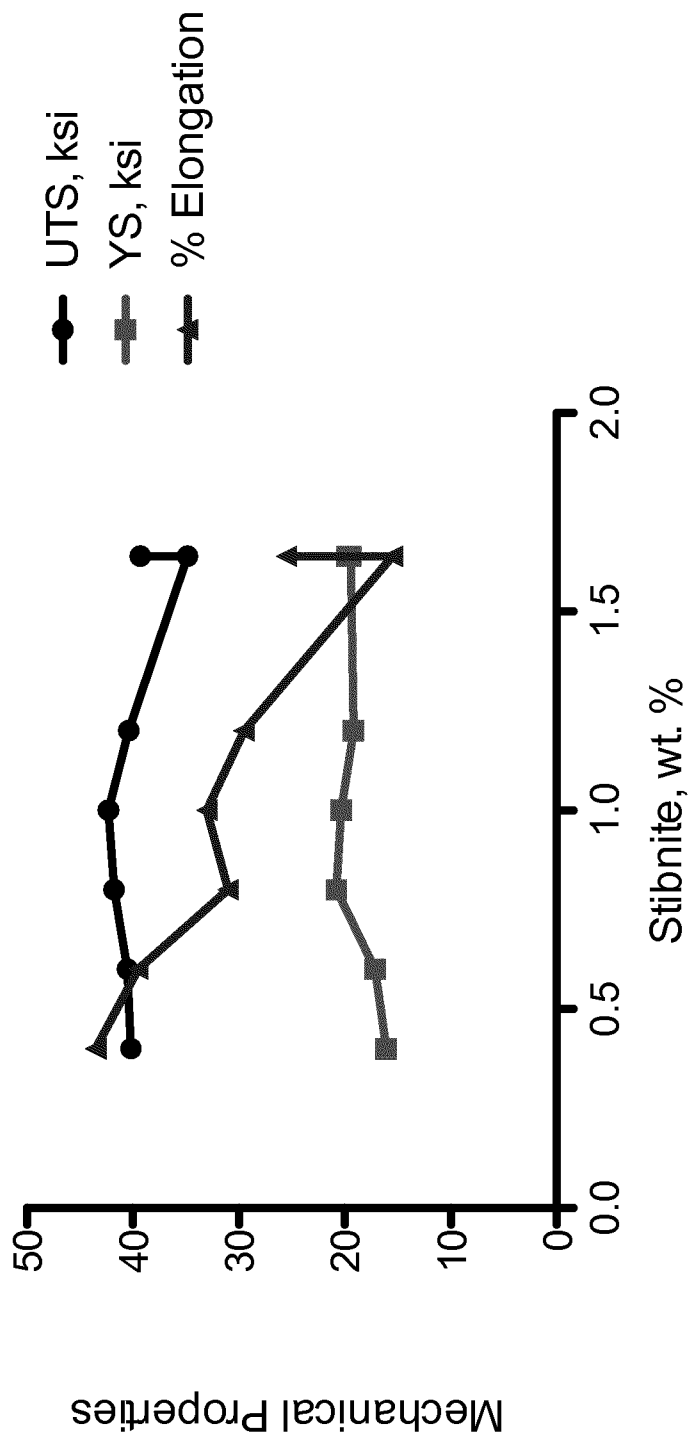


FIGURE 13A

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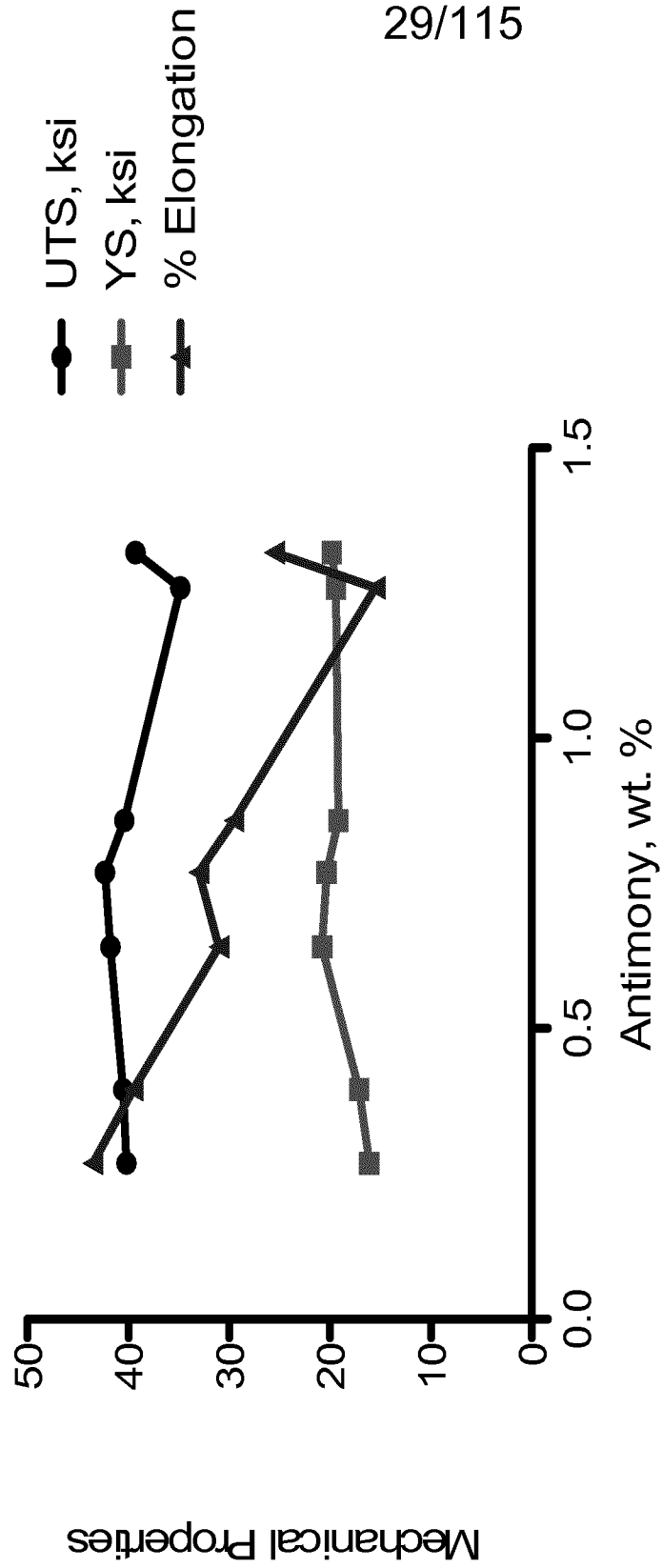


FIGURE 13B

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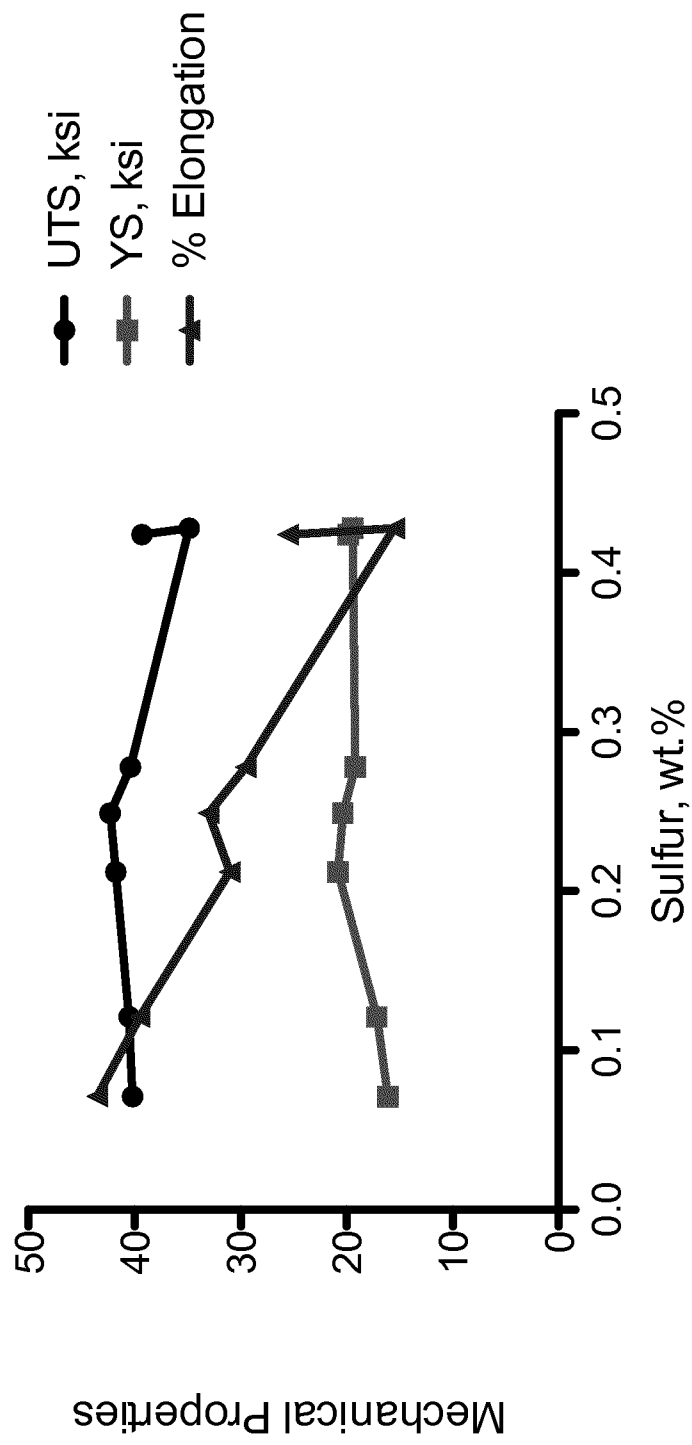


FIGURE 13C

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FIGURE 14

Heat No	Cu	Sn	Zn	Ni	S	P	Mn	Pb	Fe	Sb	Al	Si	C
1109319	82.47	3.07	12.74	1.10	.160	.017	.010	.030	.110	.260	<.010	<.010	
84XX42-022812-H20P2-7X	85.93	3.19	8.76	.880	.260	.018	.010	.040	.150	.730	<.010	<.010	
84XX9-013112-H18P2-7-X-C	85.04	3.18	8.87	1.11	.380	.018	.010	.040	.170	1.15	<.010	<.010	

¹Determined by difference.²Determined by combustion-infrared absorbance.

Other elements tested (<0.01%): As, B, Be, Cd, Cr, Mg, Mo, Nb, Se, Te, Ti, & V.

Results in weight percent unless otherwise indicated.

Method(s): CAP-017M (ICP-AES) and ASTM E 1019-11 (Comb./IGF

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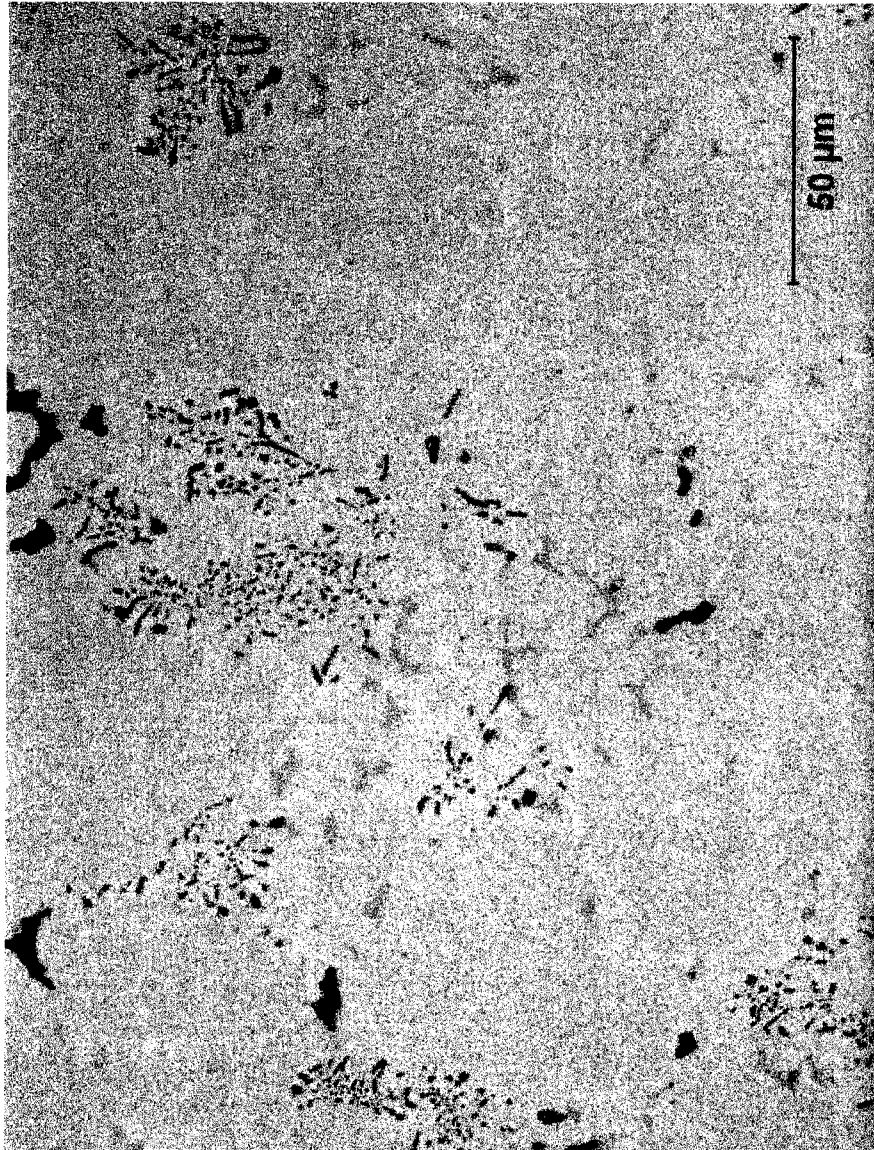


FIGURE 15A

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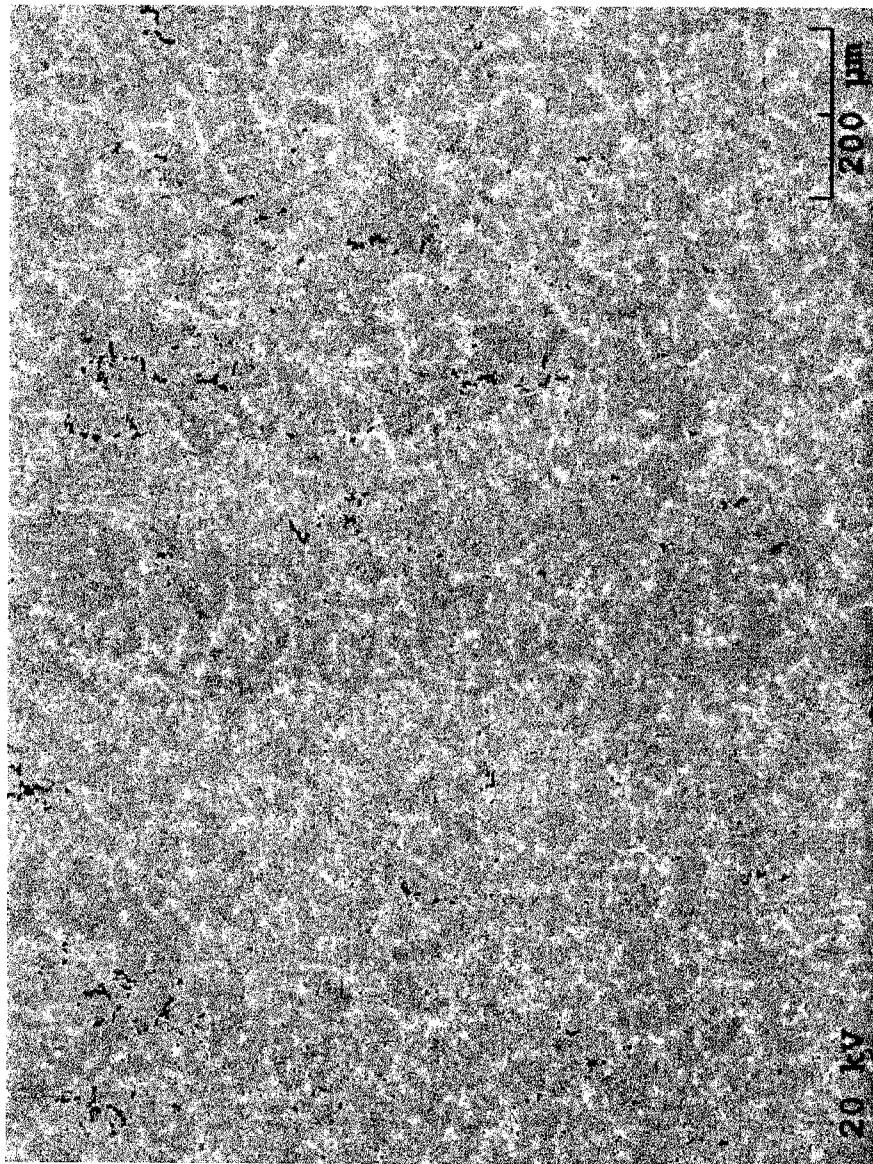


FIGURE 15B

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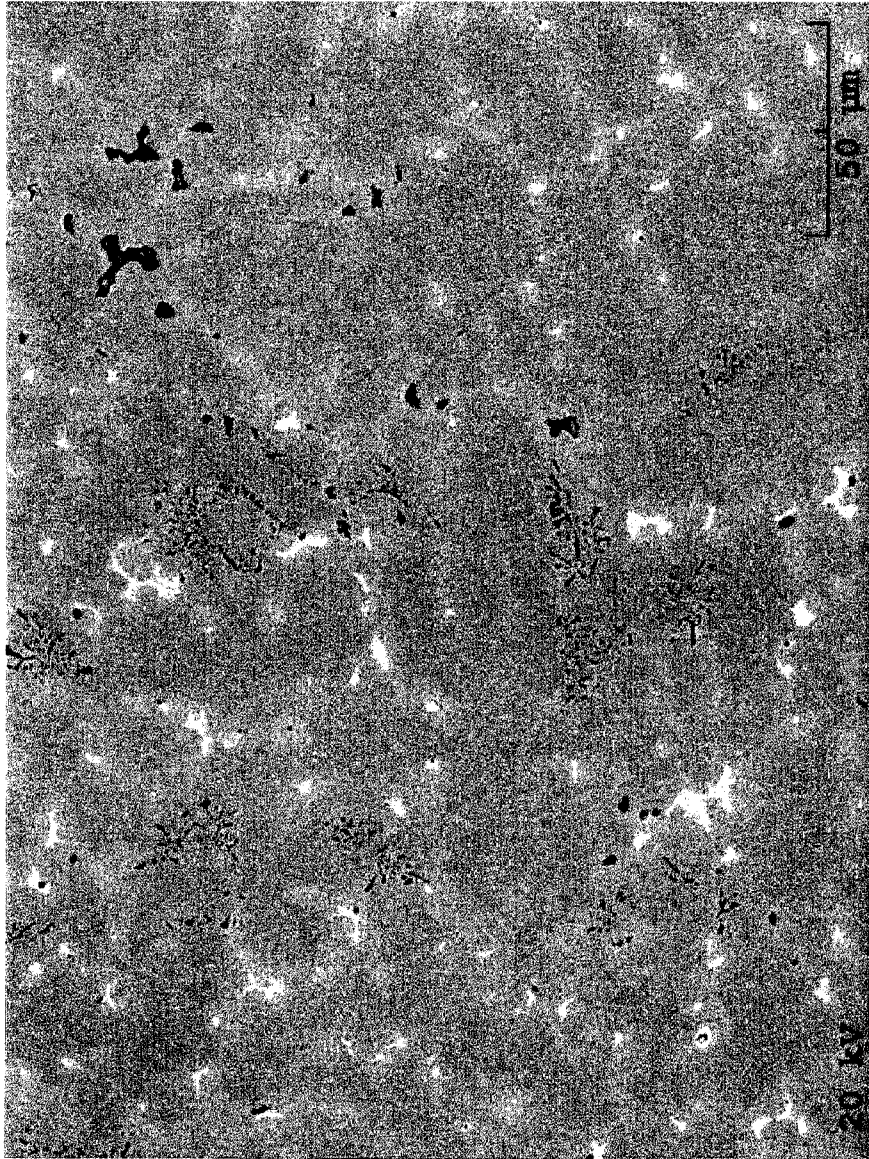


FIGURE 15C

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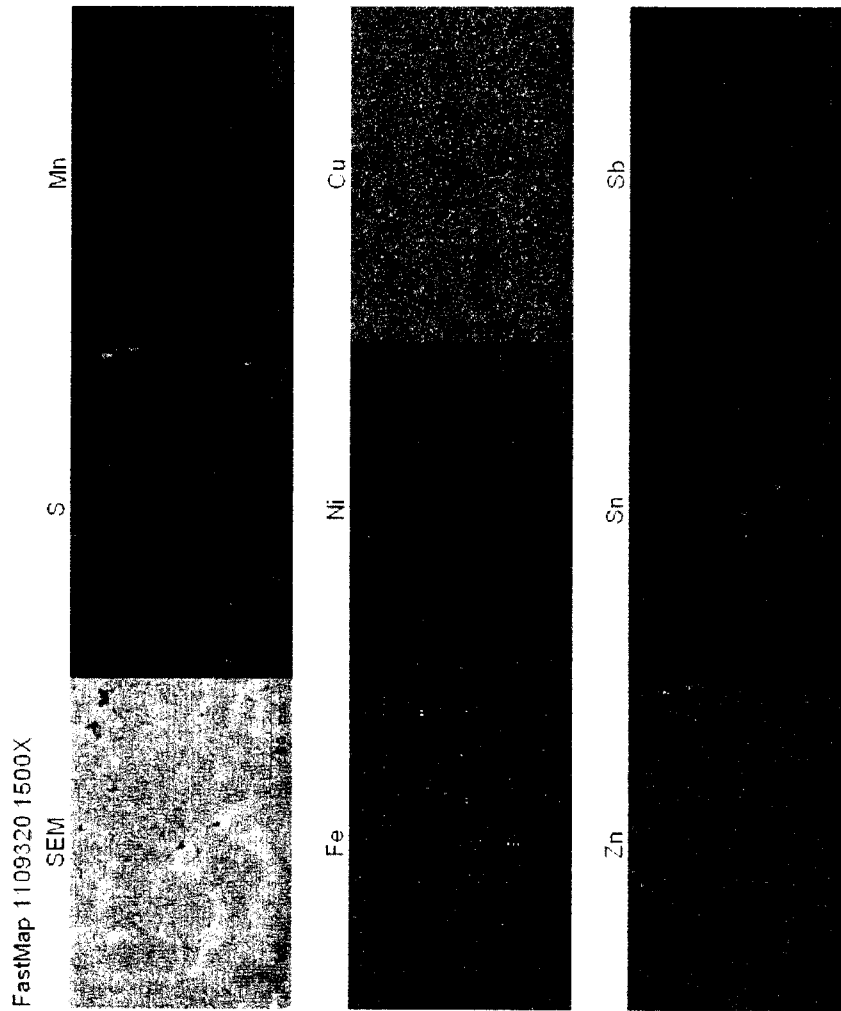


FIGURE 15D

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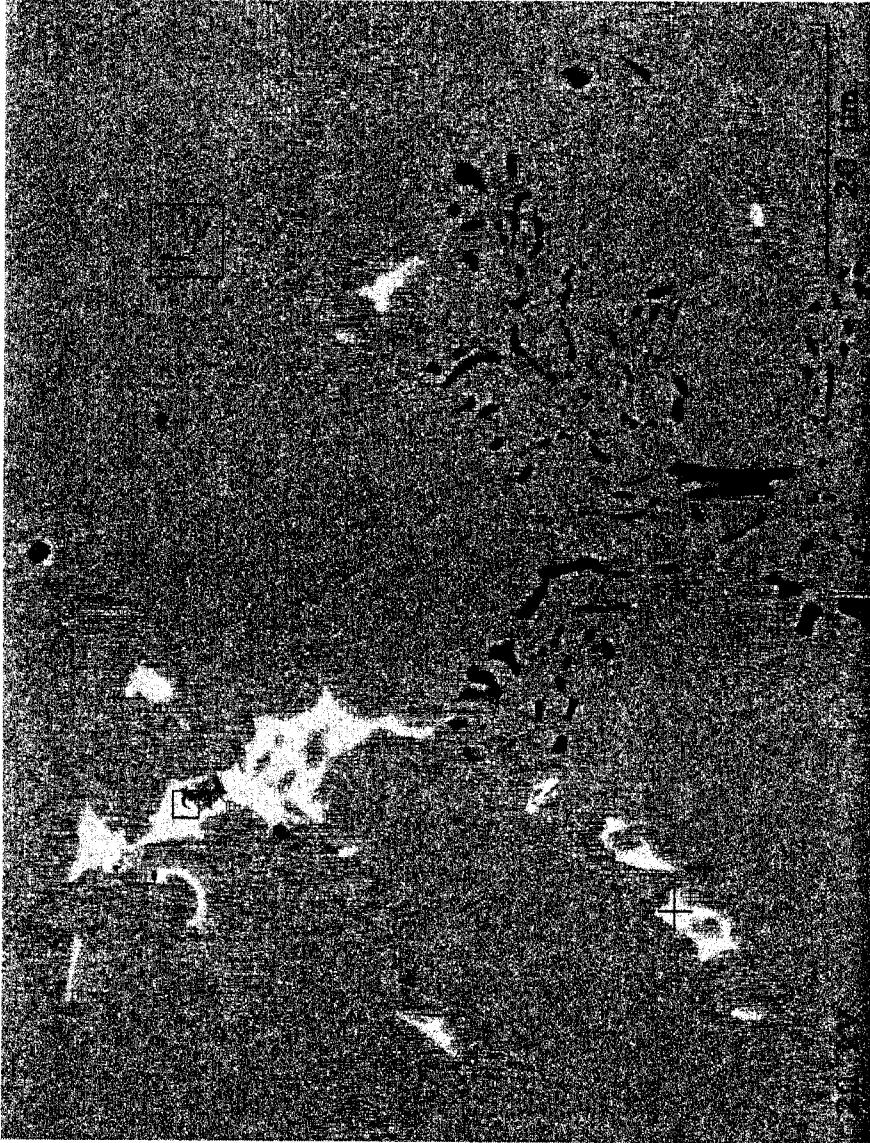


FIGURE 15E

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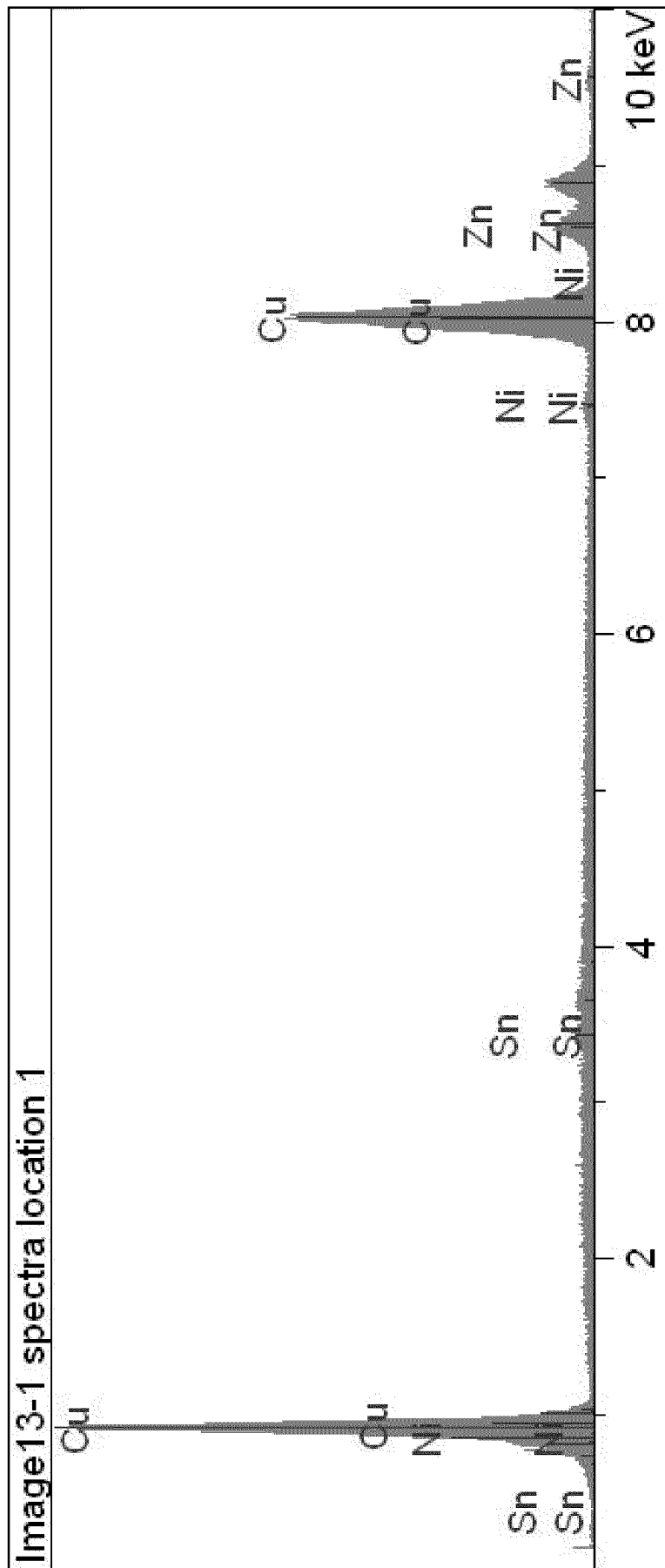


FIGURE 15F

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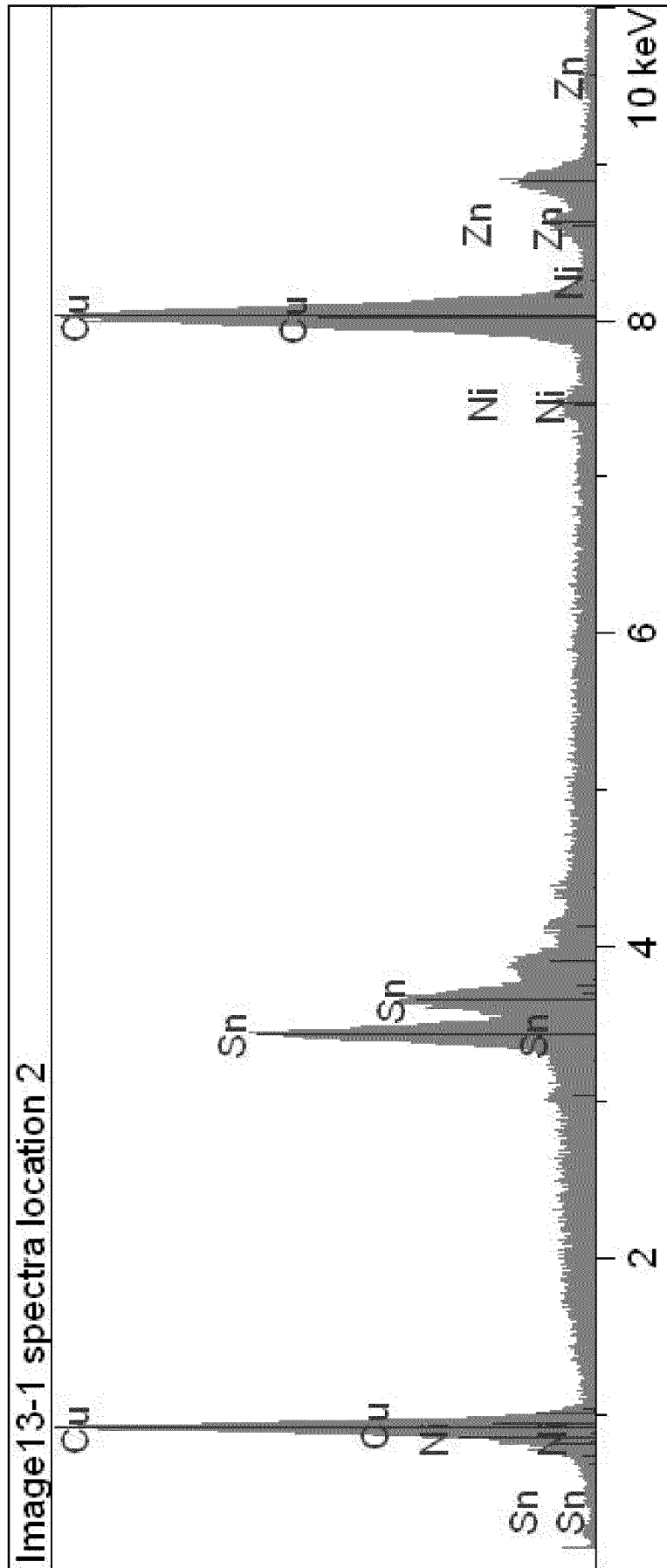


FIGURE 15G

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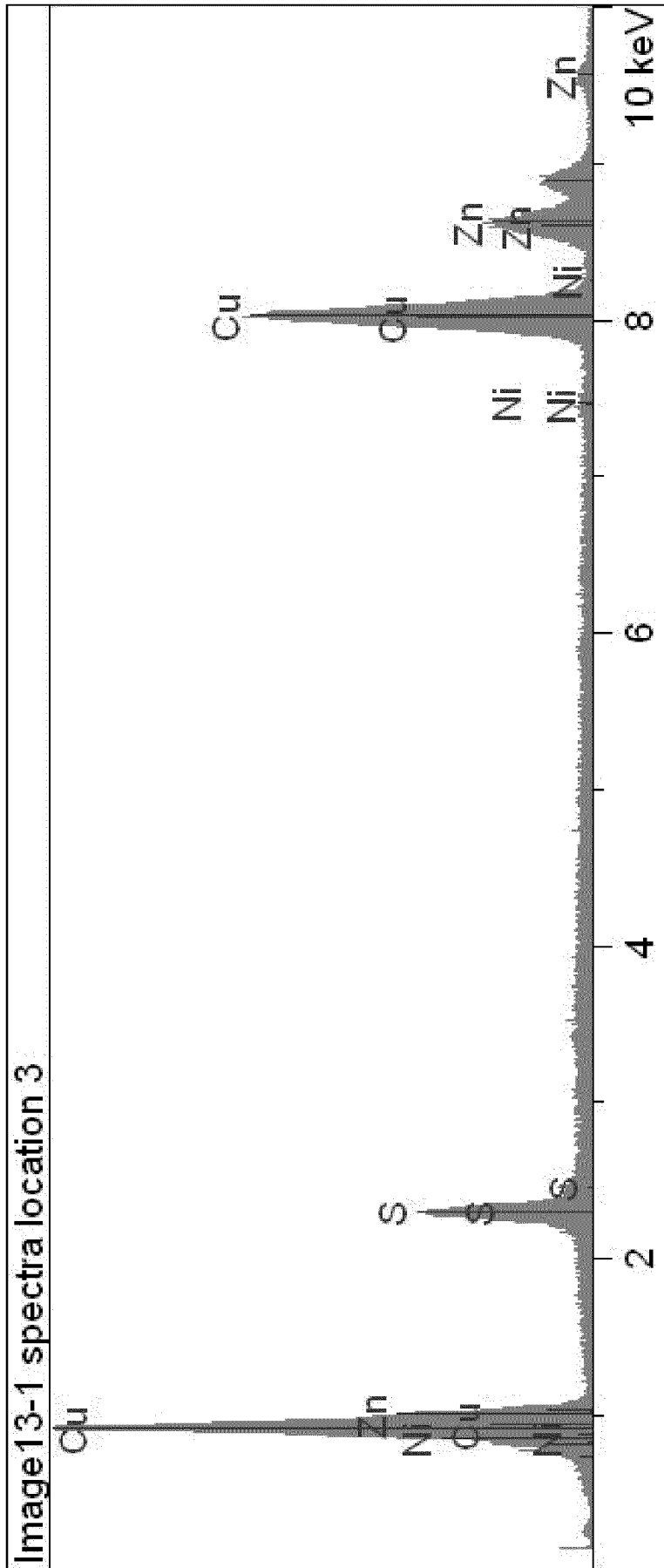


FIGURE 15H

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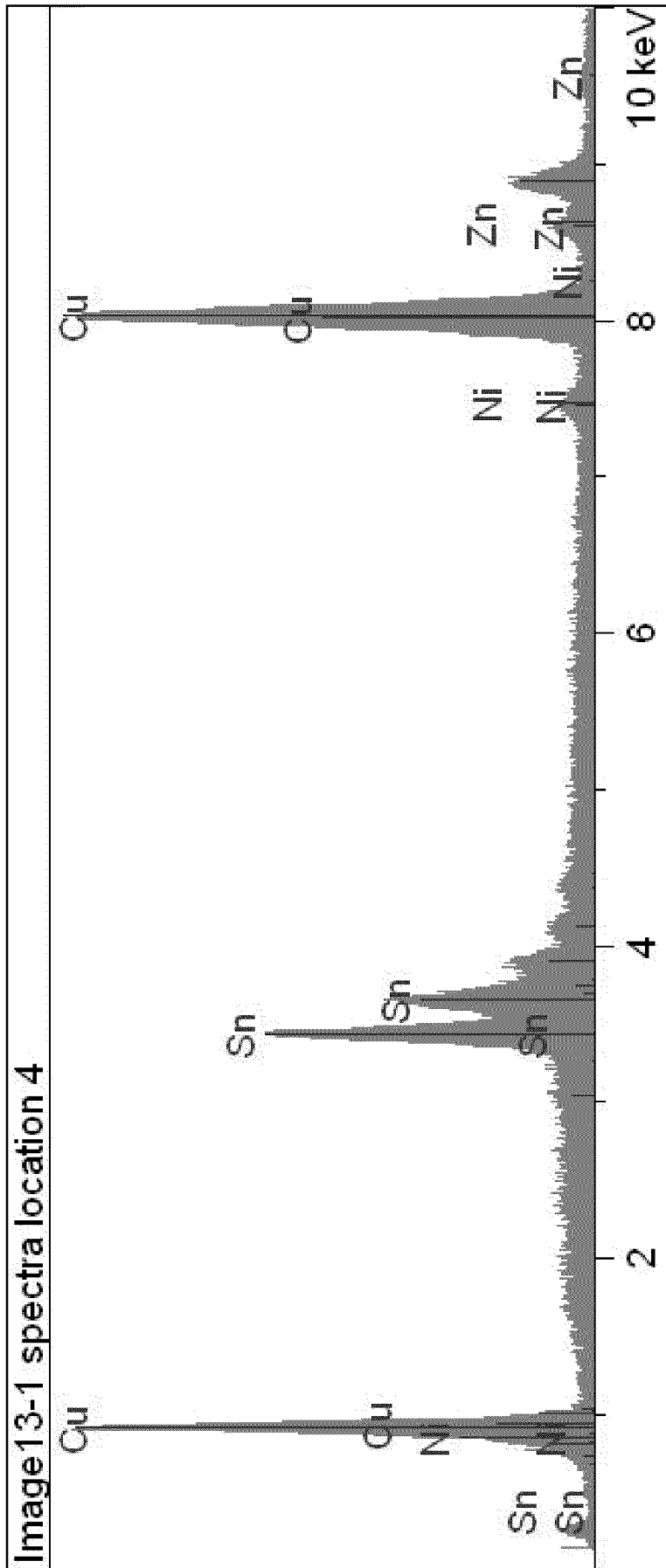


FIGURE 15I

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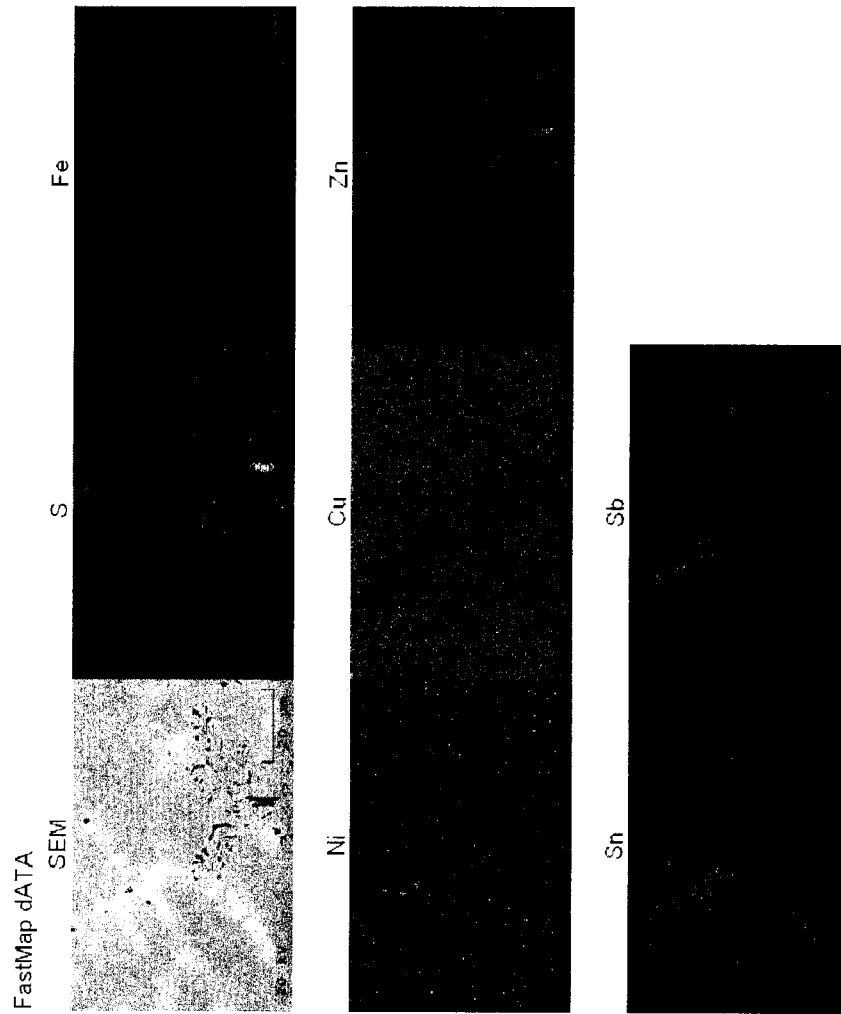


FIGURE 15J

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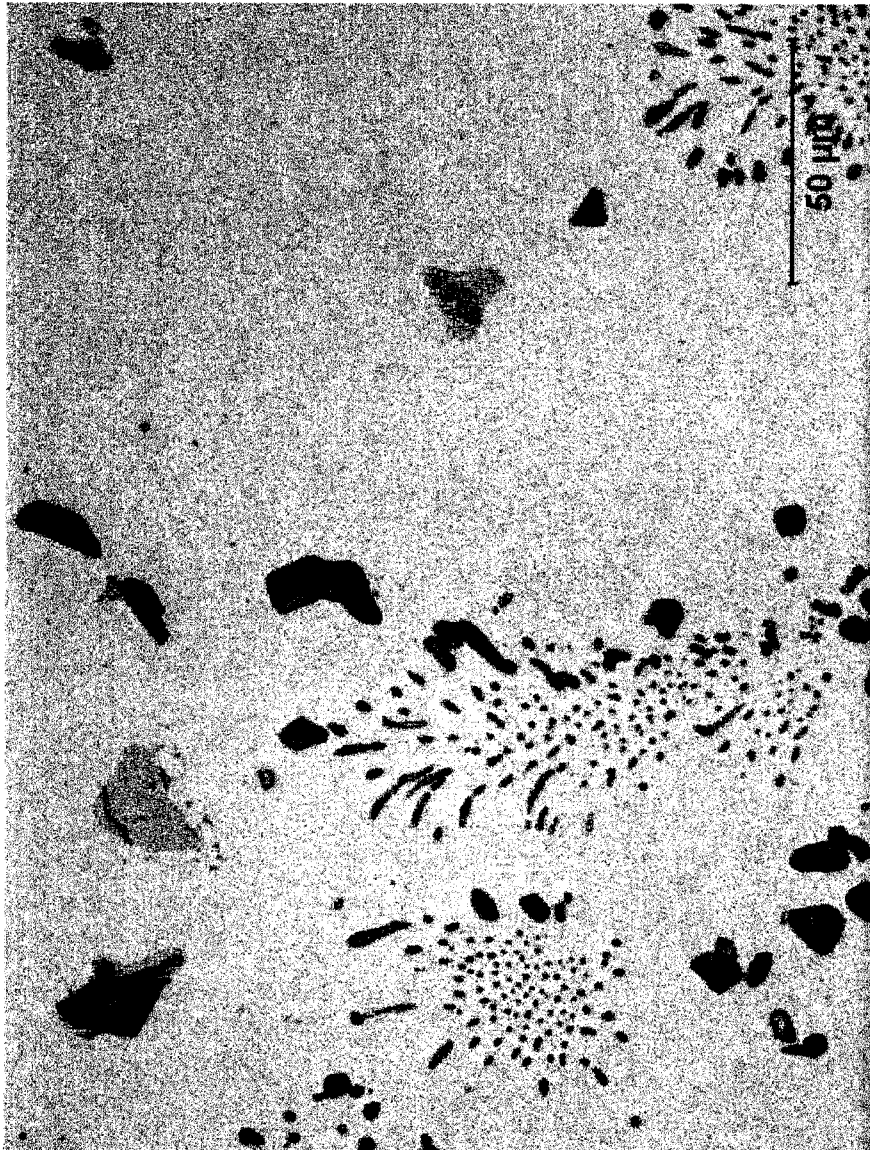


FIGURE 16A

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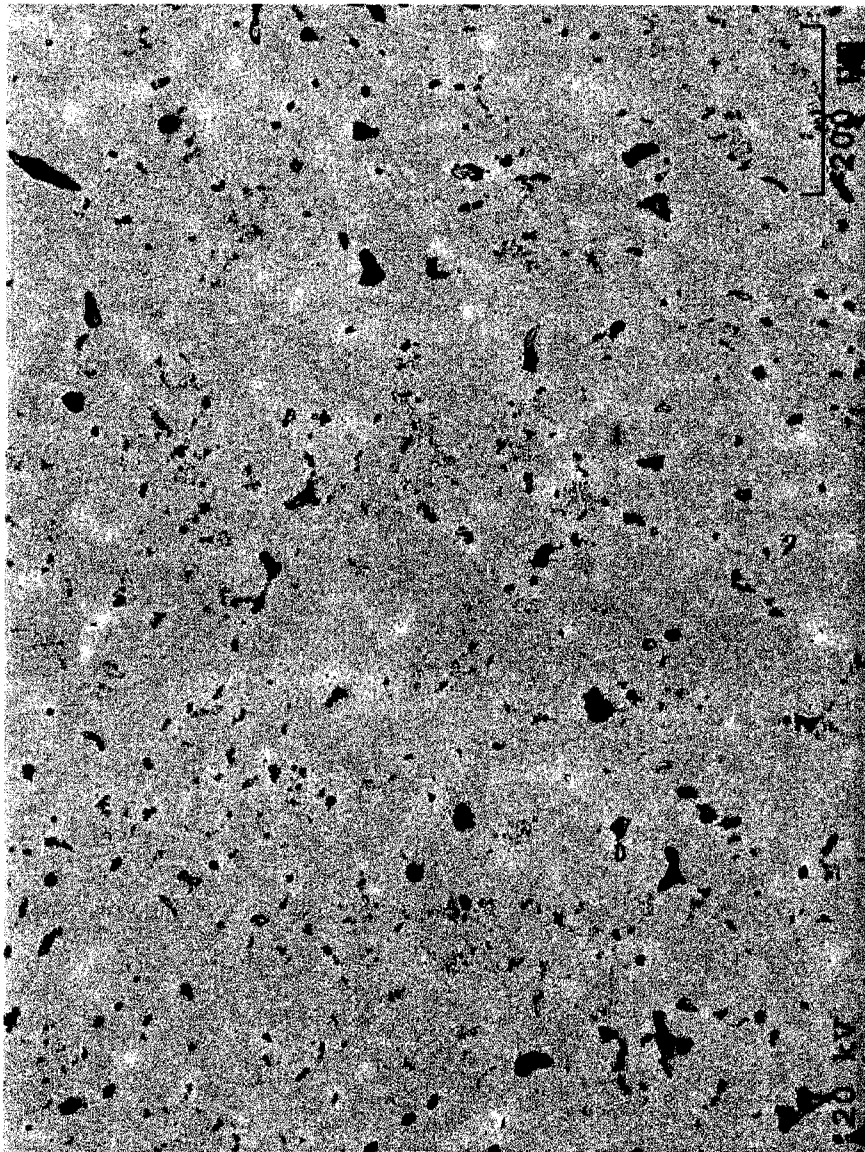


FIGURE 16B

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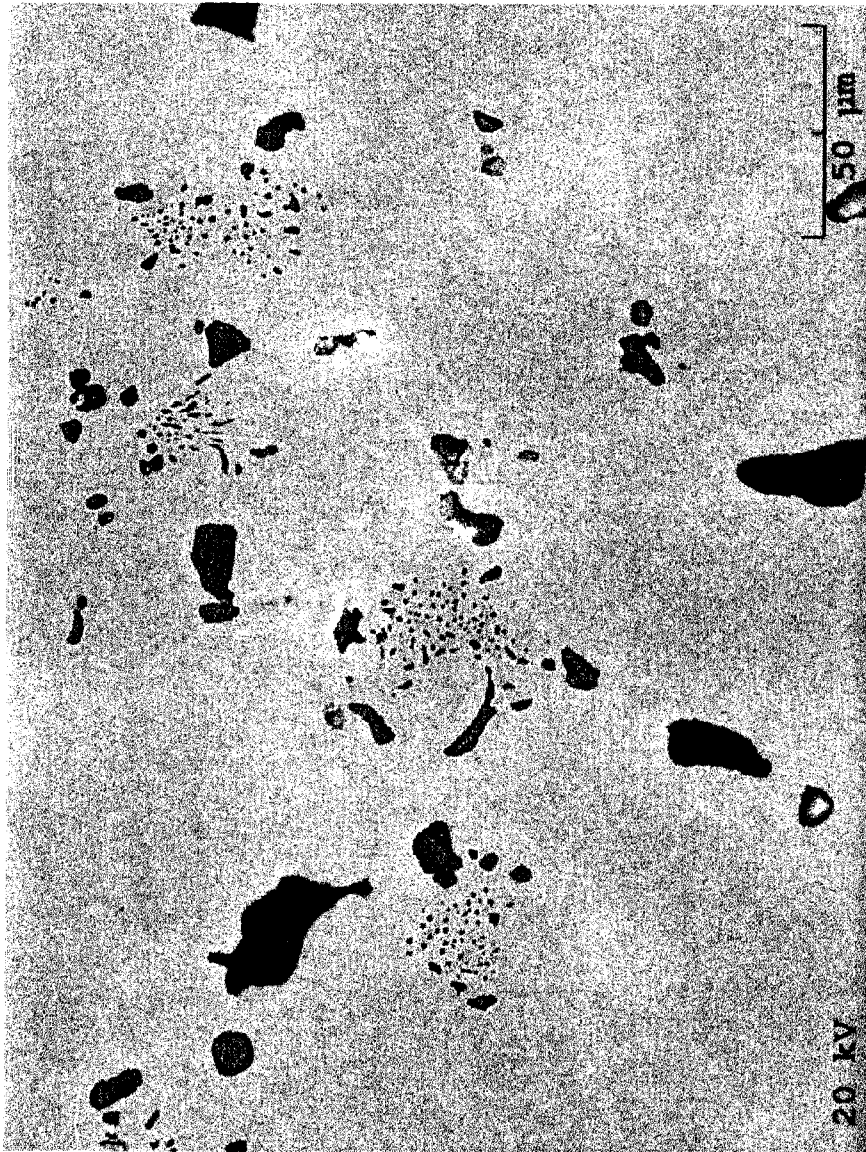


FIGURE 16C

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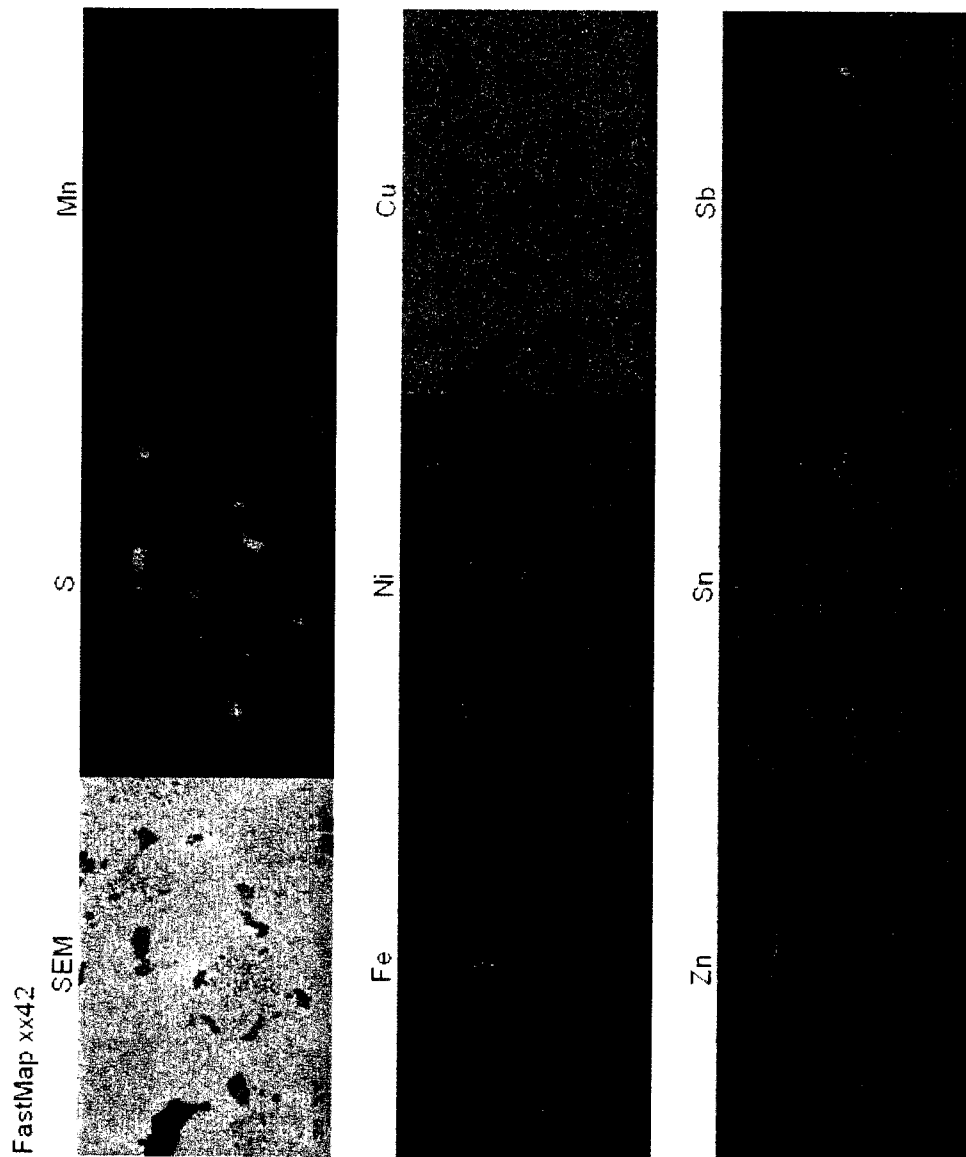


FIGURE 16D

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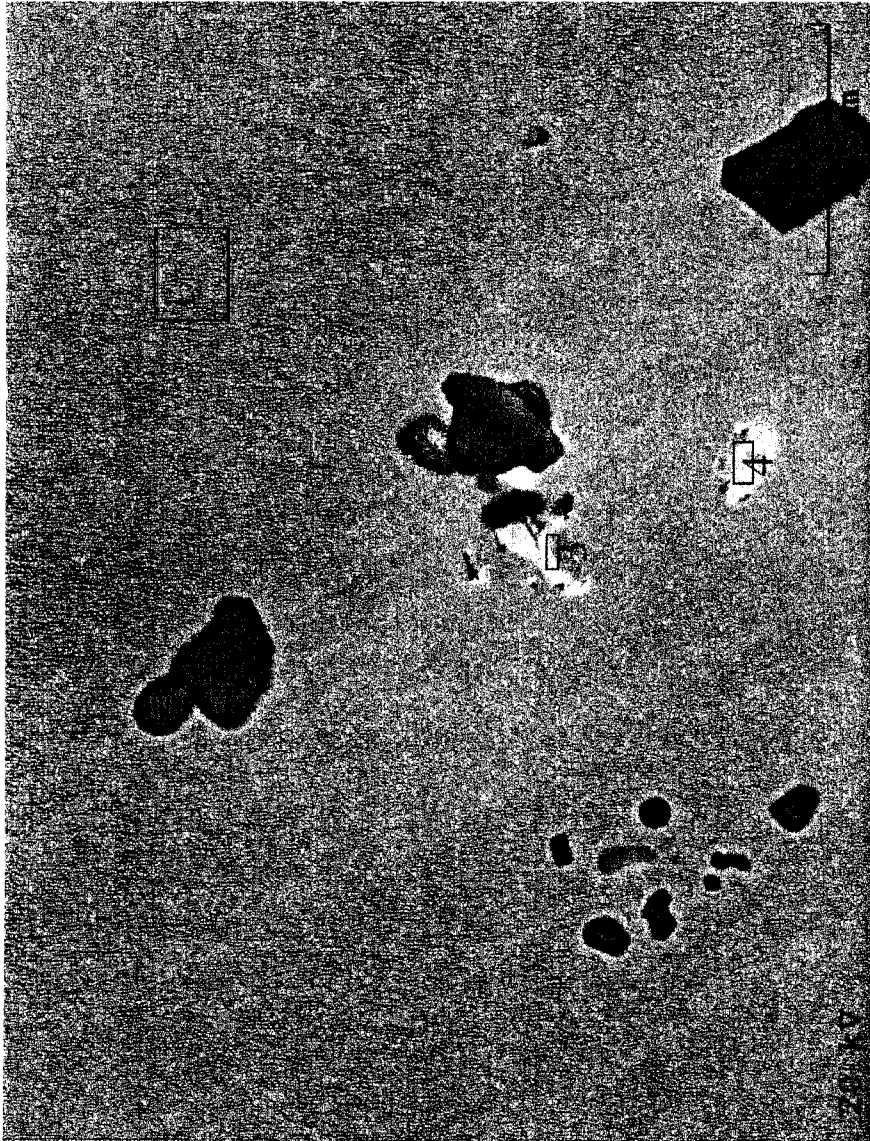


FIGURE 16E

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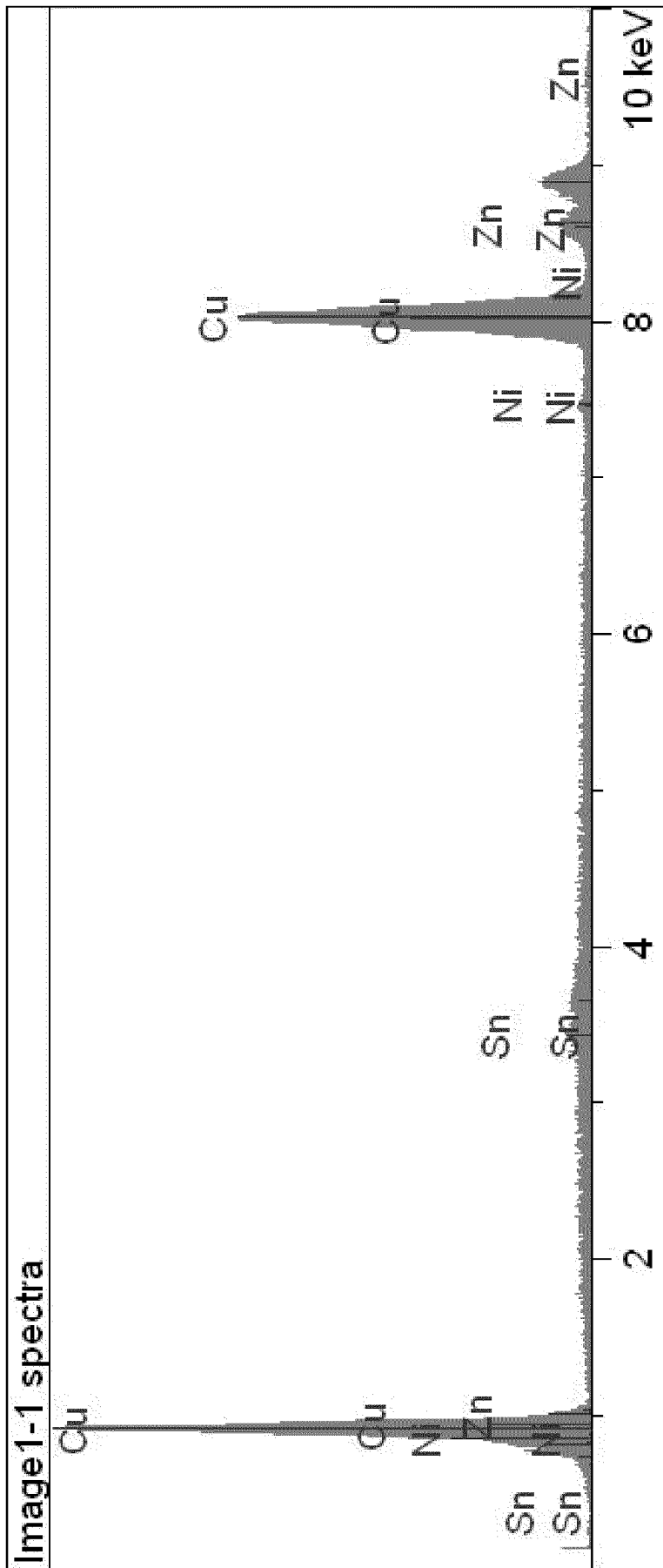
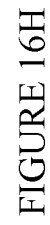


FIGURE 16F

FIGURE 16G

Image 1-3 spectra



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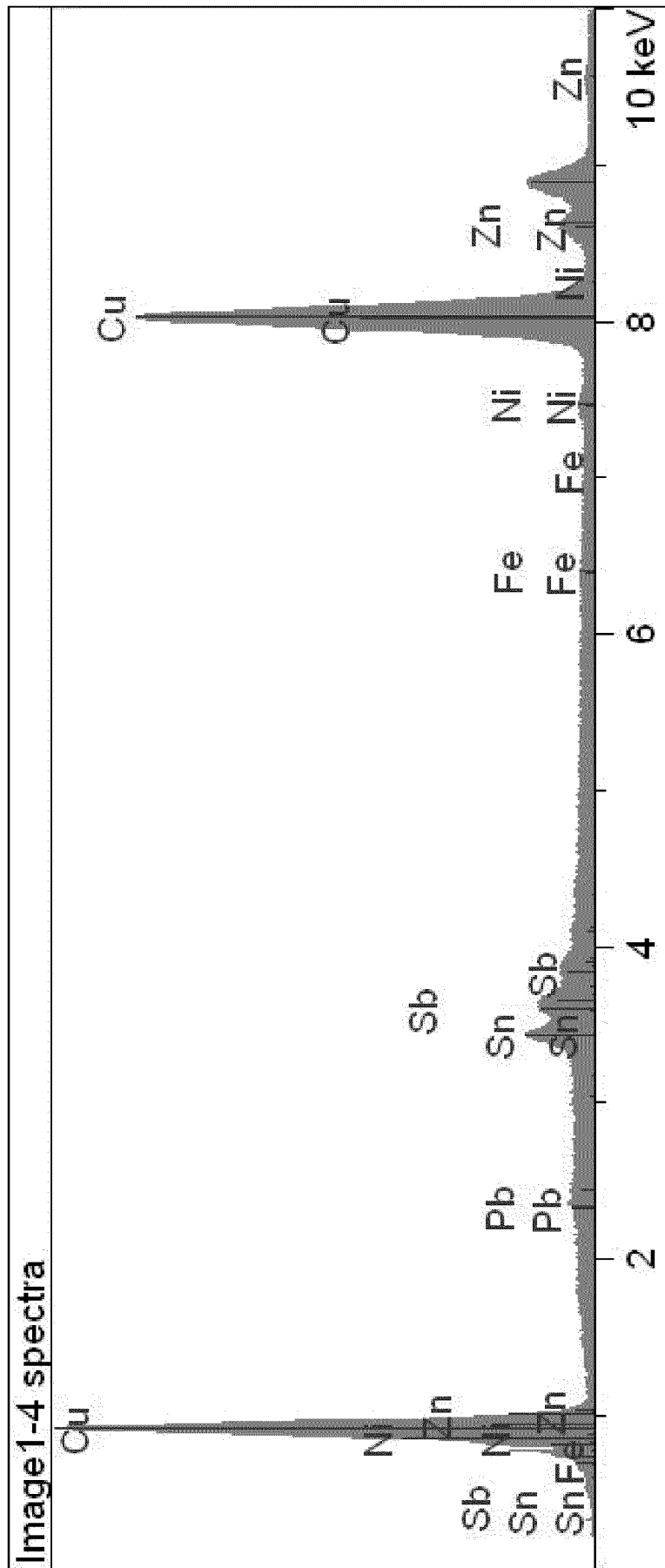


FIGURE 16I

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FIGURE 16J

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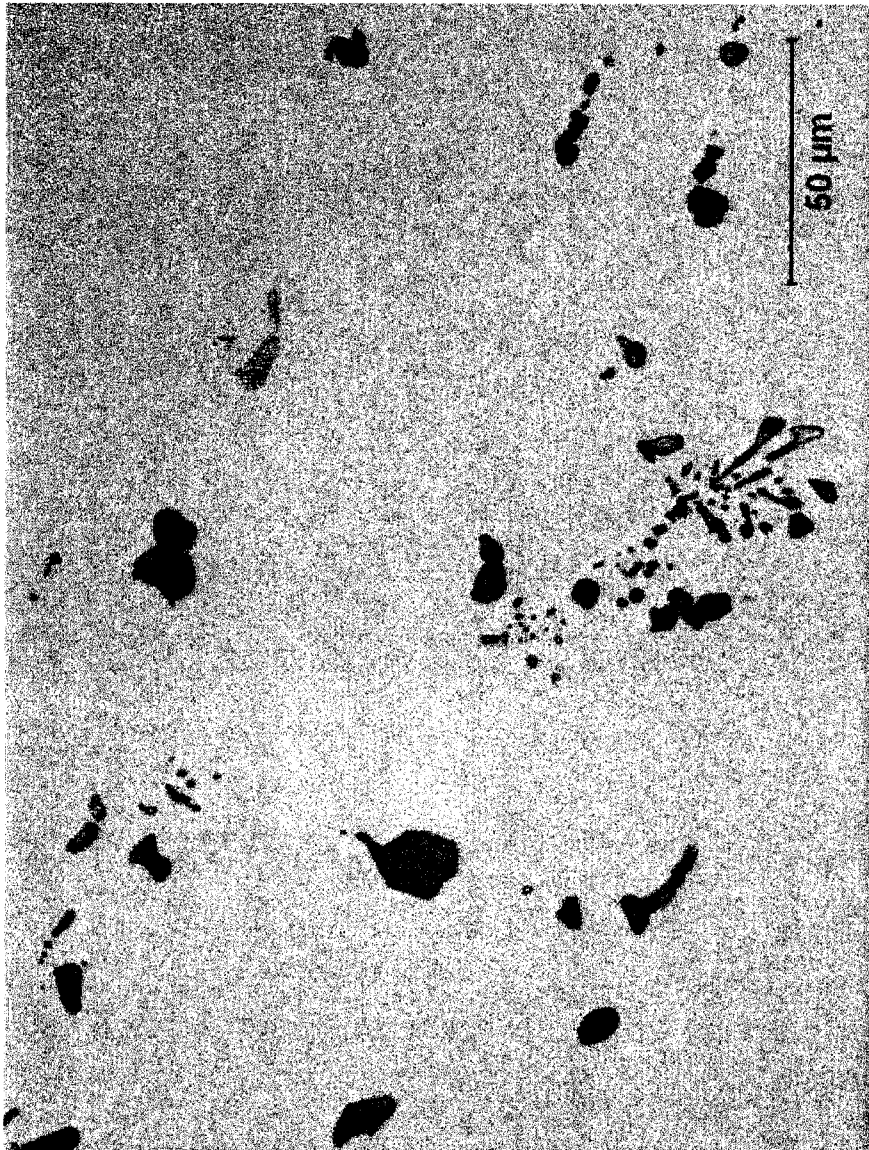


FIGURE 17A

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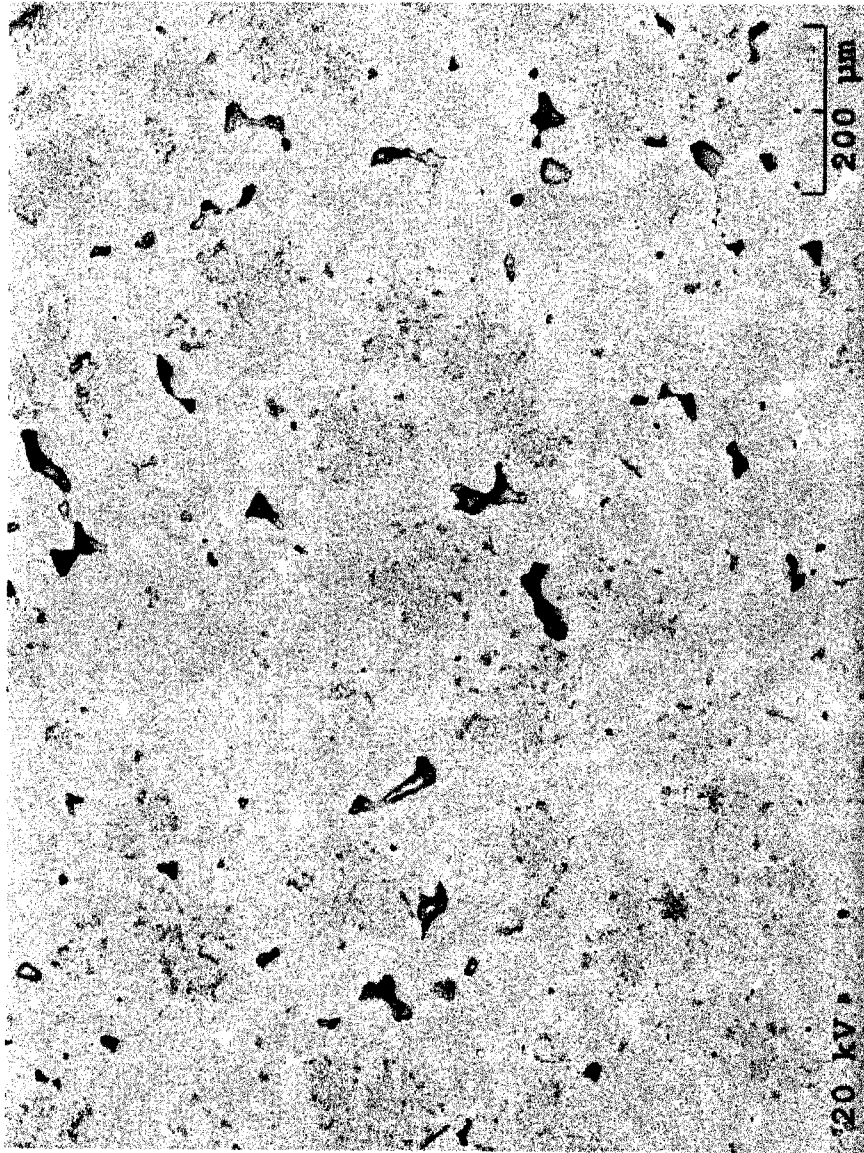


FIGURE 17B

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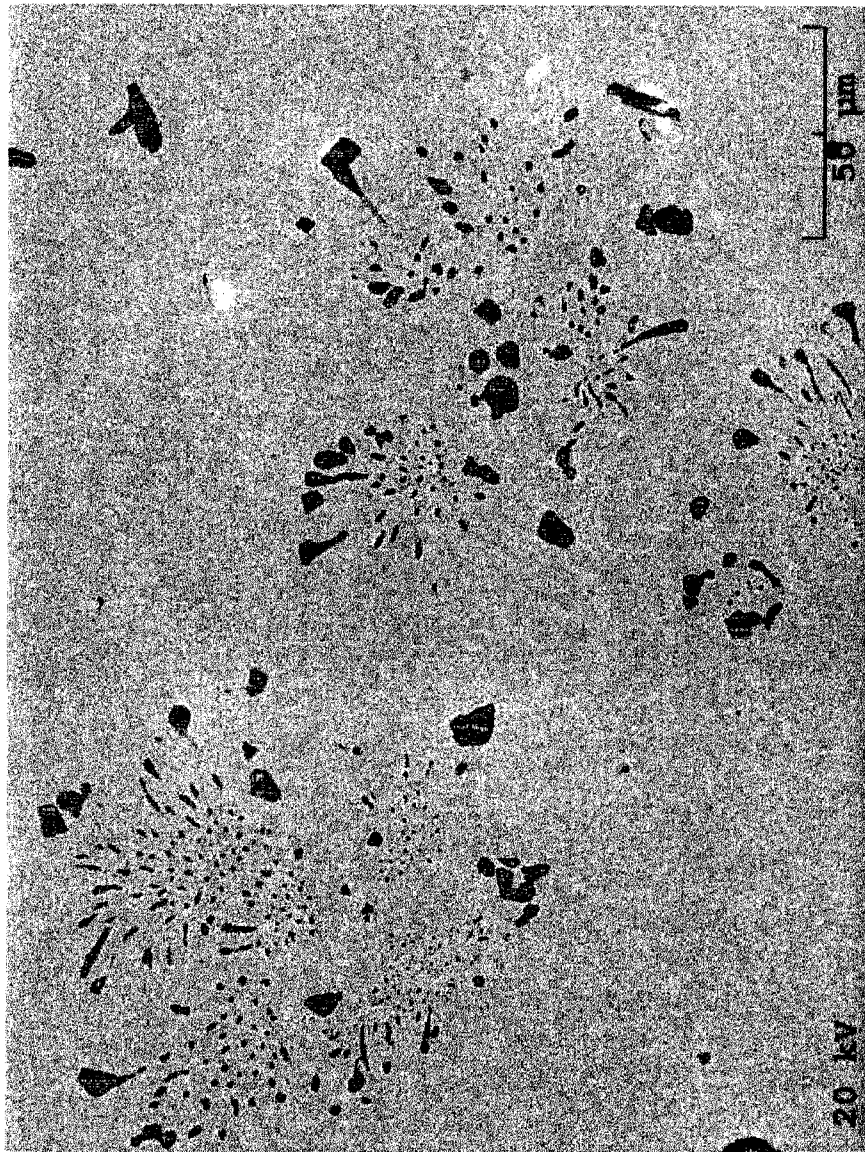


FIGURE 17C

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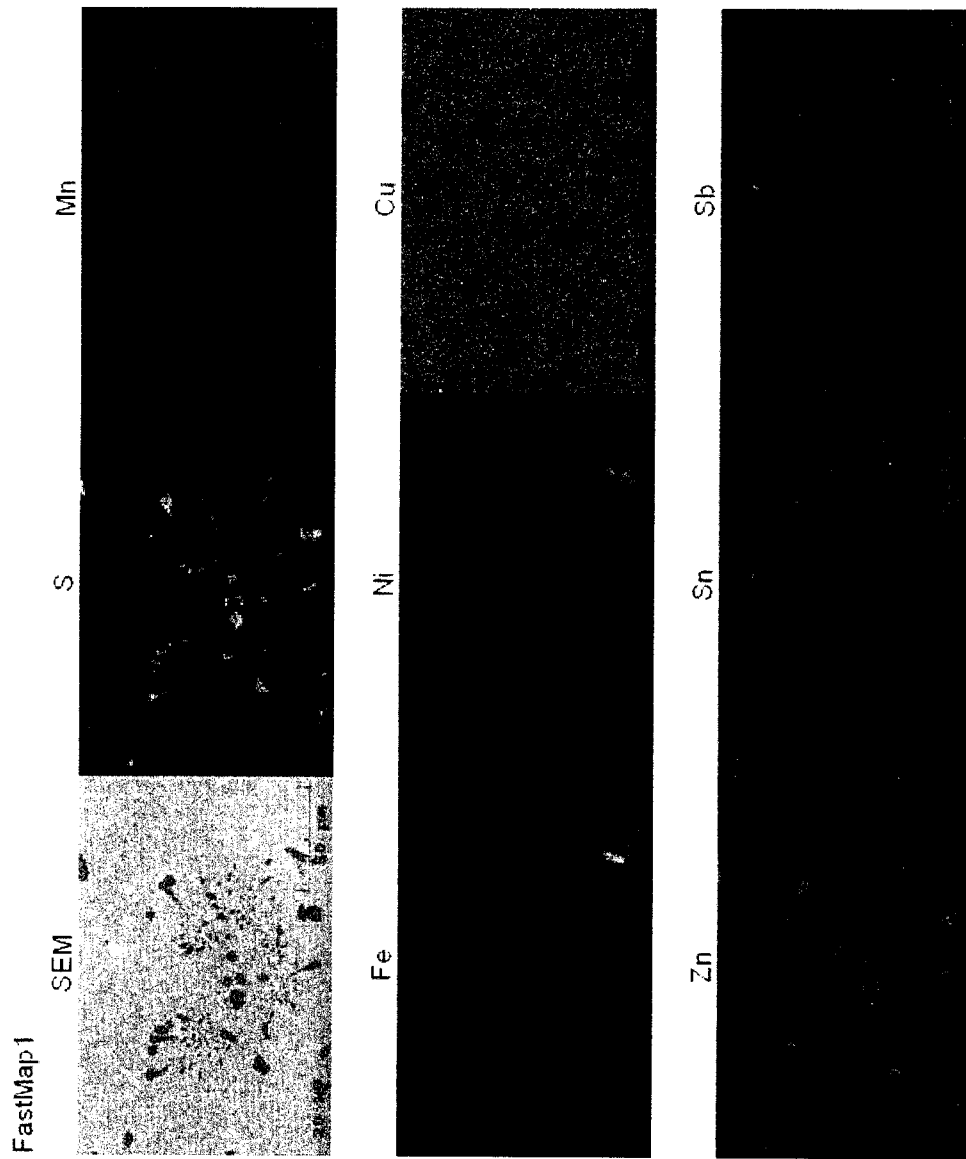


FIGURE 17D

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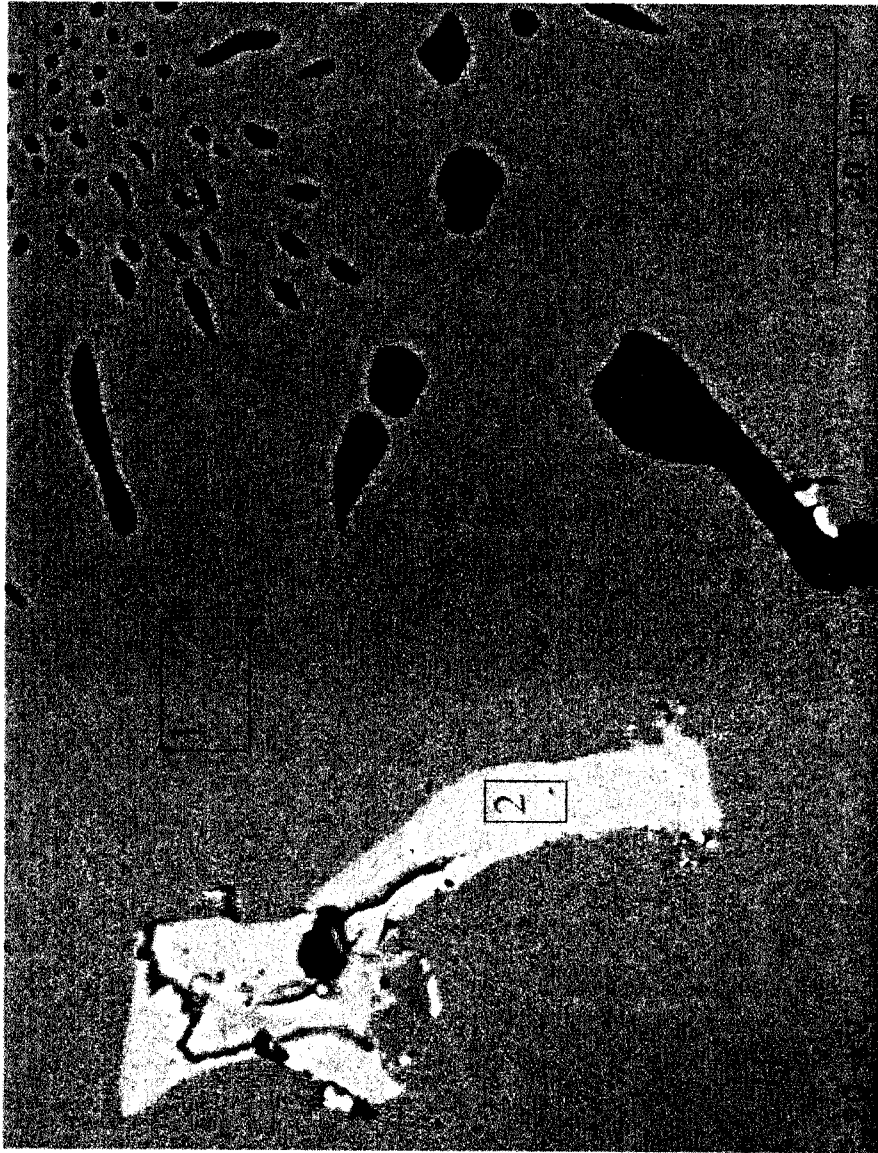


FIGURE 17E

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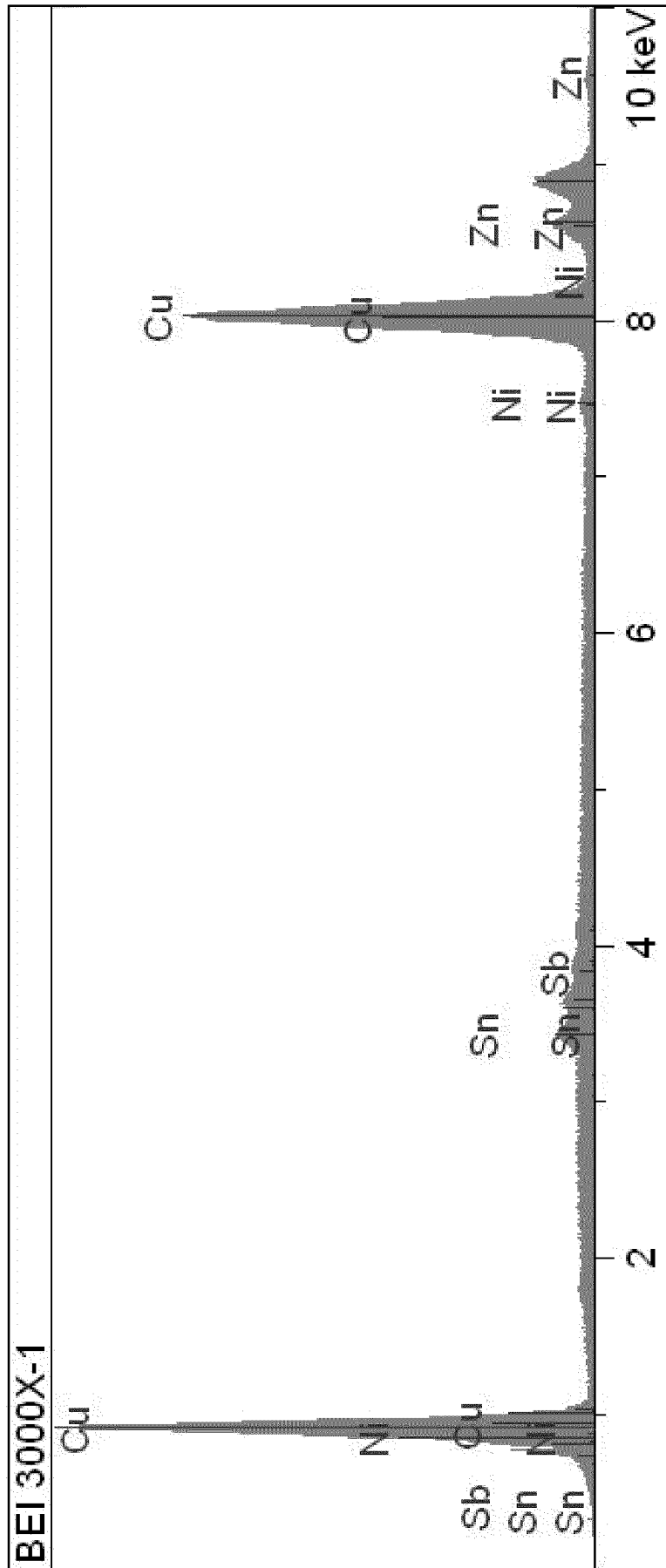


FIGURE 17F

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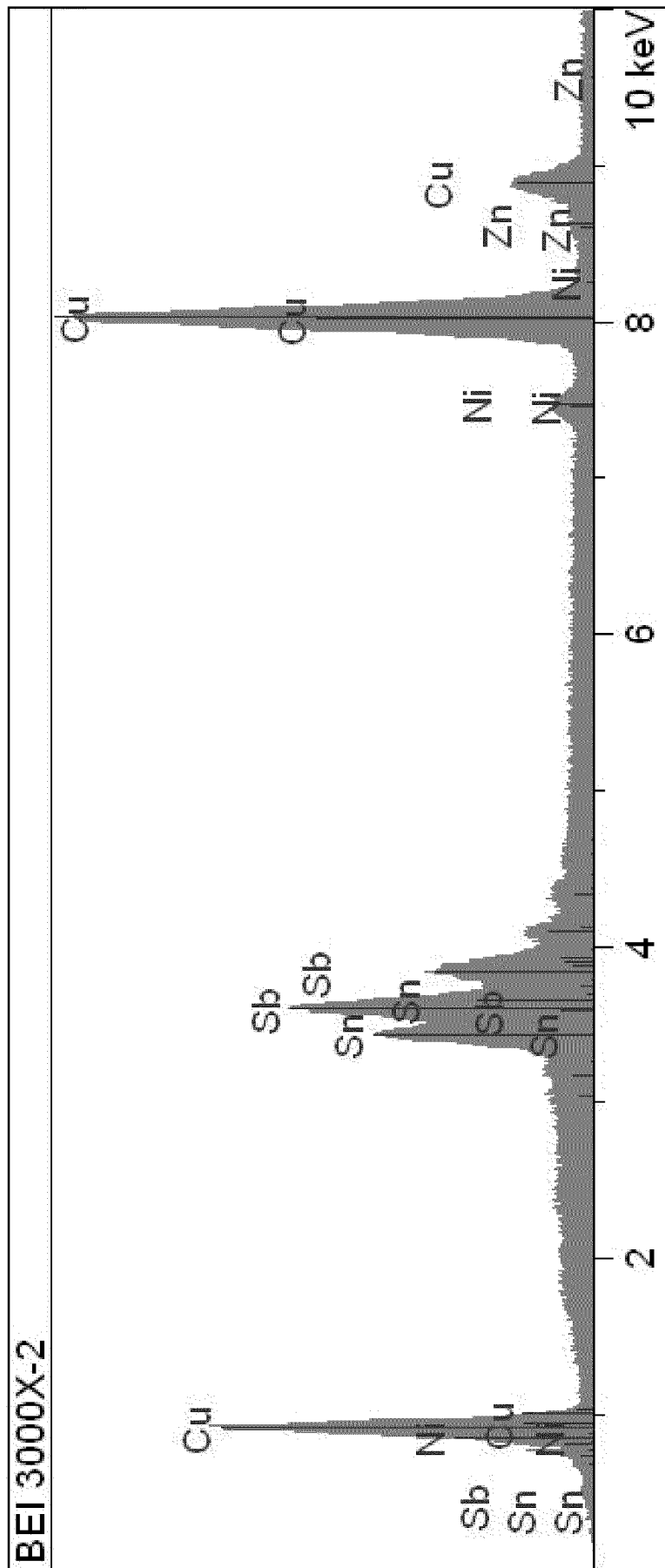


FIGURE 17G

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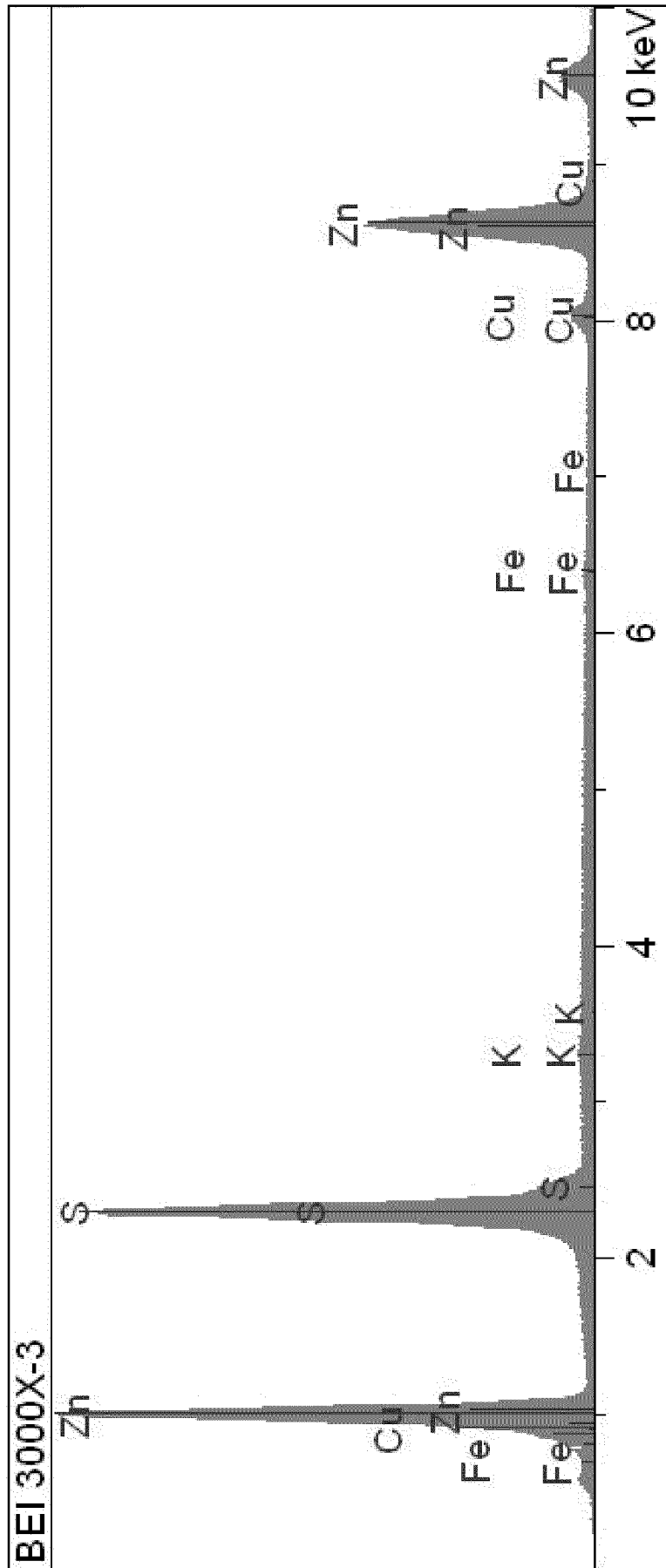


FIGURE 17H

FIGURE 17I

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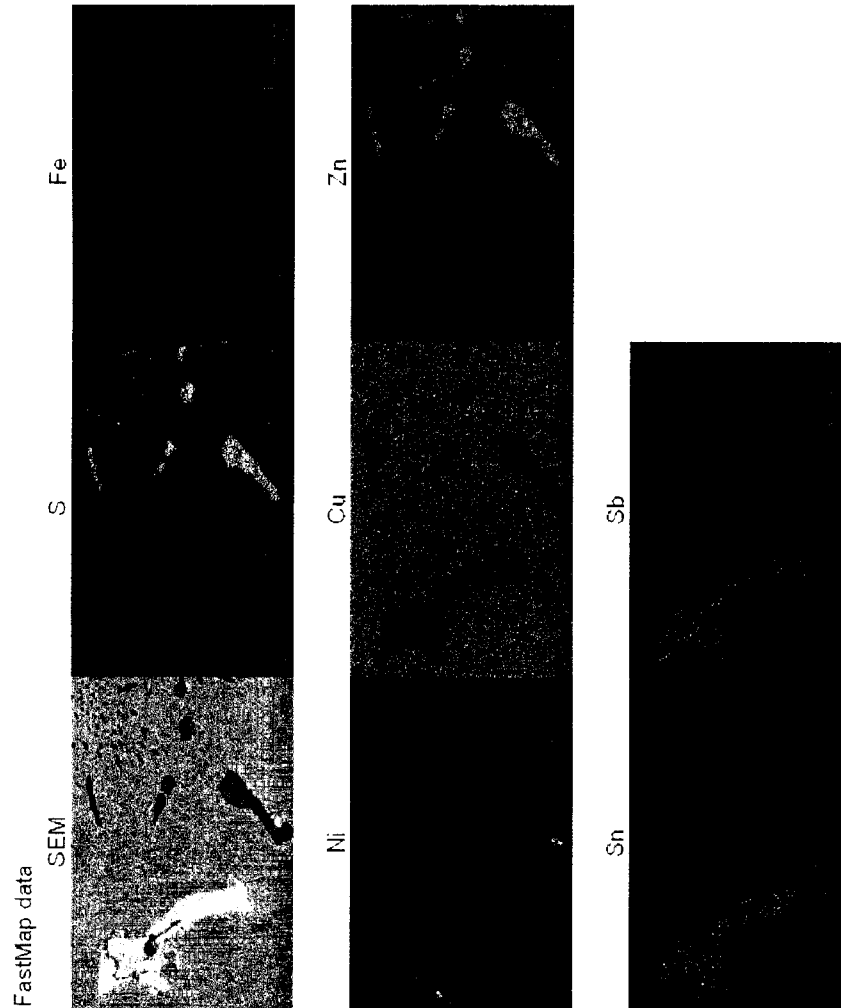


FIGURE 17J

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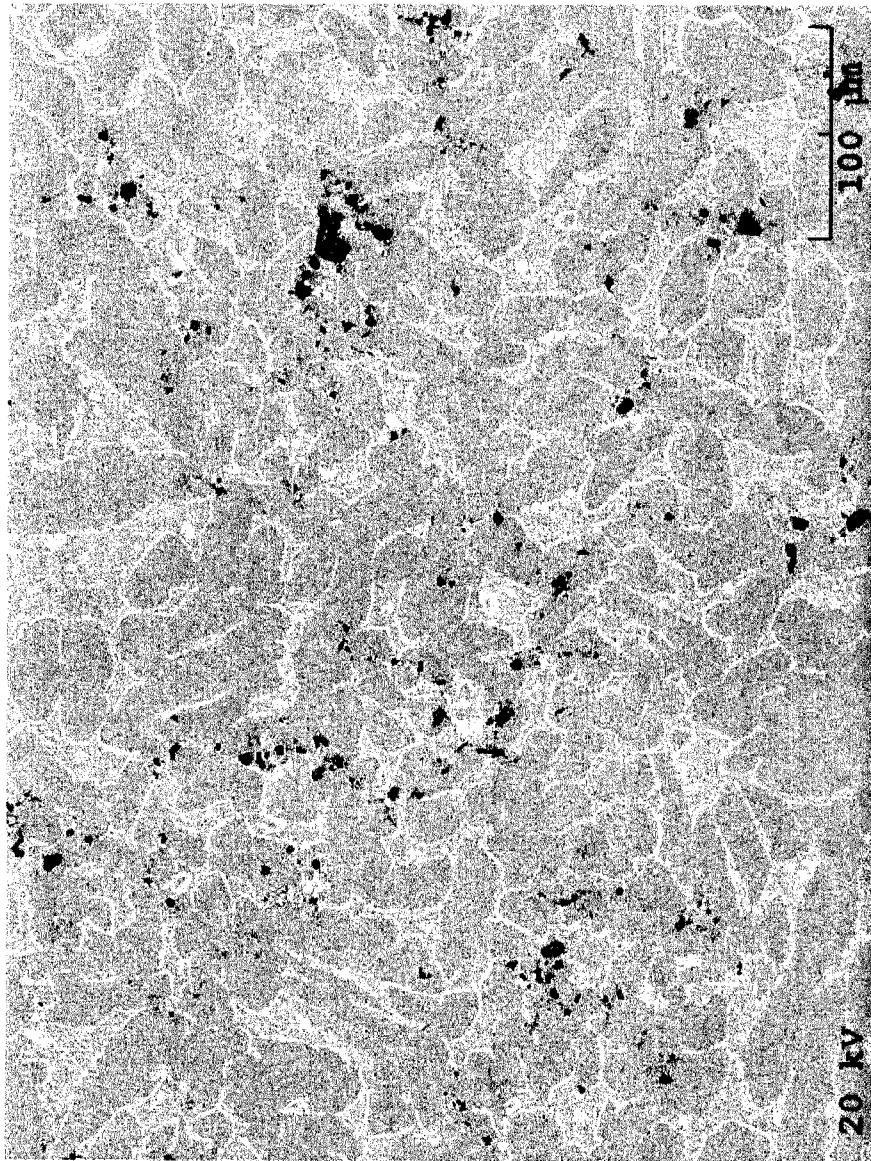


FIGURE 18A

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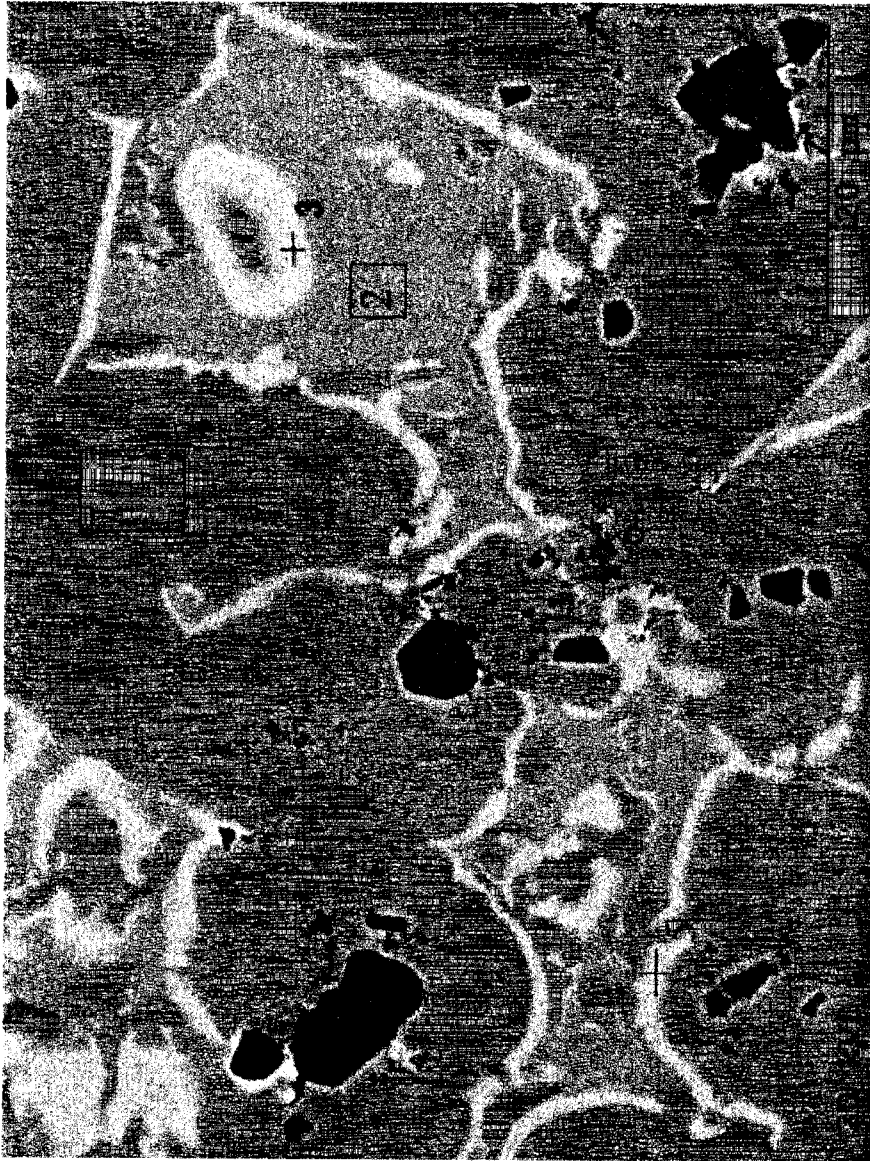


FIGURE 18B

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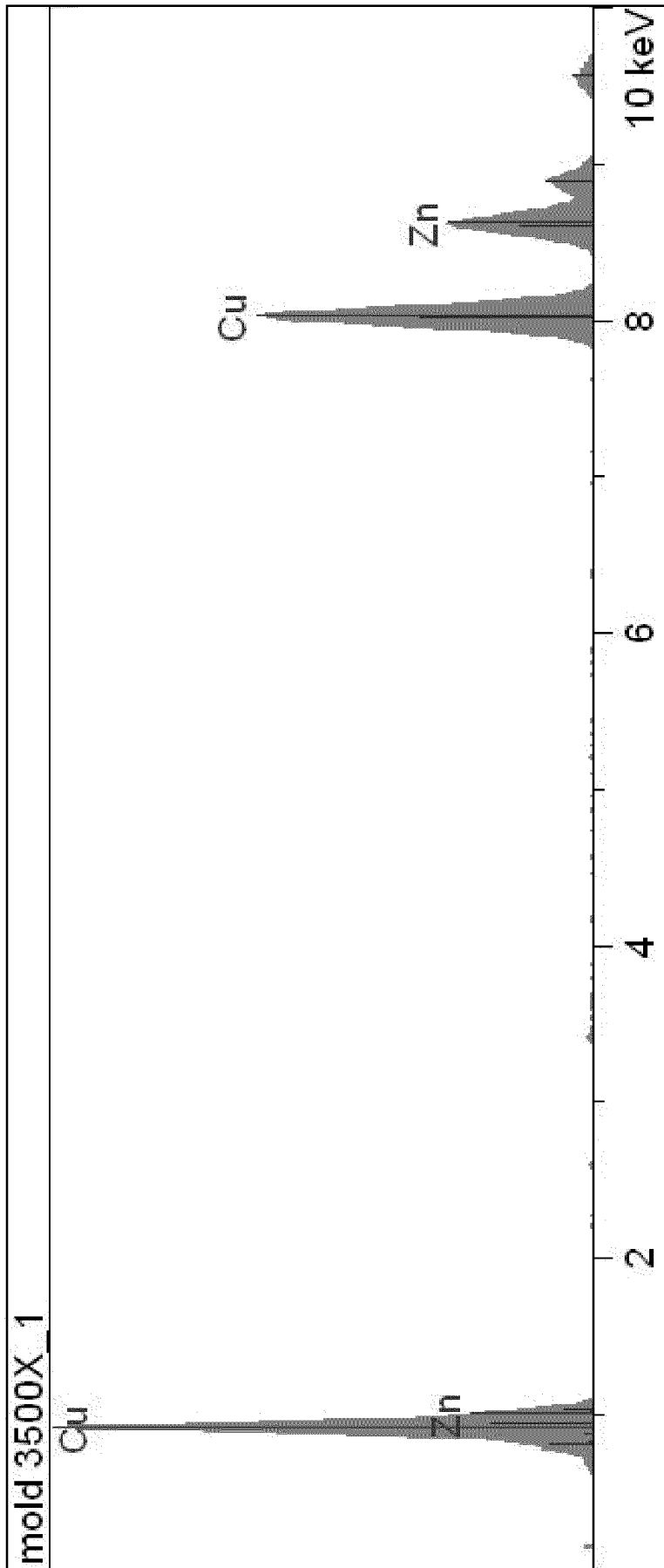


FIGURE 18C

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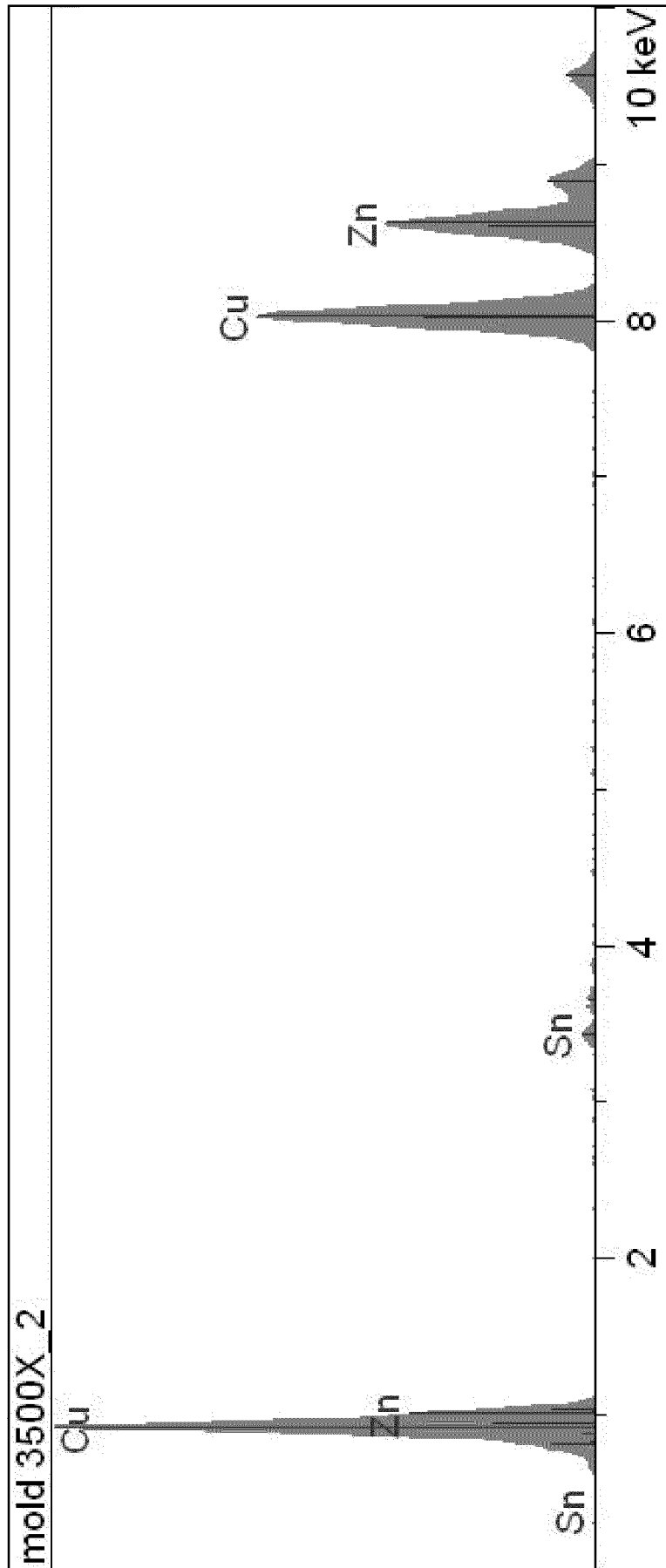


FIGURE 18D

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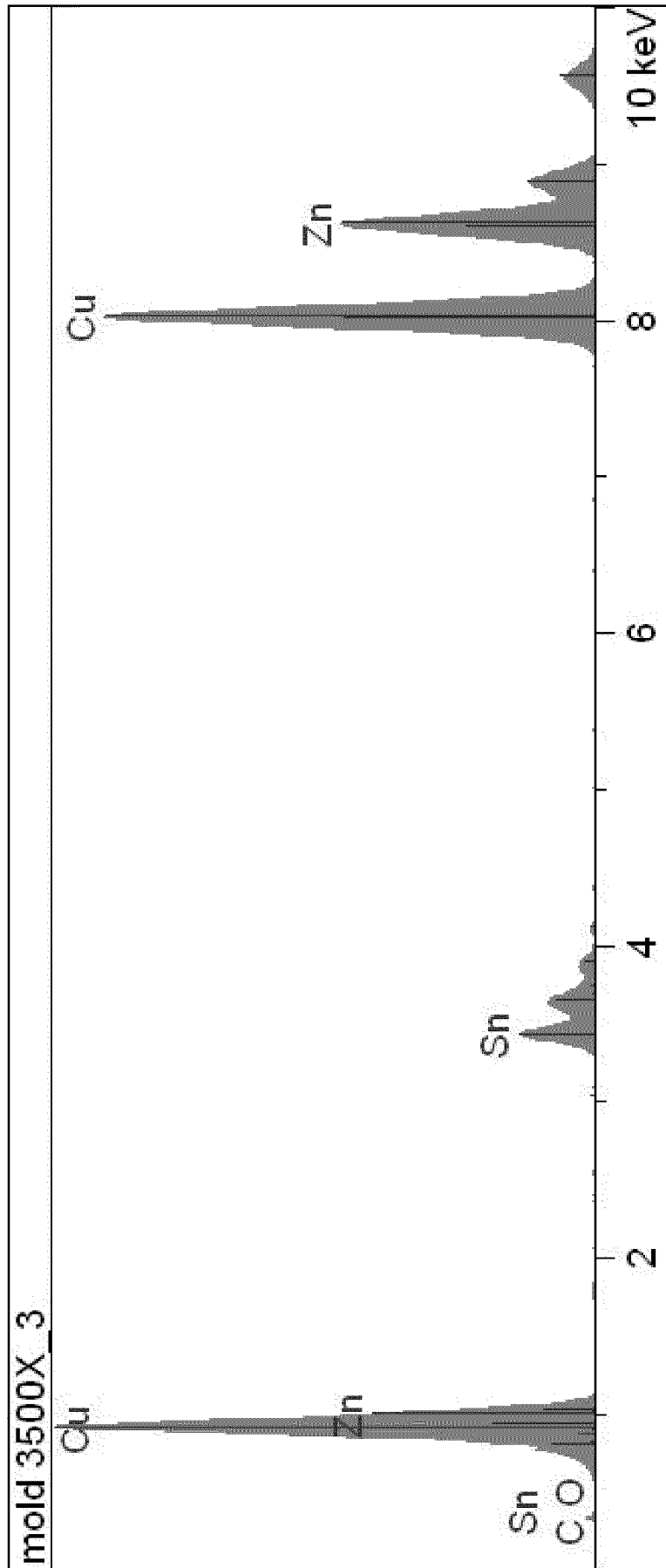


FIGURE 18E

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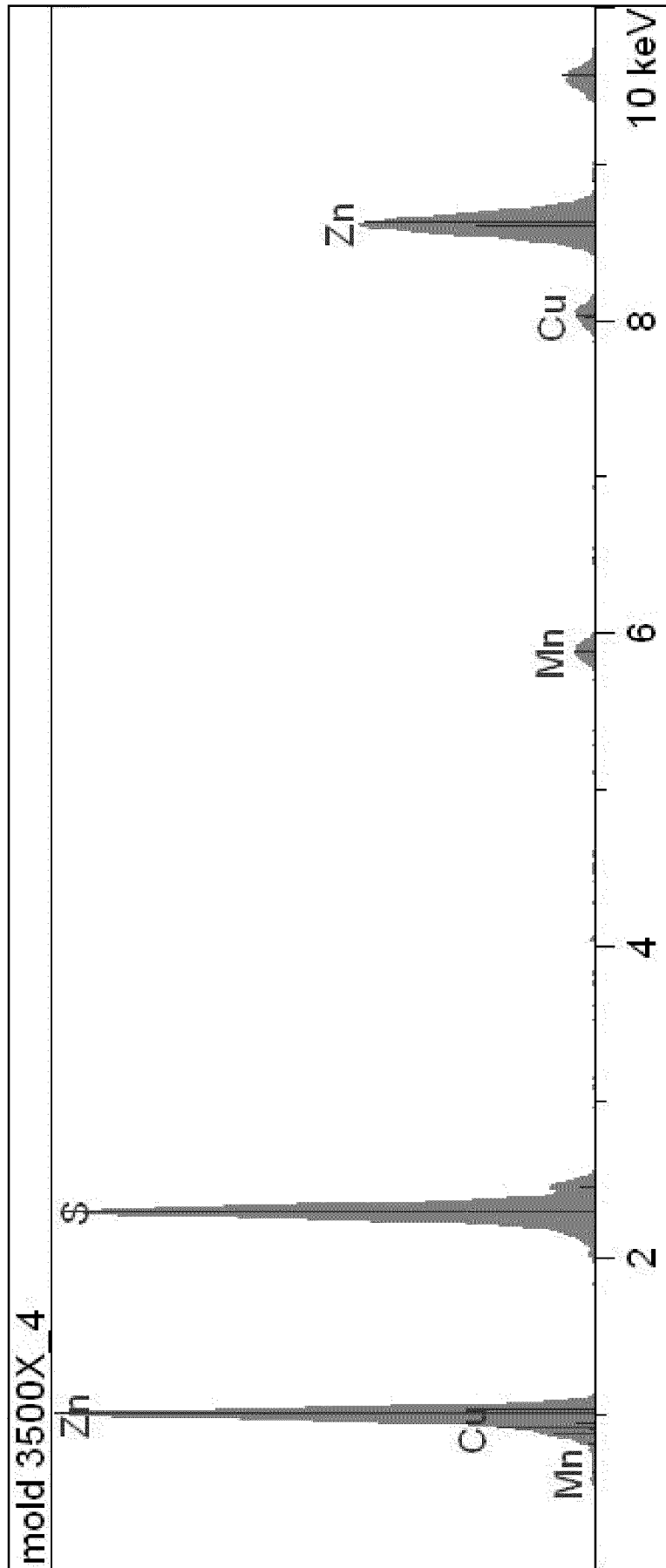


FIGURE 18F

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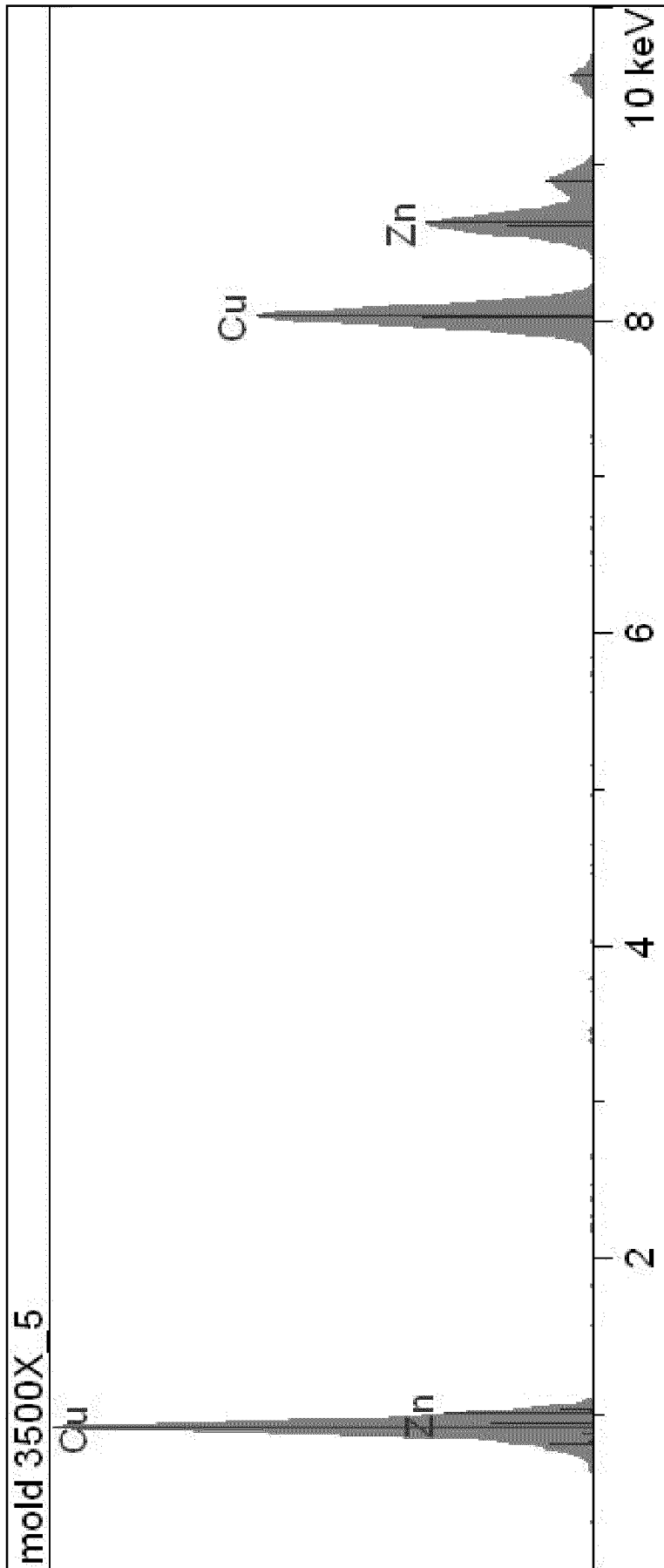


FIGURE 18G

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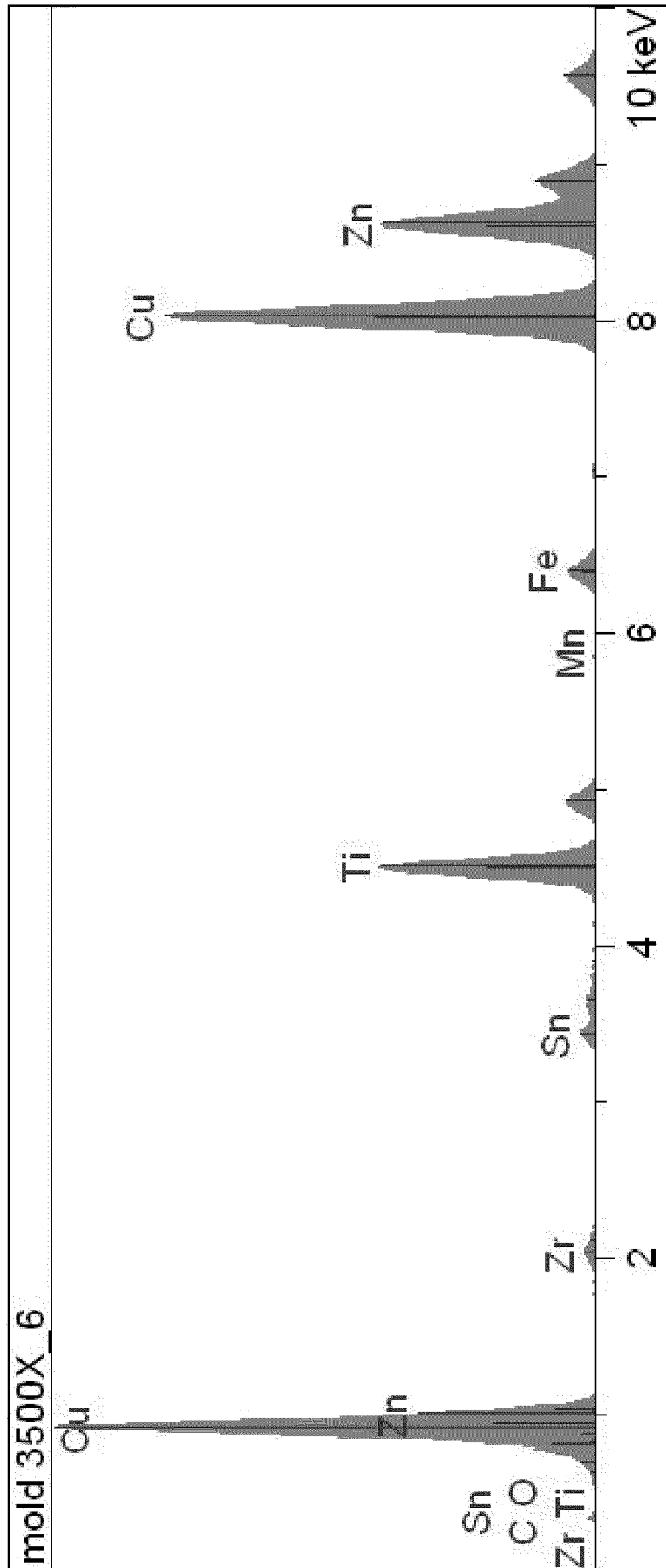


FIGURE 18H

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FIGURE 18I

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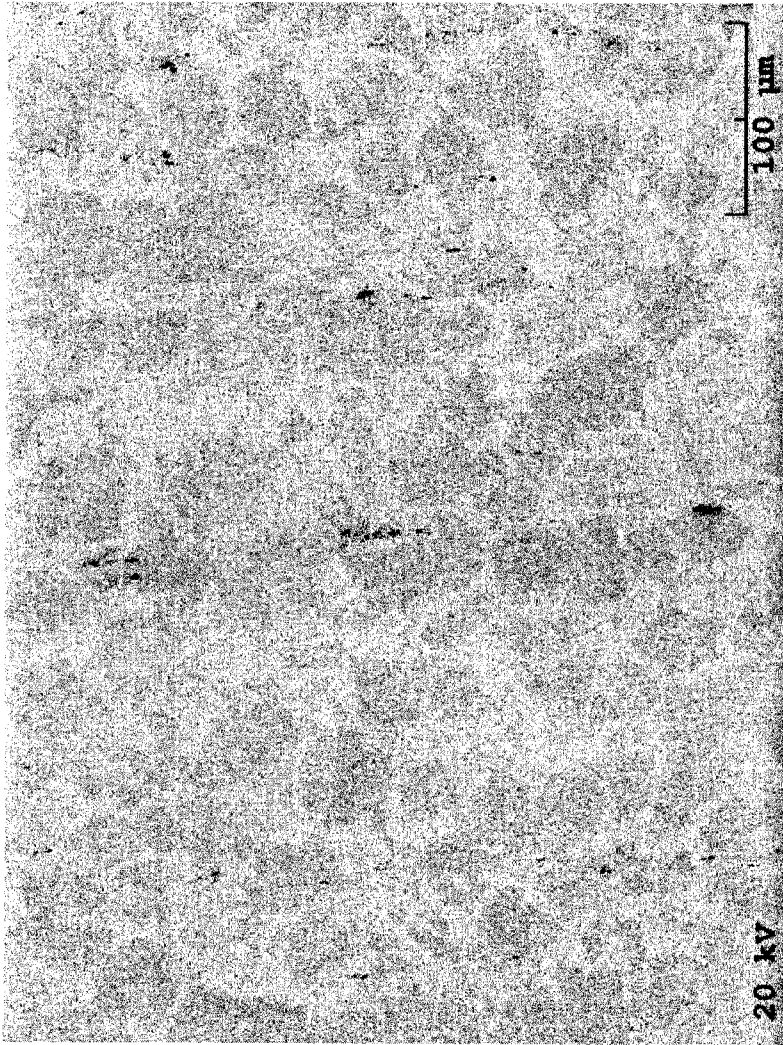


FIGURE 19A

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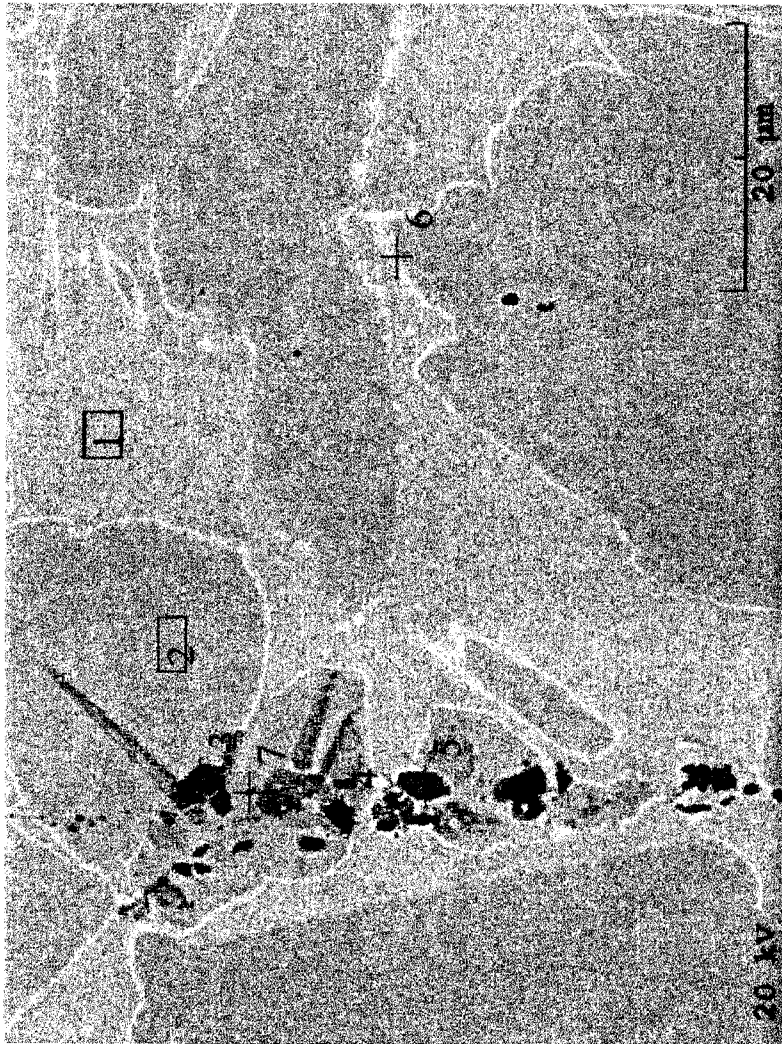


FIGURE 19B

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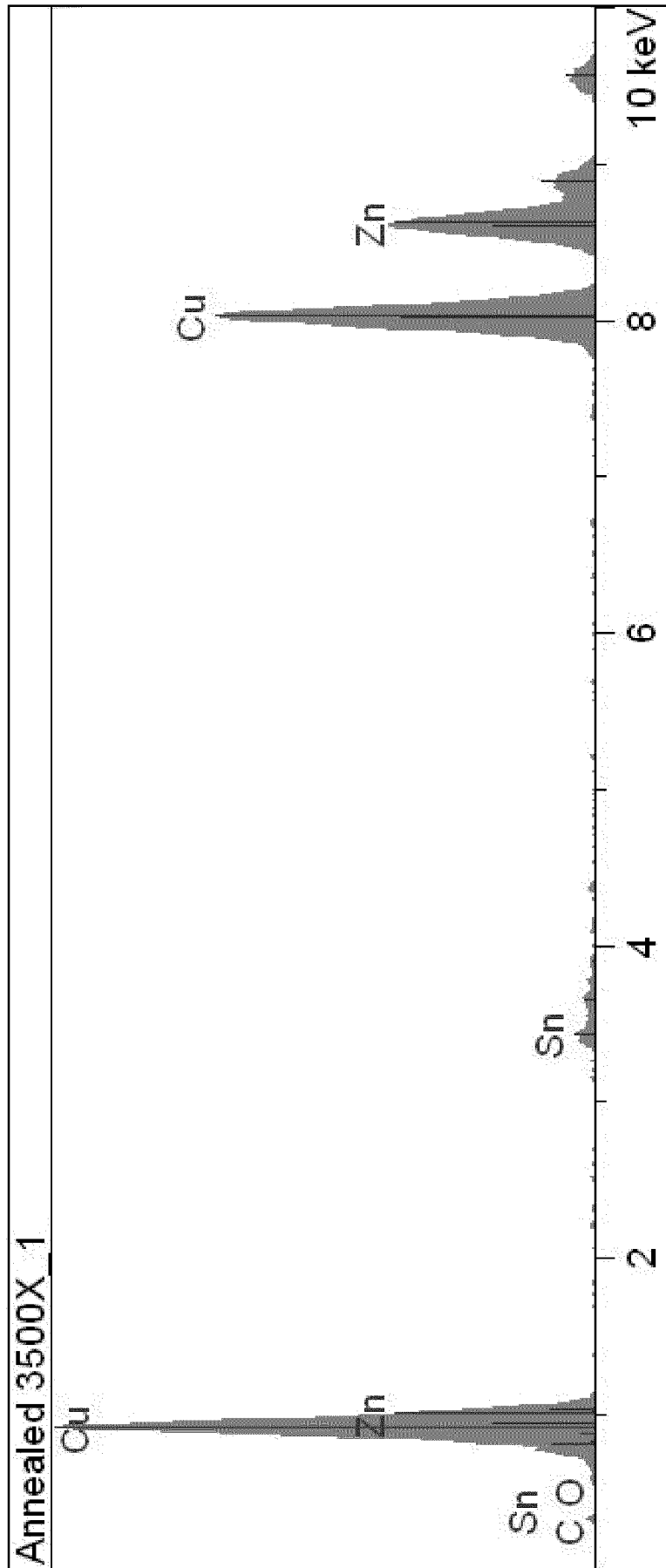


FIGURE 19C

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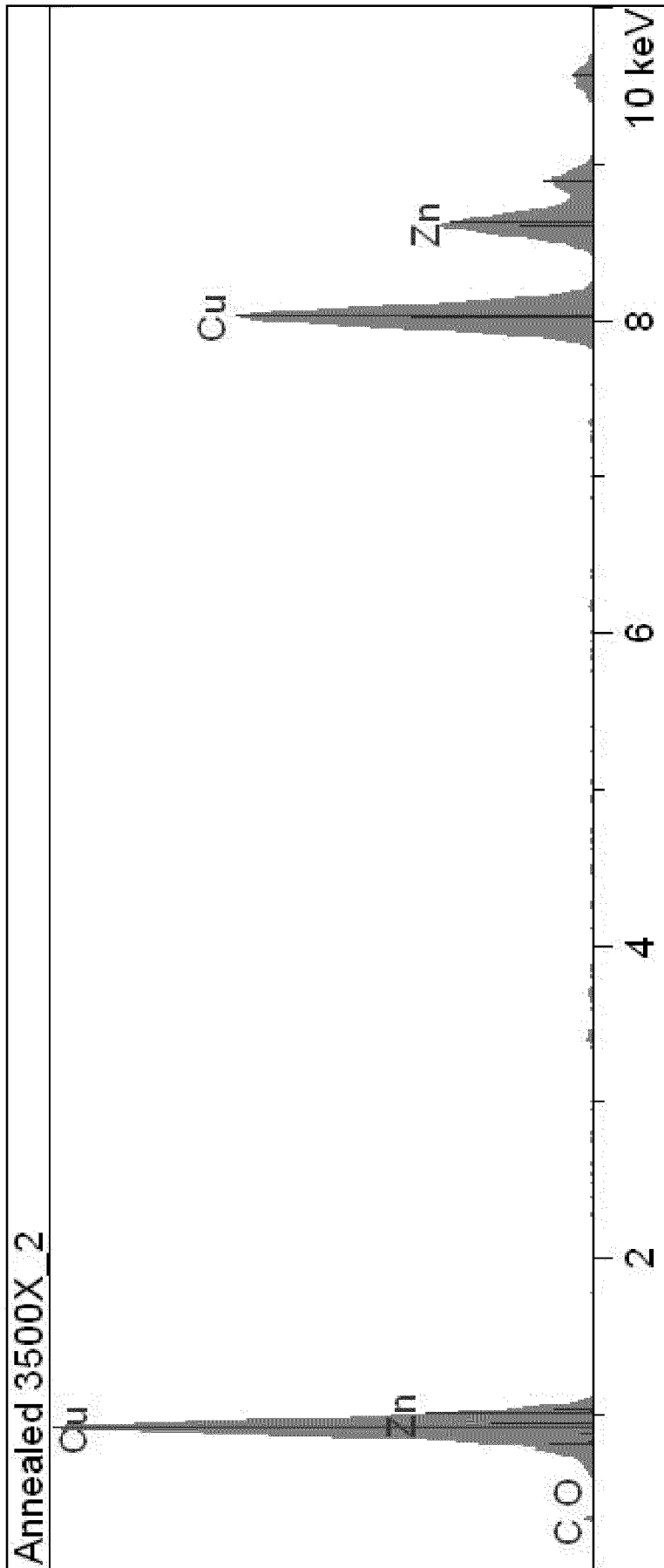


FIGURE 19D

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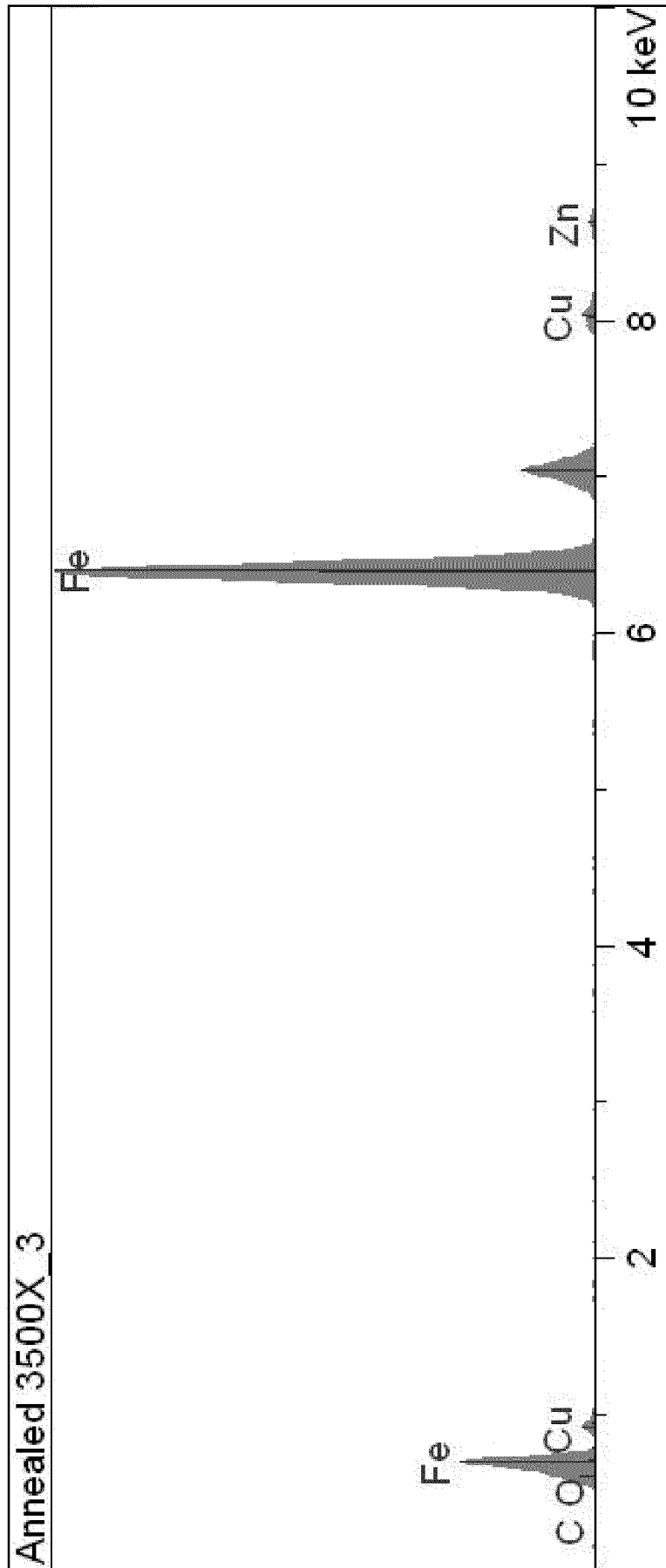


FIGURE 19E

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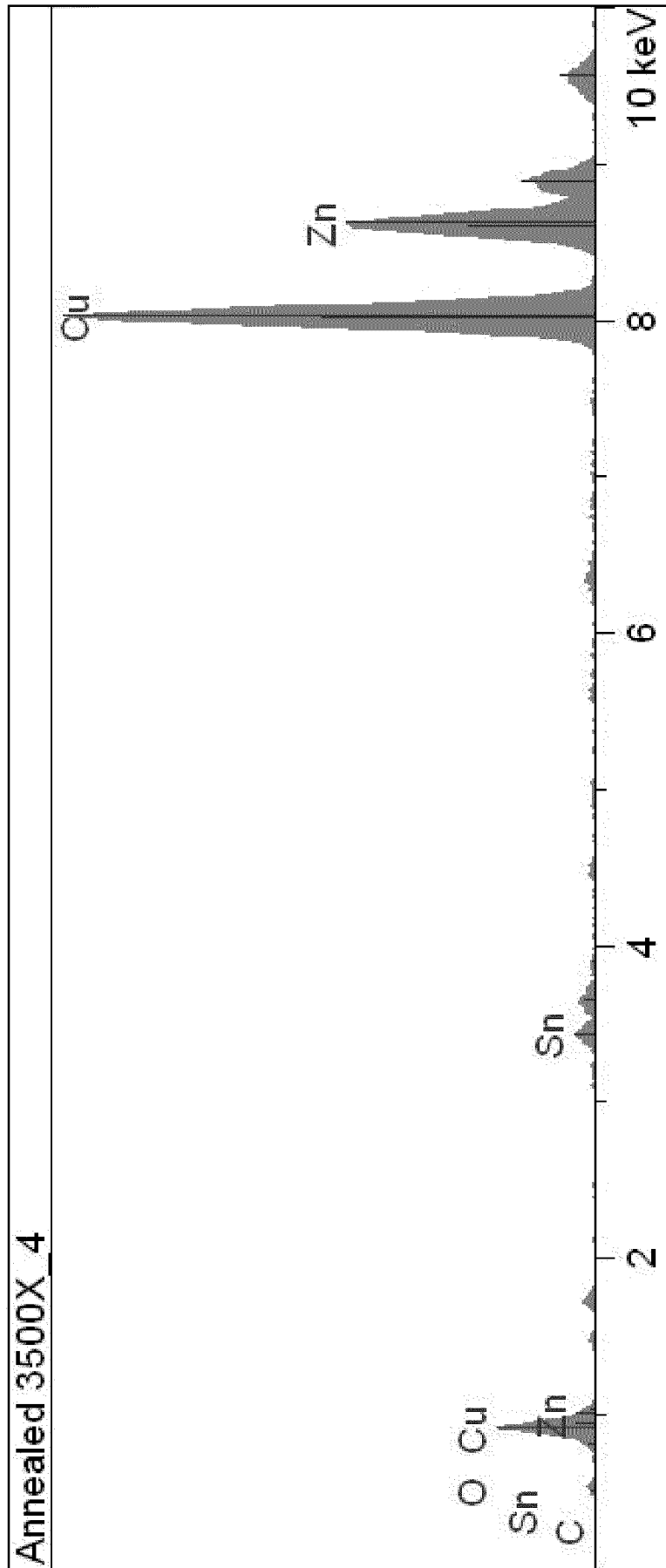


FIGURE 19F

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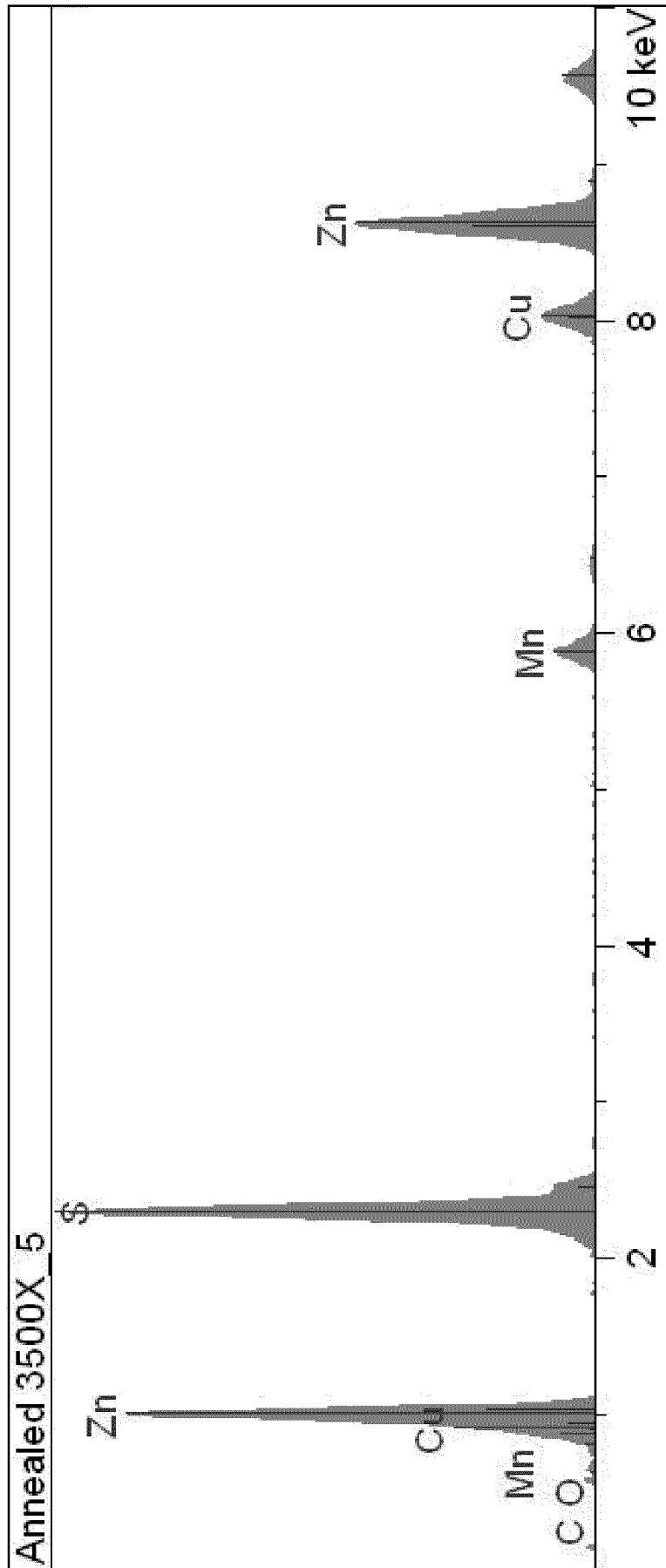


FIGURE 19G

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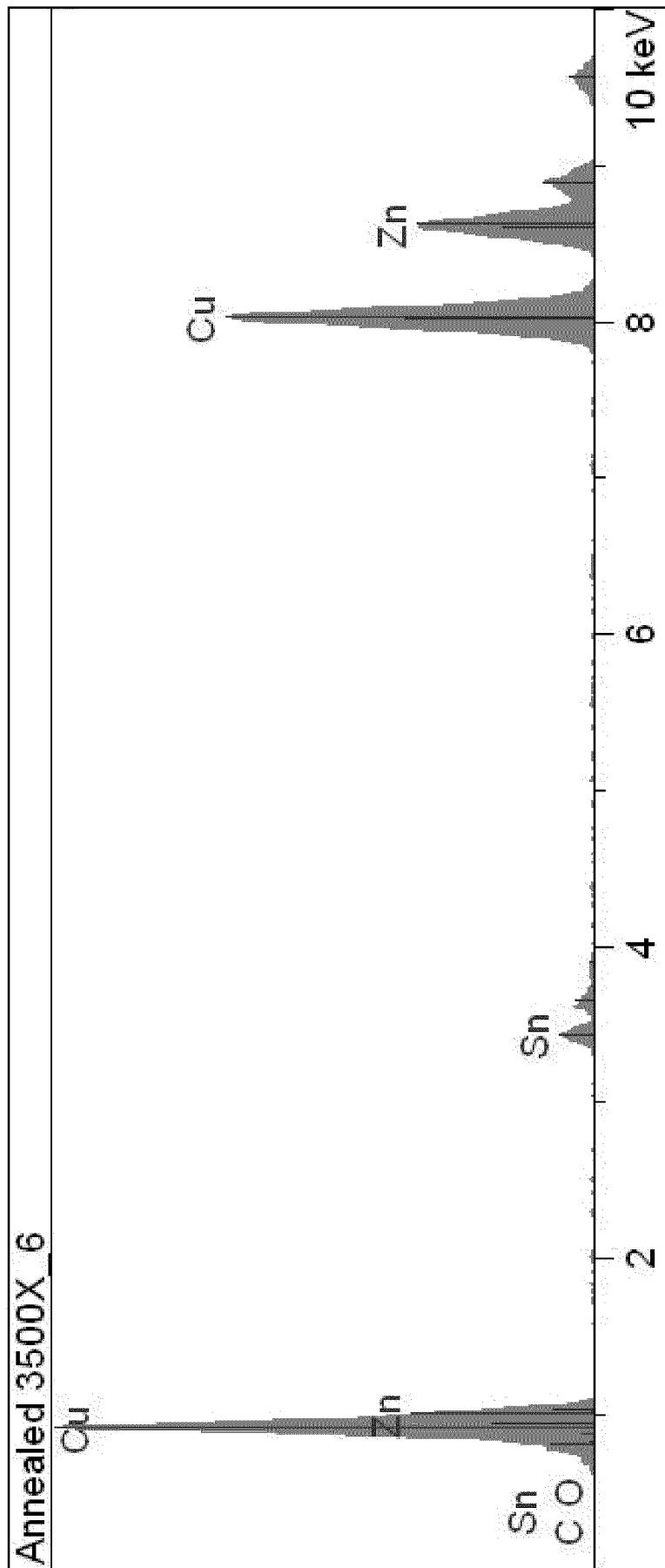


FIGURE 19H

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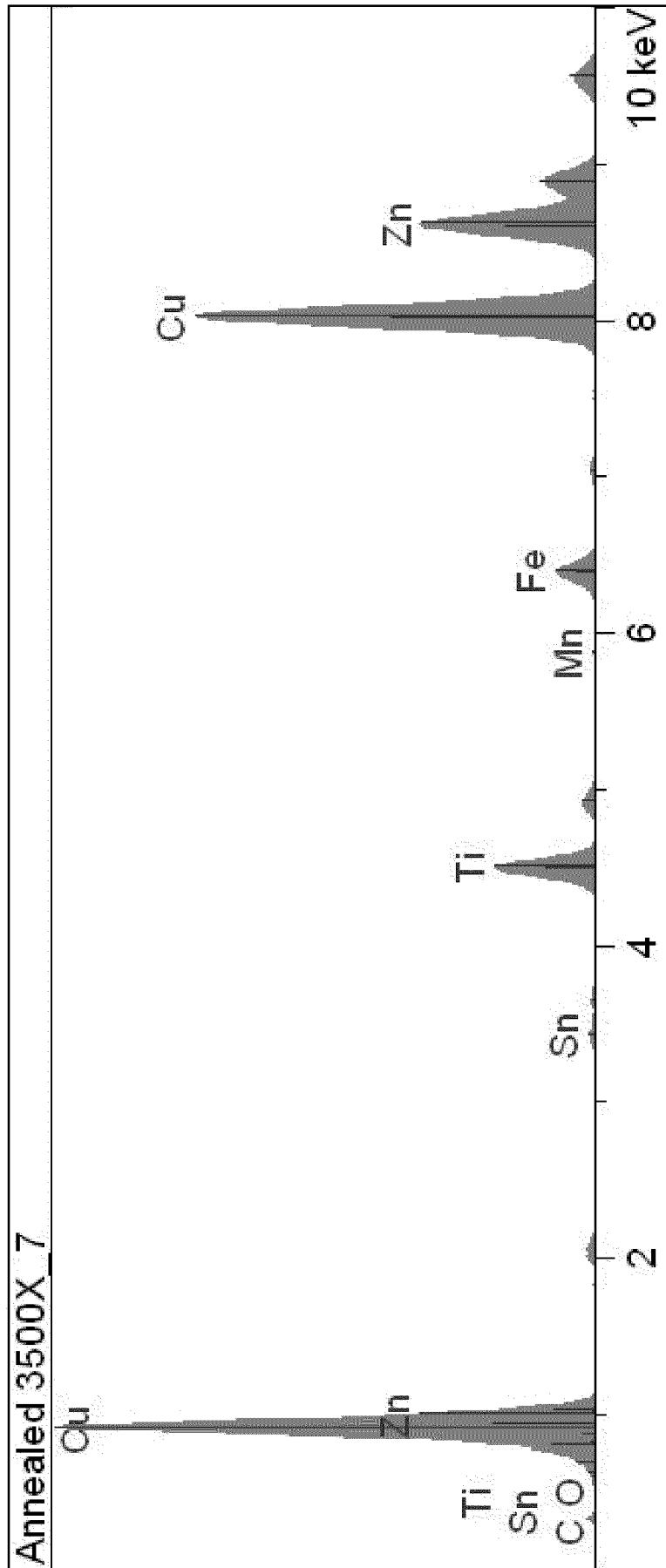


FIGURE 19I

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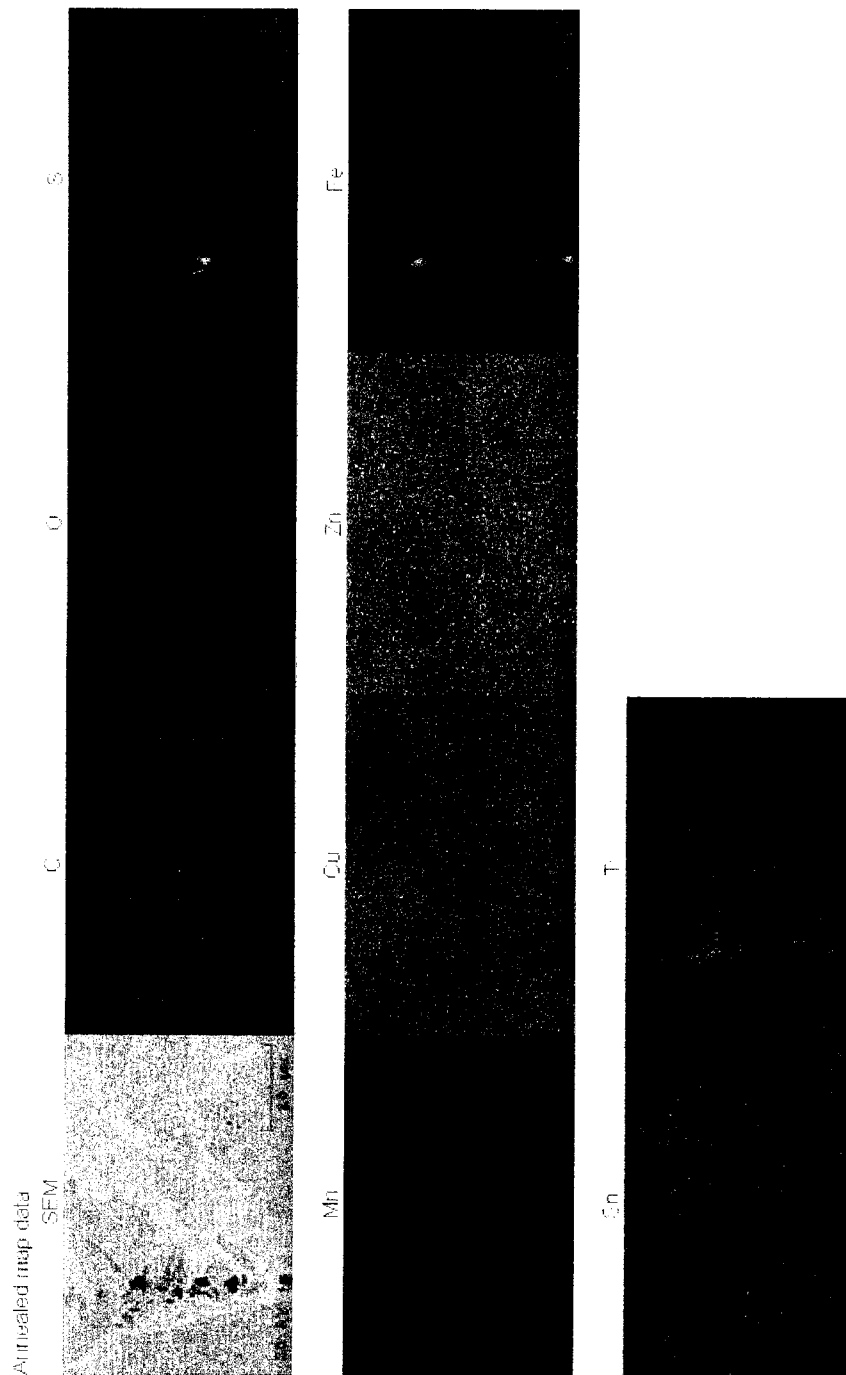


FIGURE 19J

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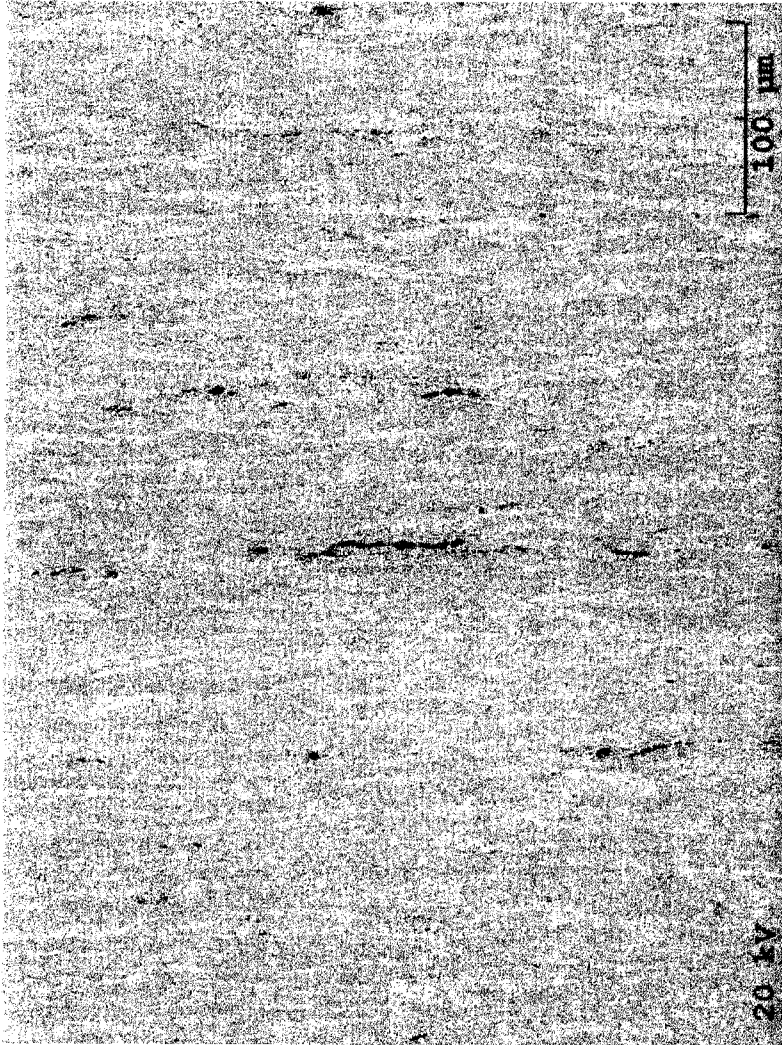


FIGURE 20A

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FIGURE 20B

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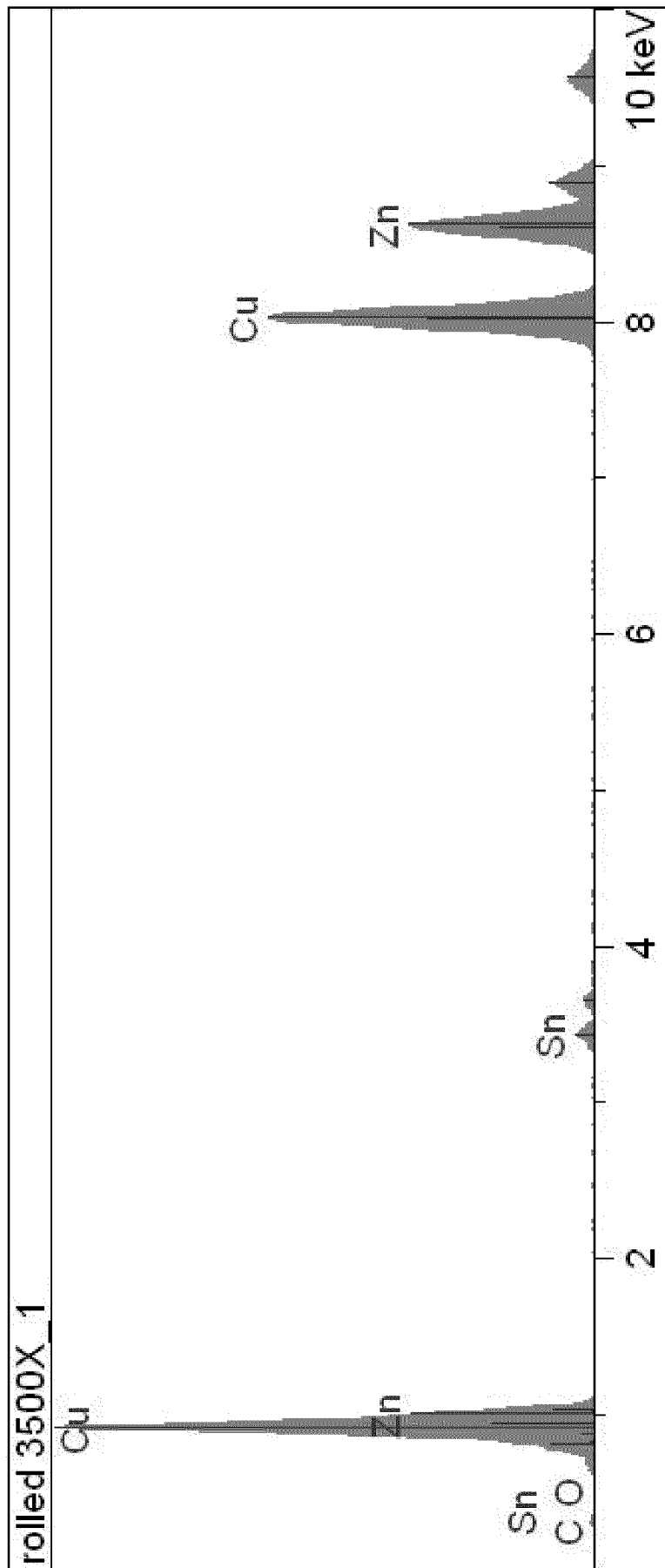


FIGURE 20C

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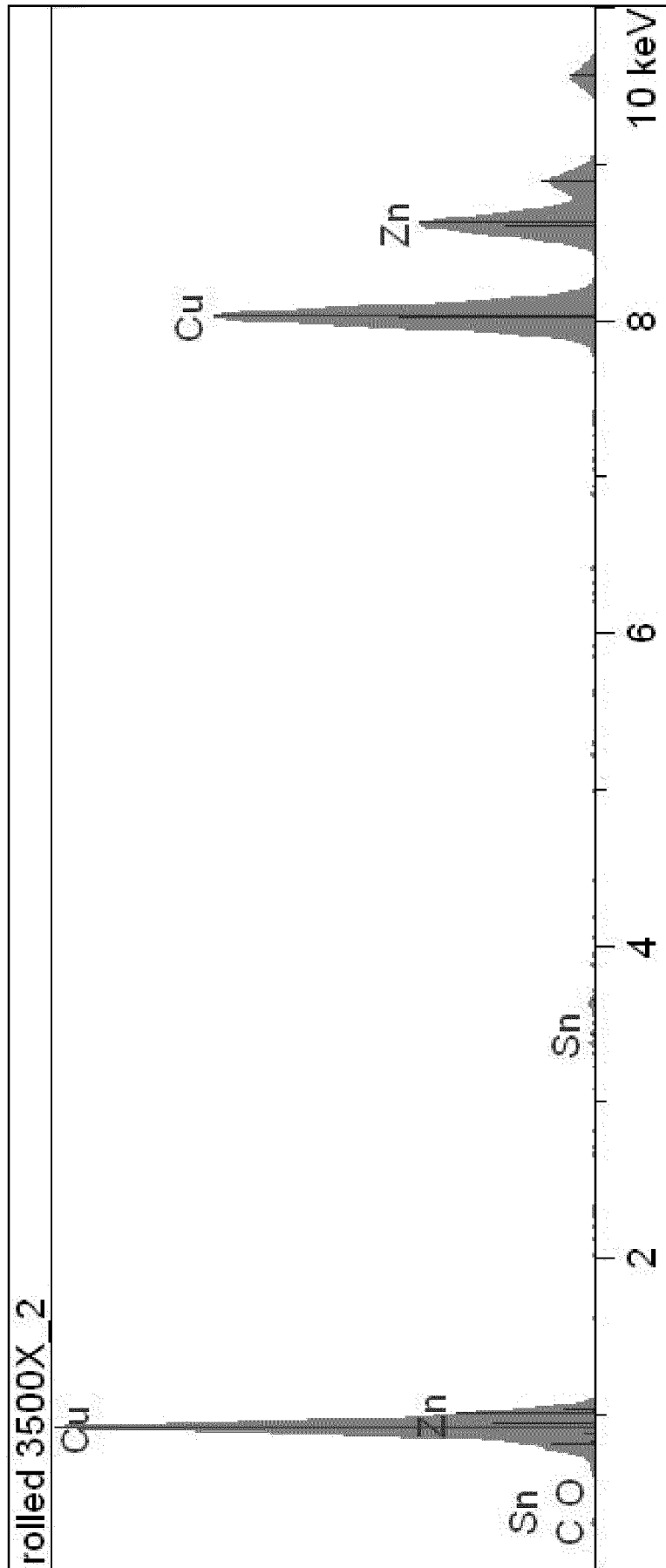


FIGURE 20D

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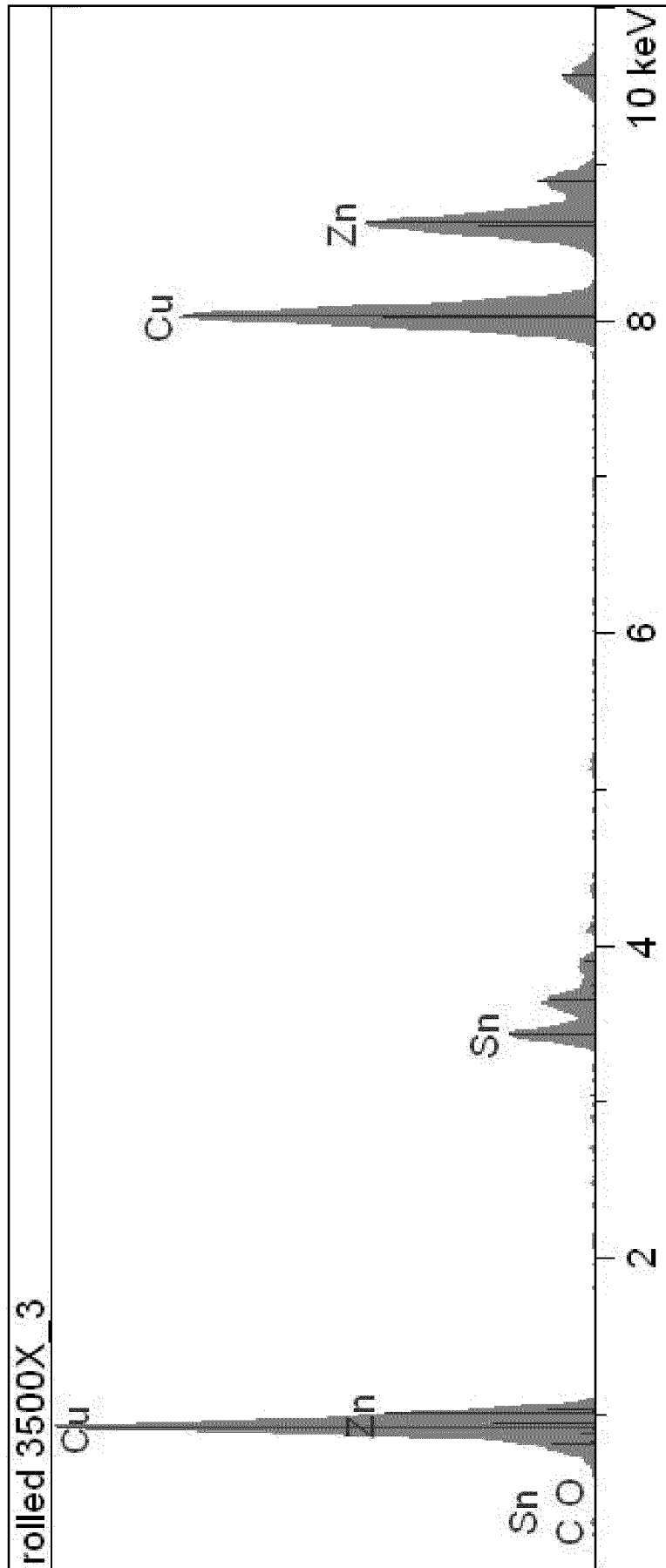


FIGURE 20E

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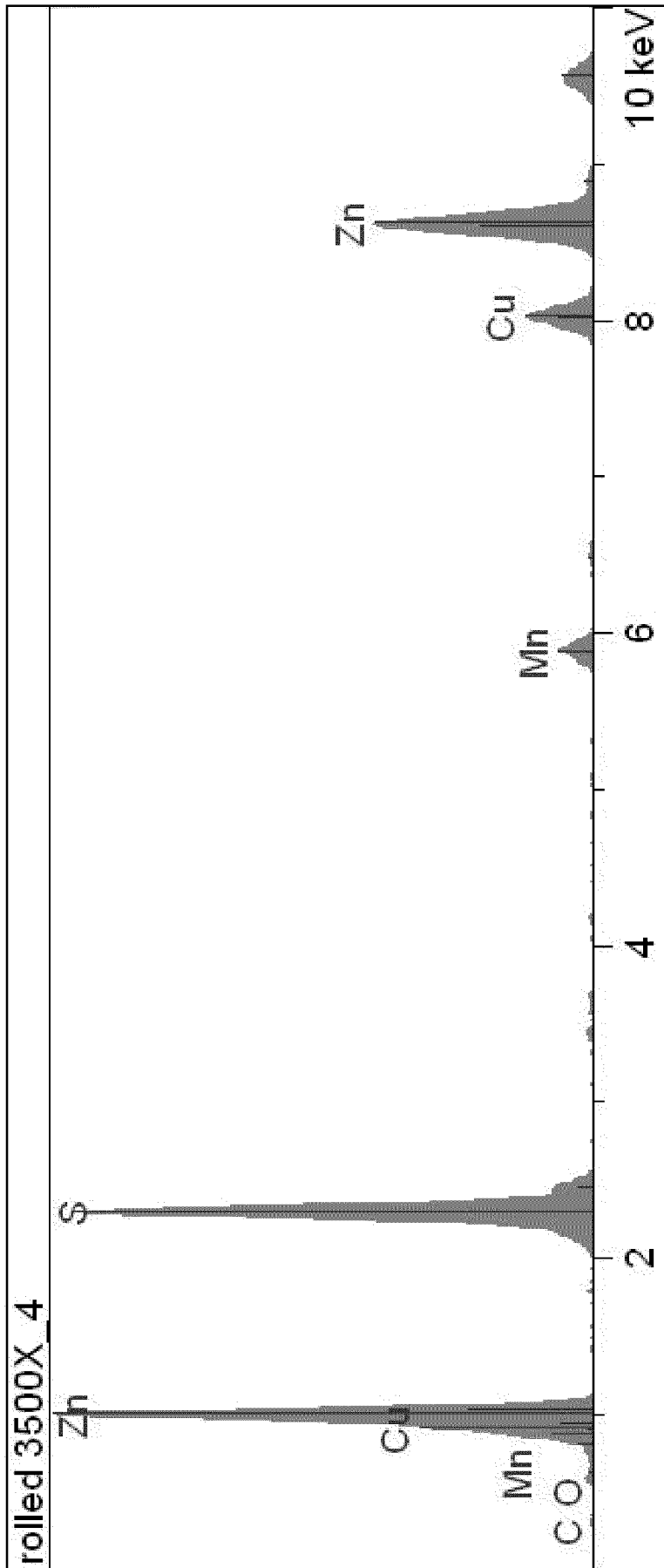


FIGURE 20F

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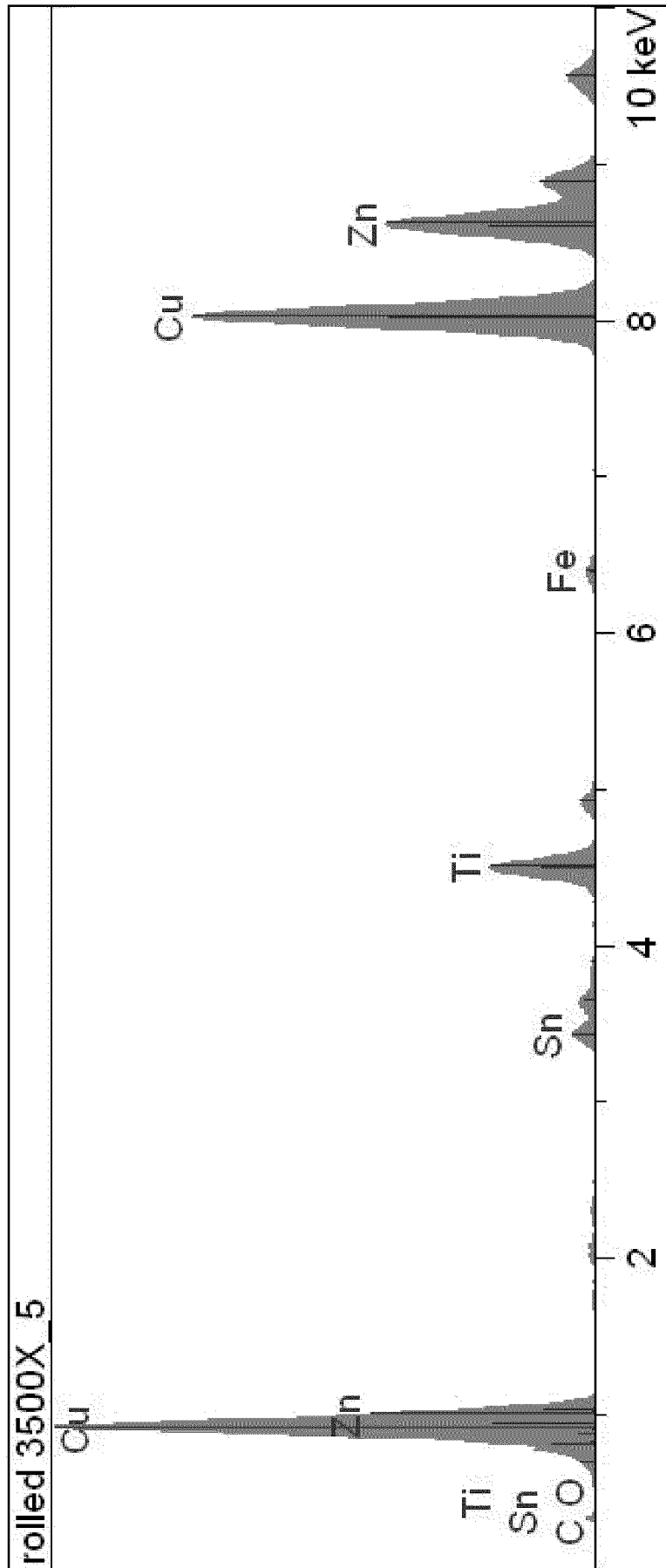


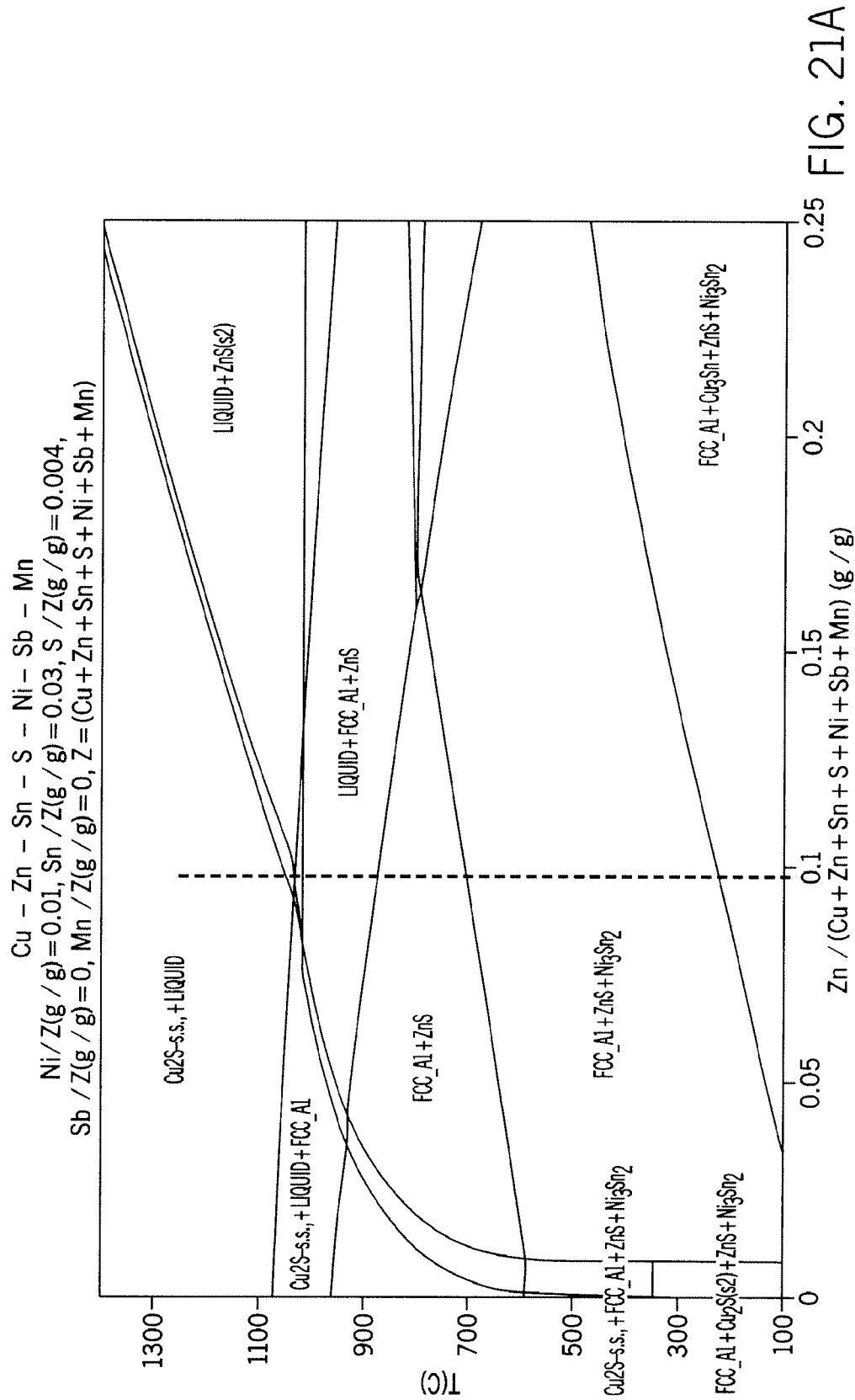
FIGURE 20G

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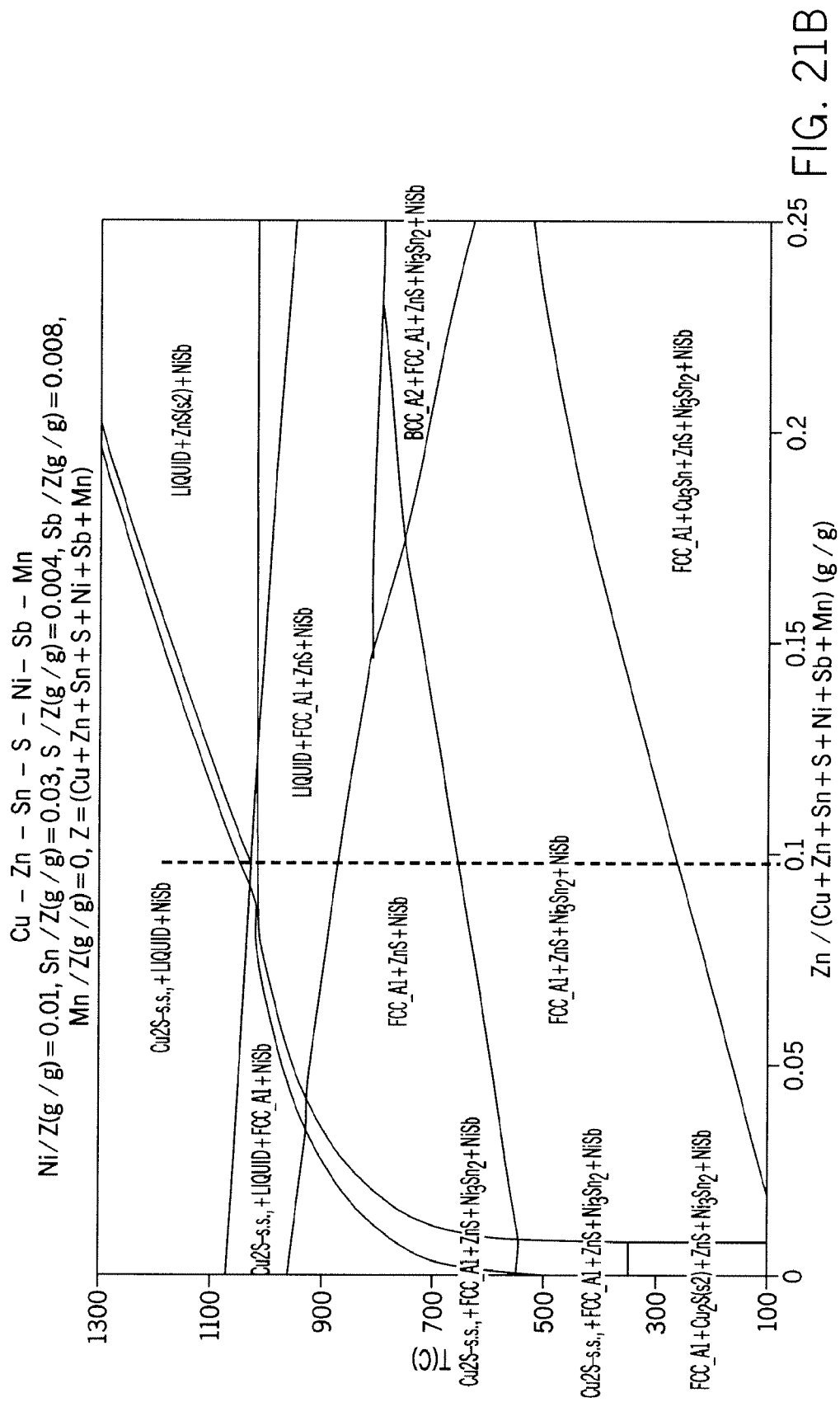


FIGURE 20H

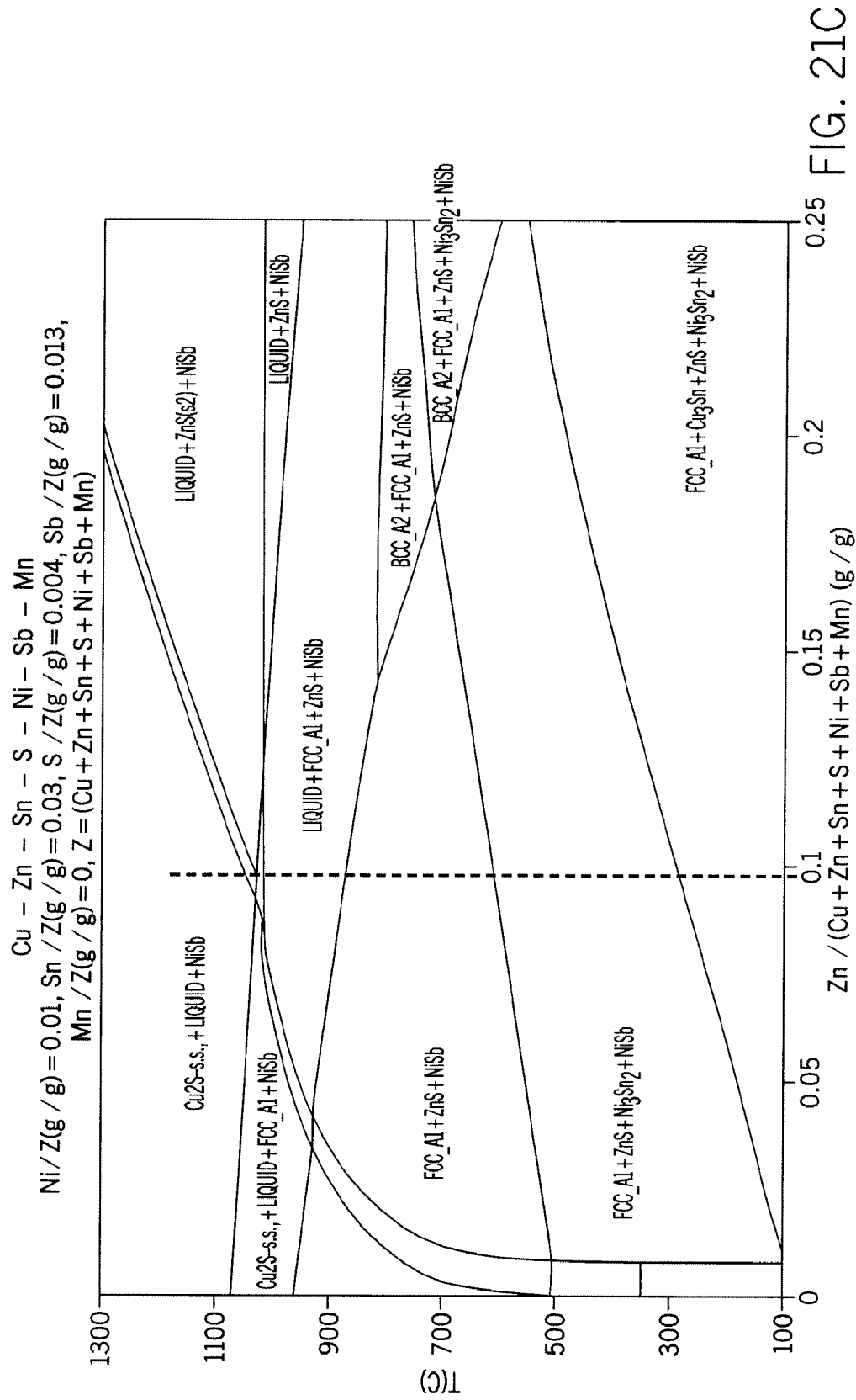
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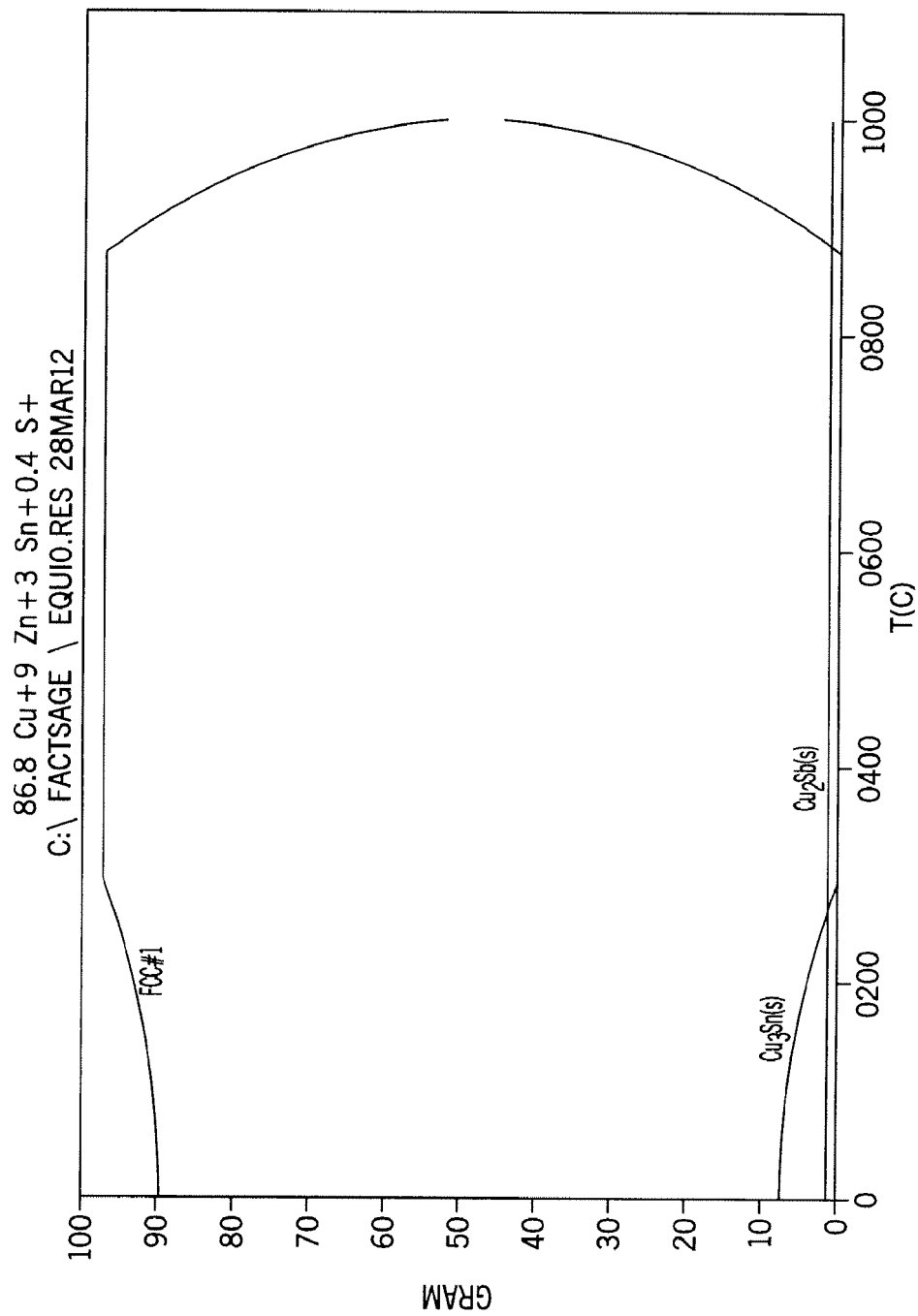


FIG. 22A

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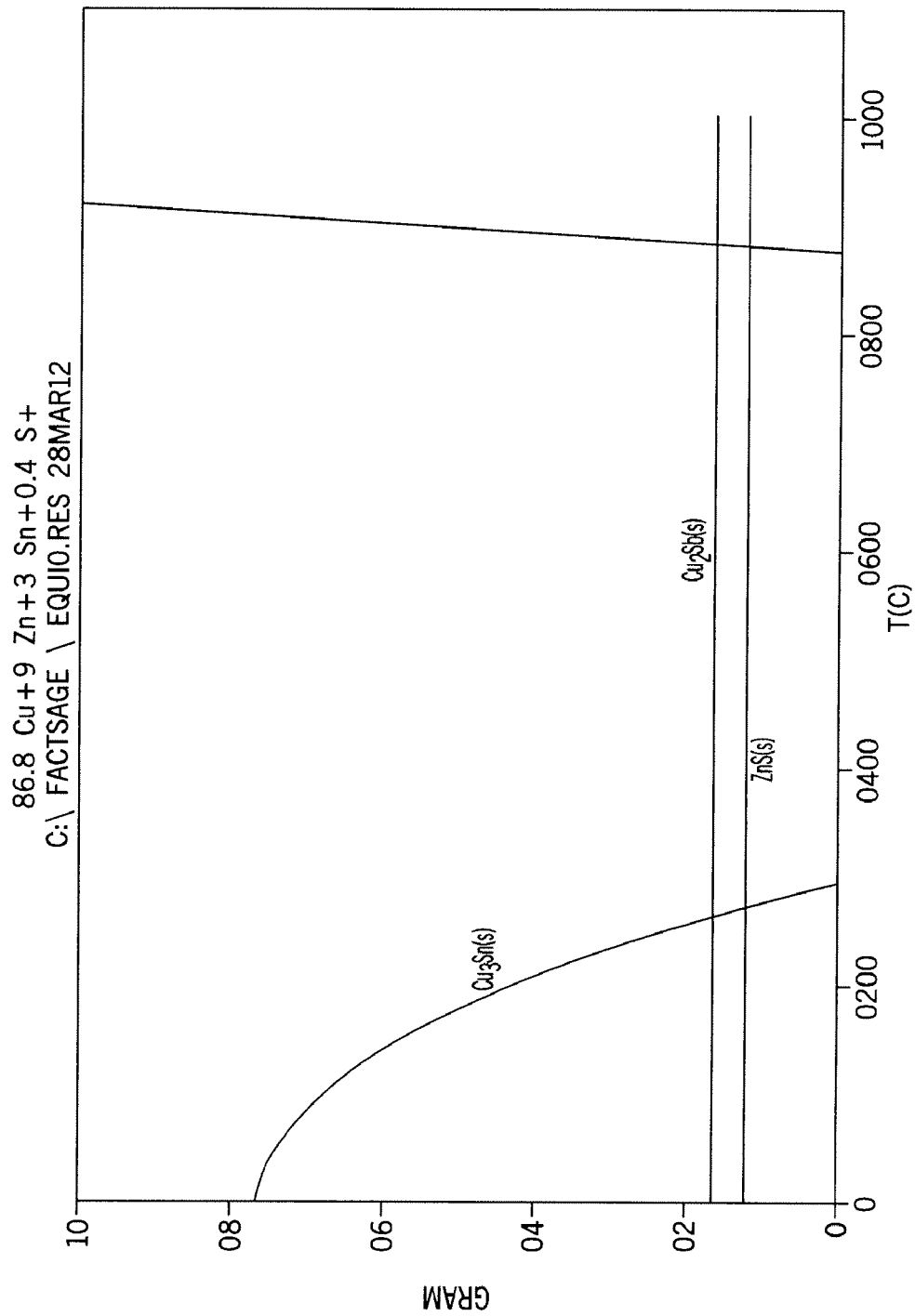


FIG. 22B

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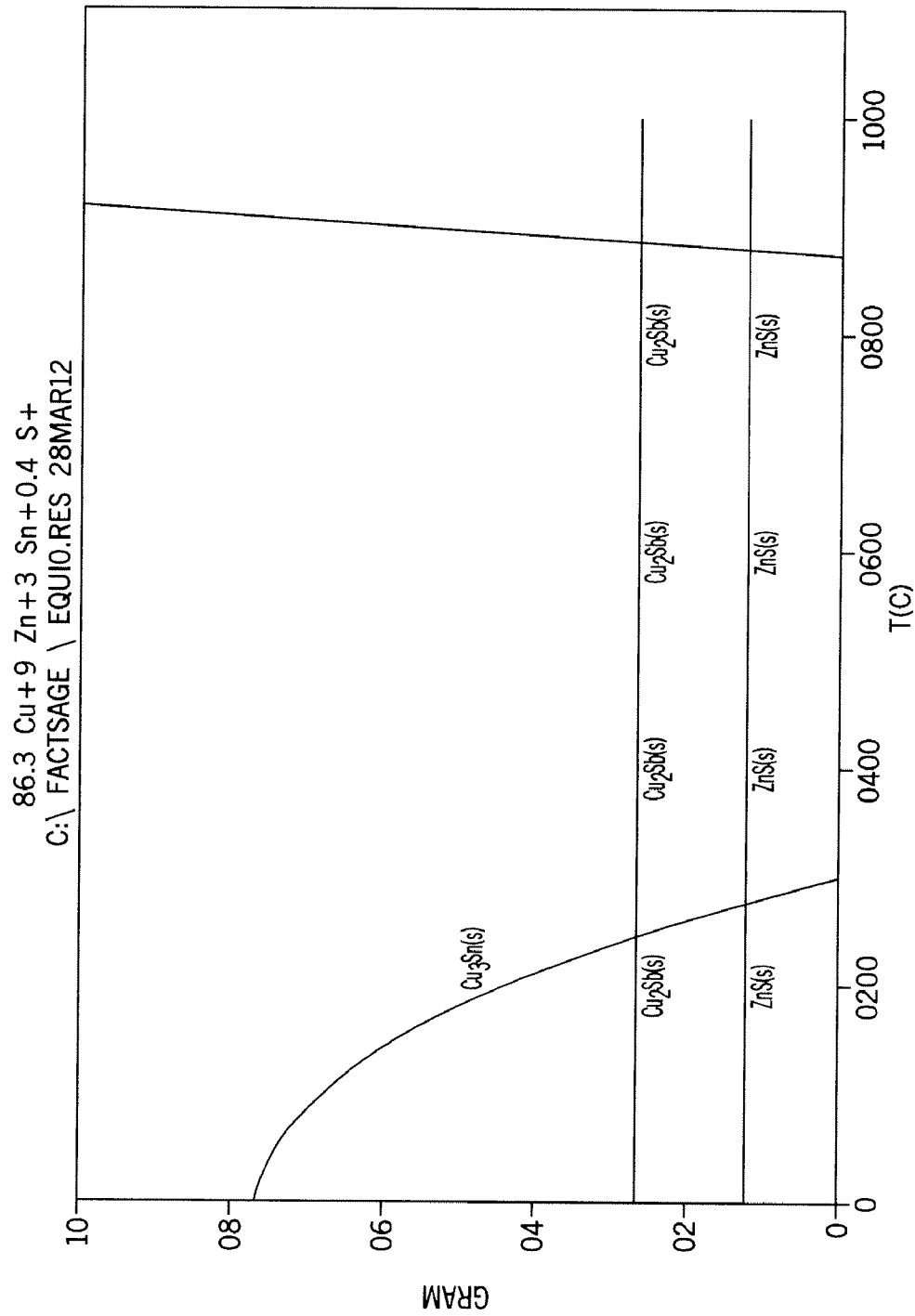


FIG. 22C

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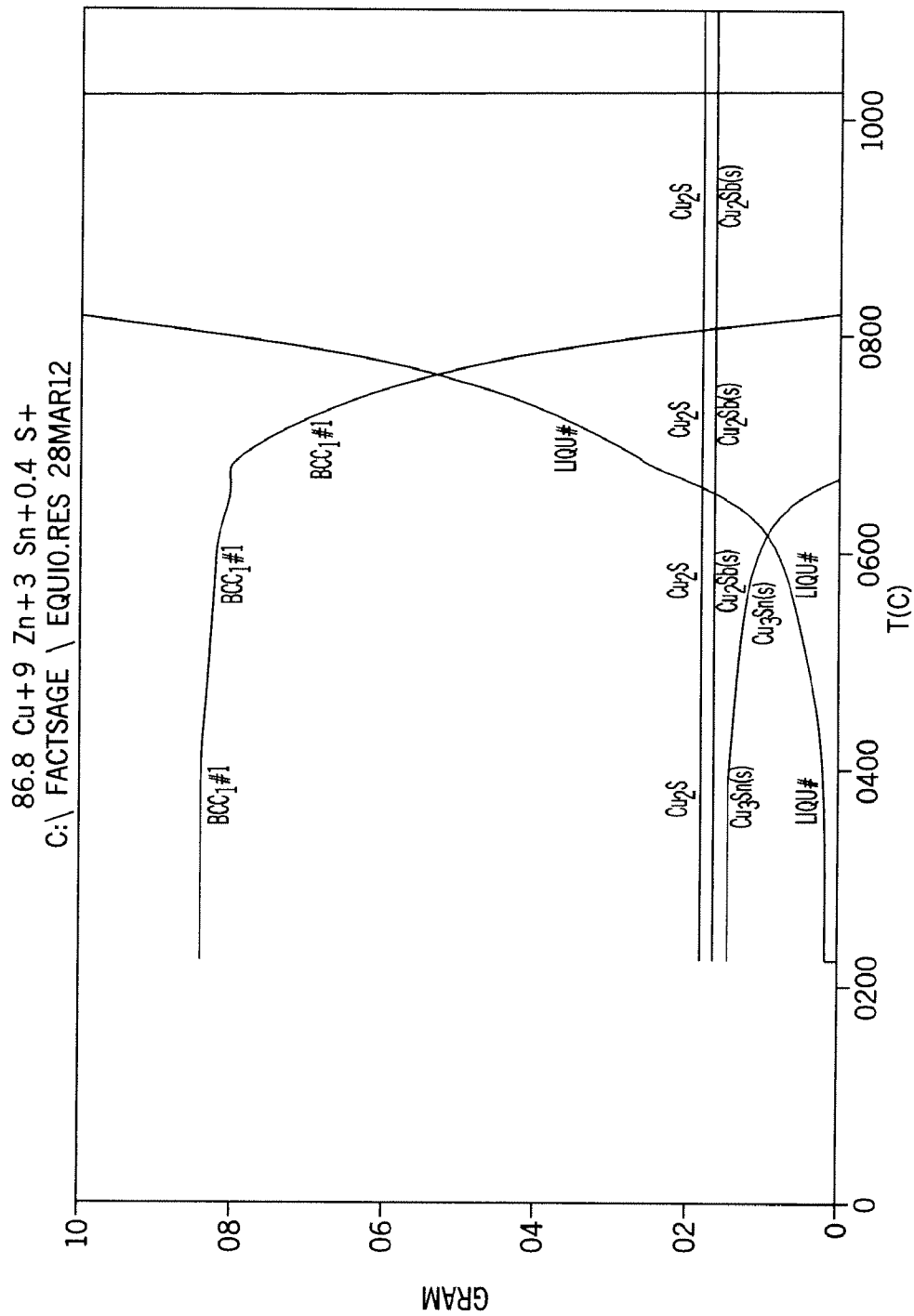


FIG. 22D

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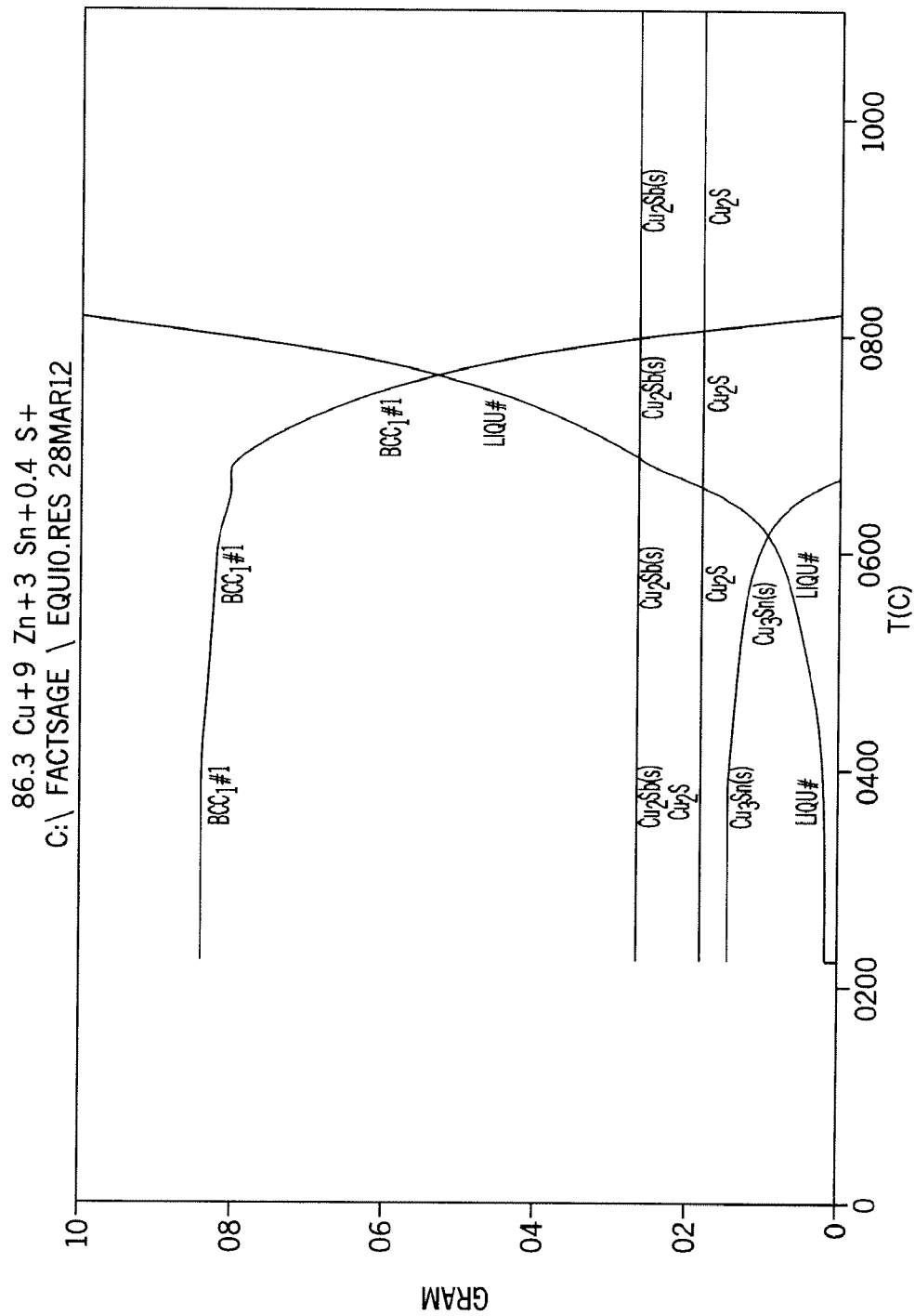
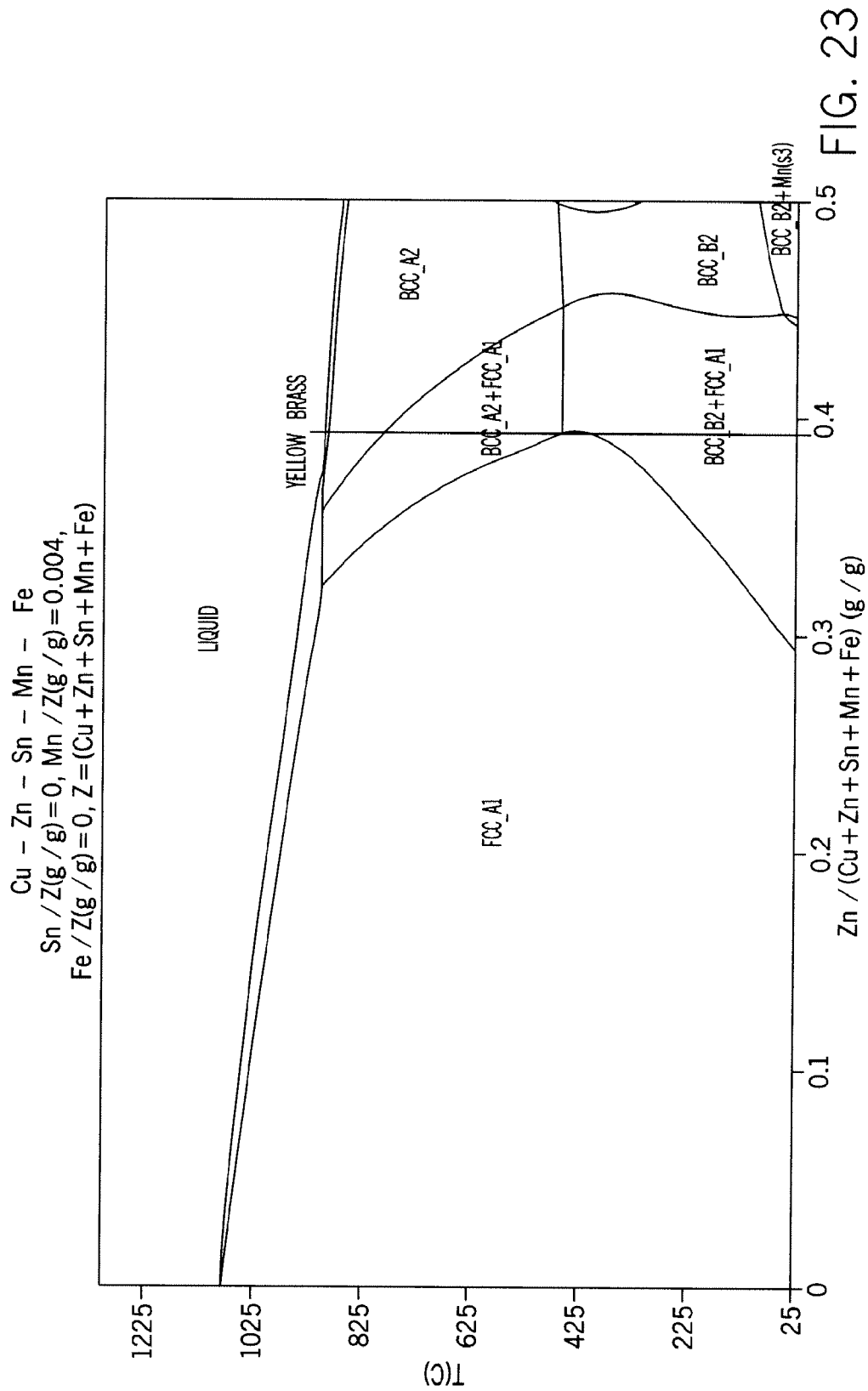


FIG. 22E

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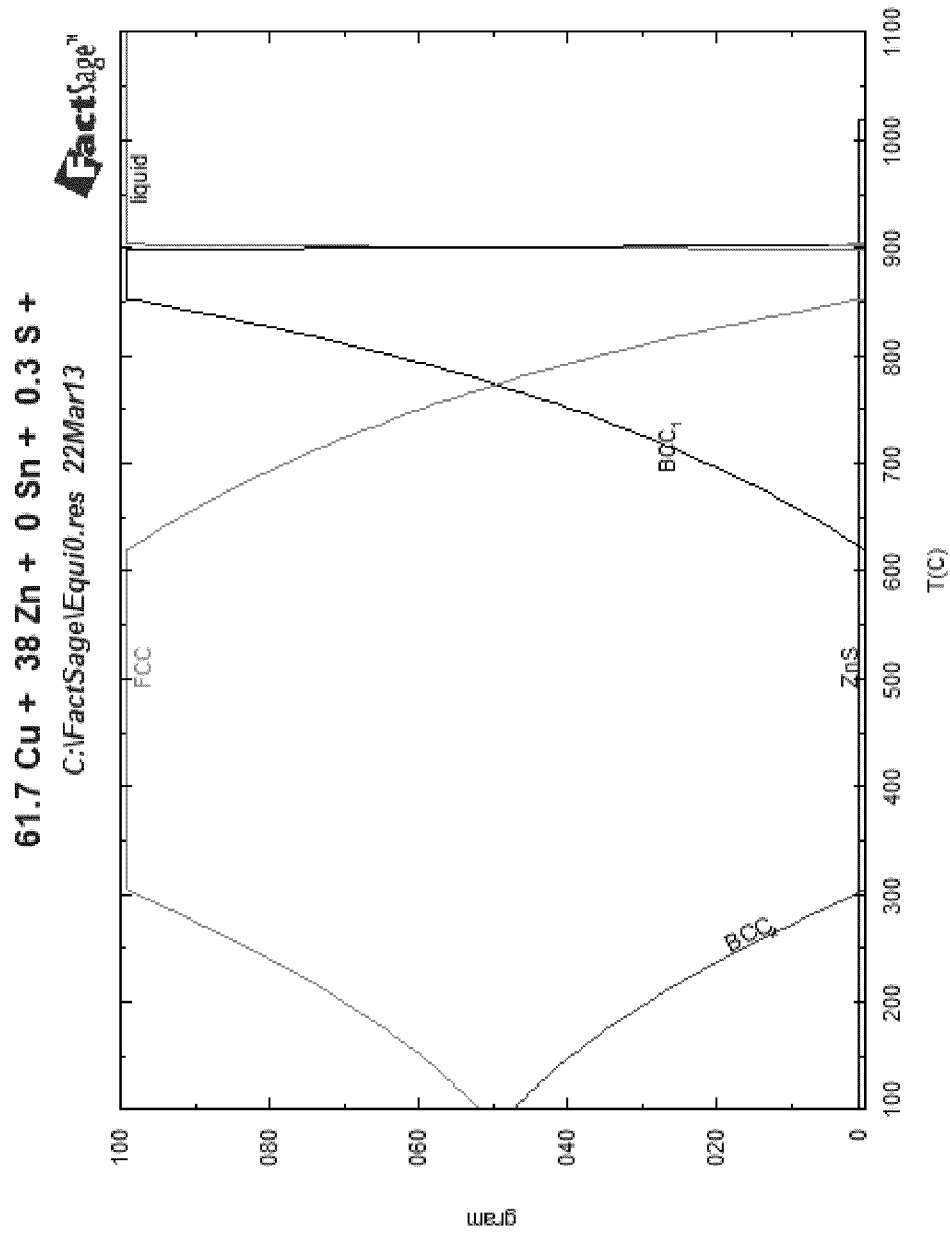


FIGURE 24A

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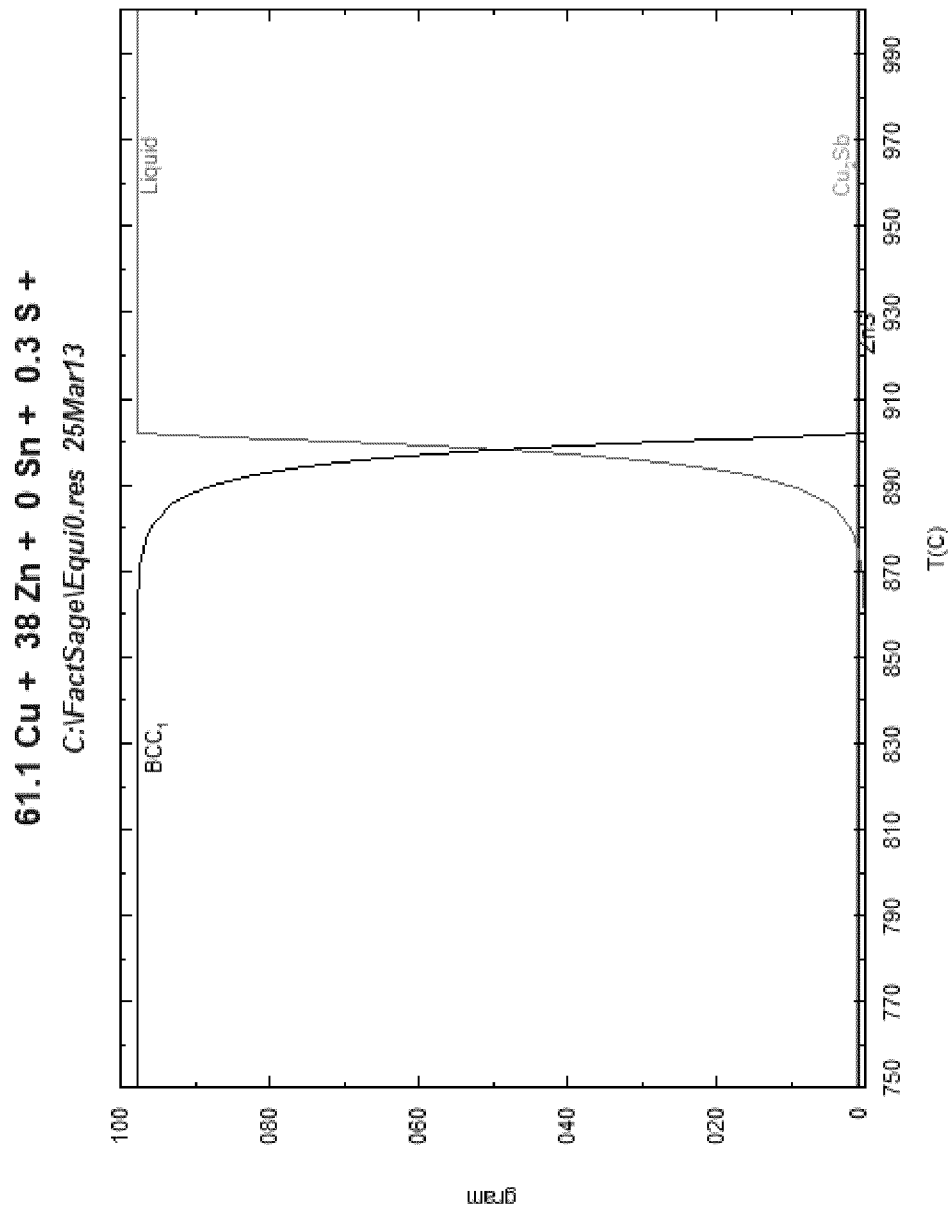


FIGURE 24B

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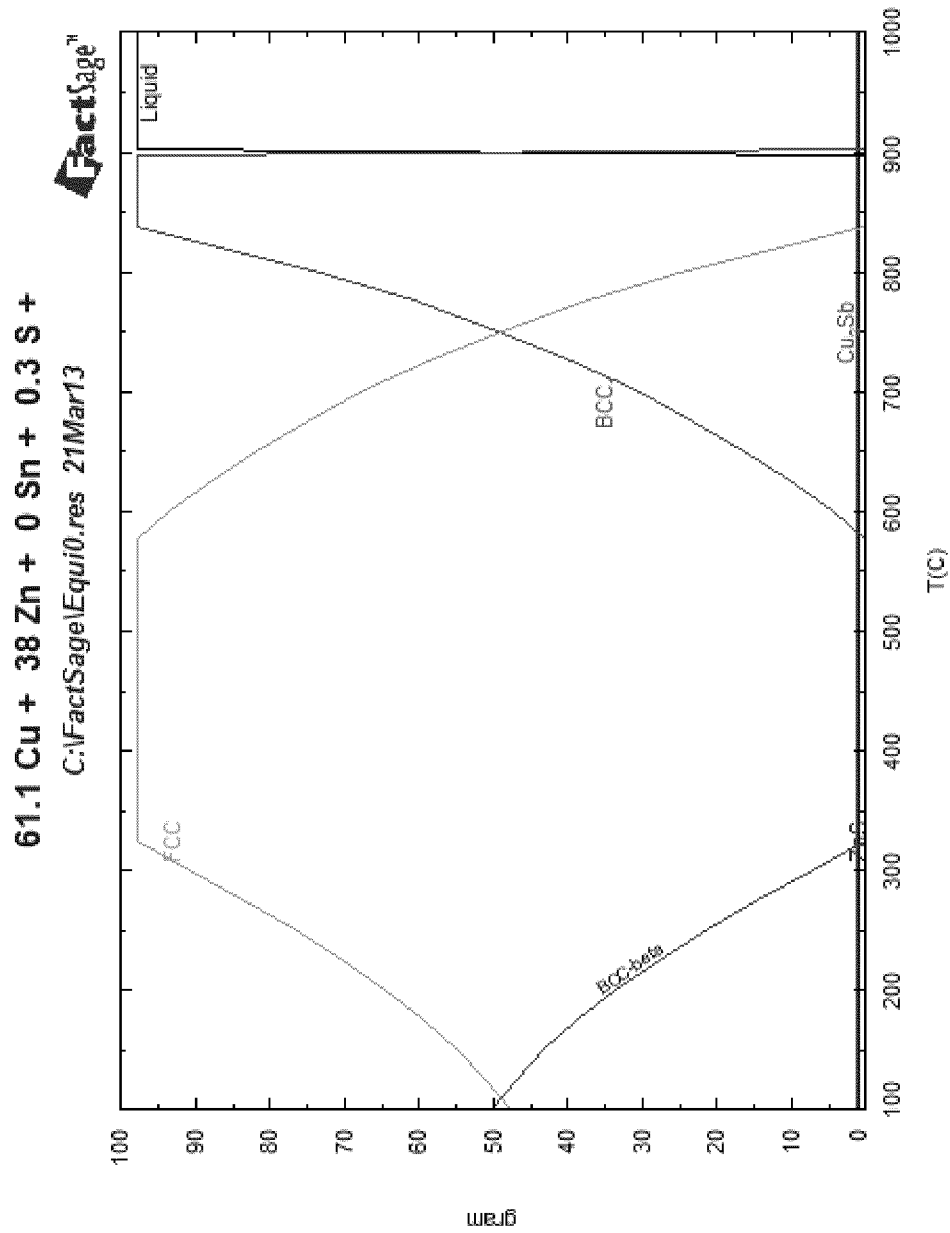


FIGURE 24C

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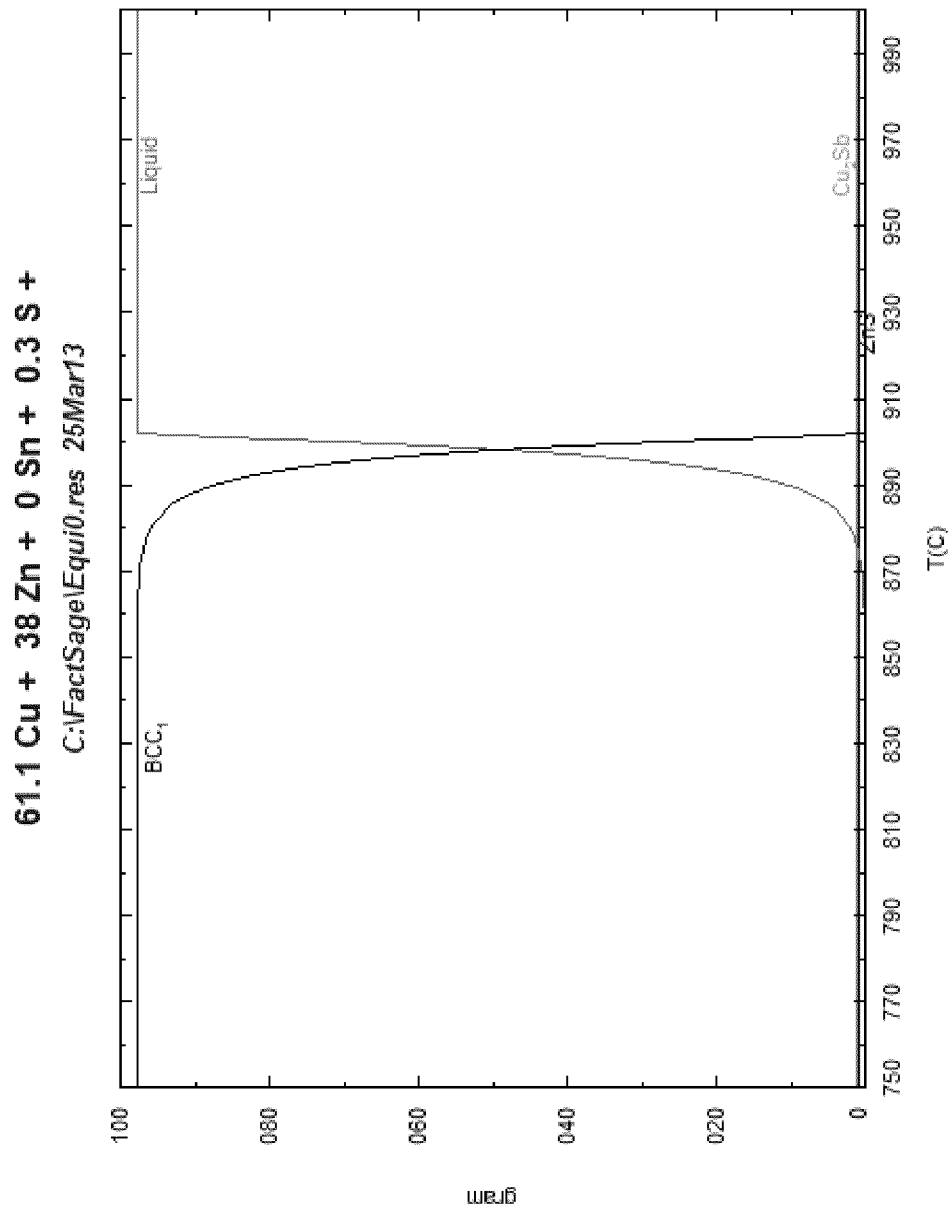


FIGURE 24D

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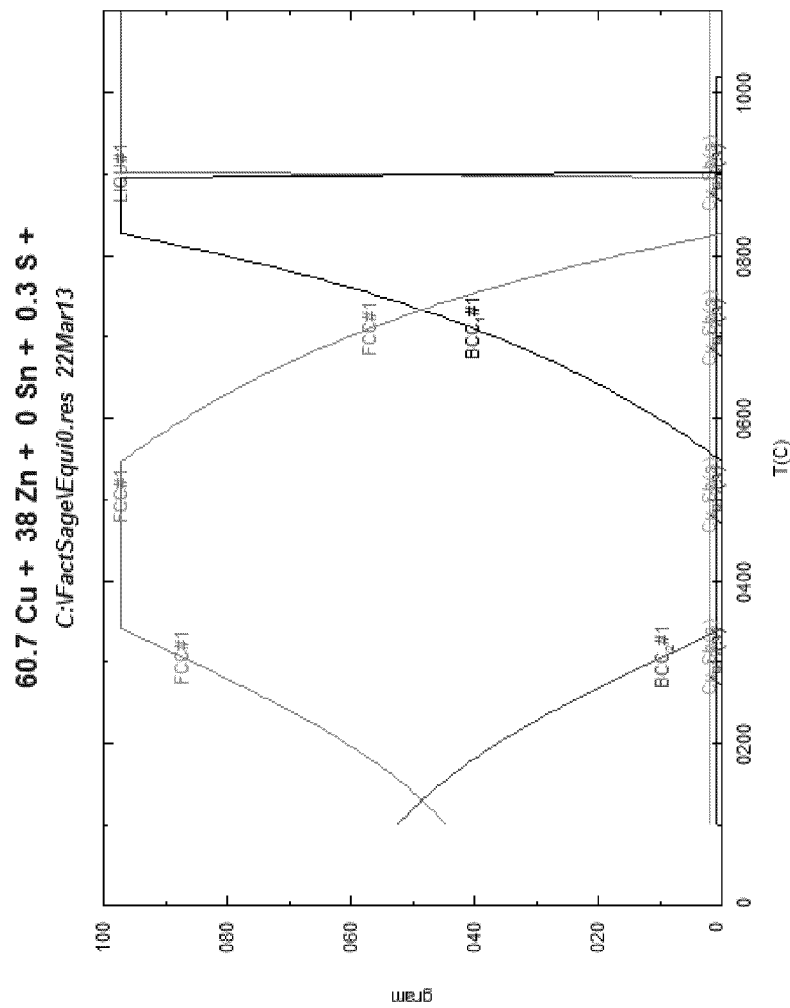


FIGURE 24E

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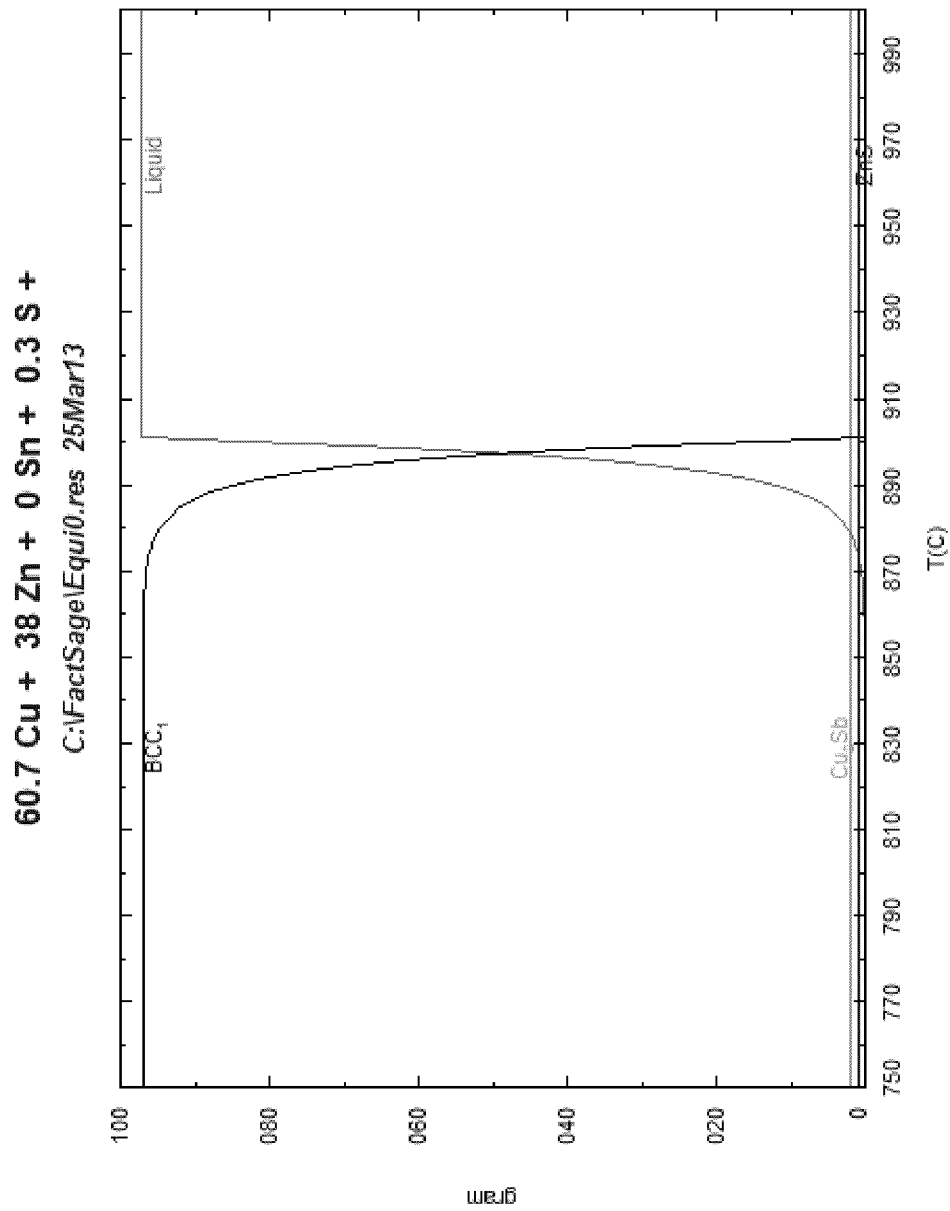


FIGURE 24F

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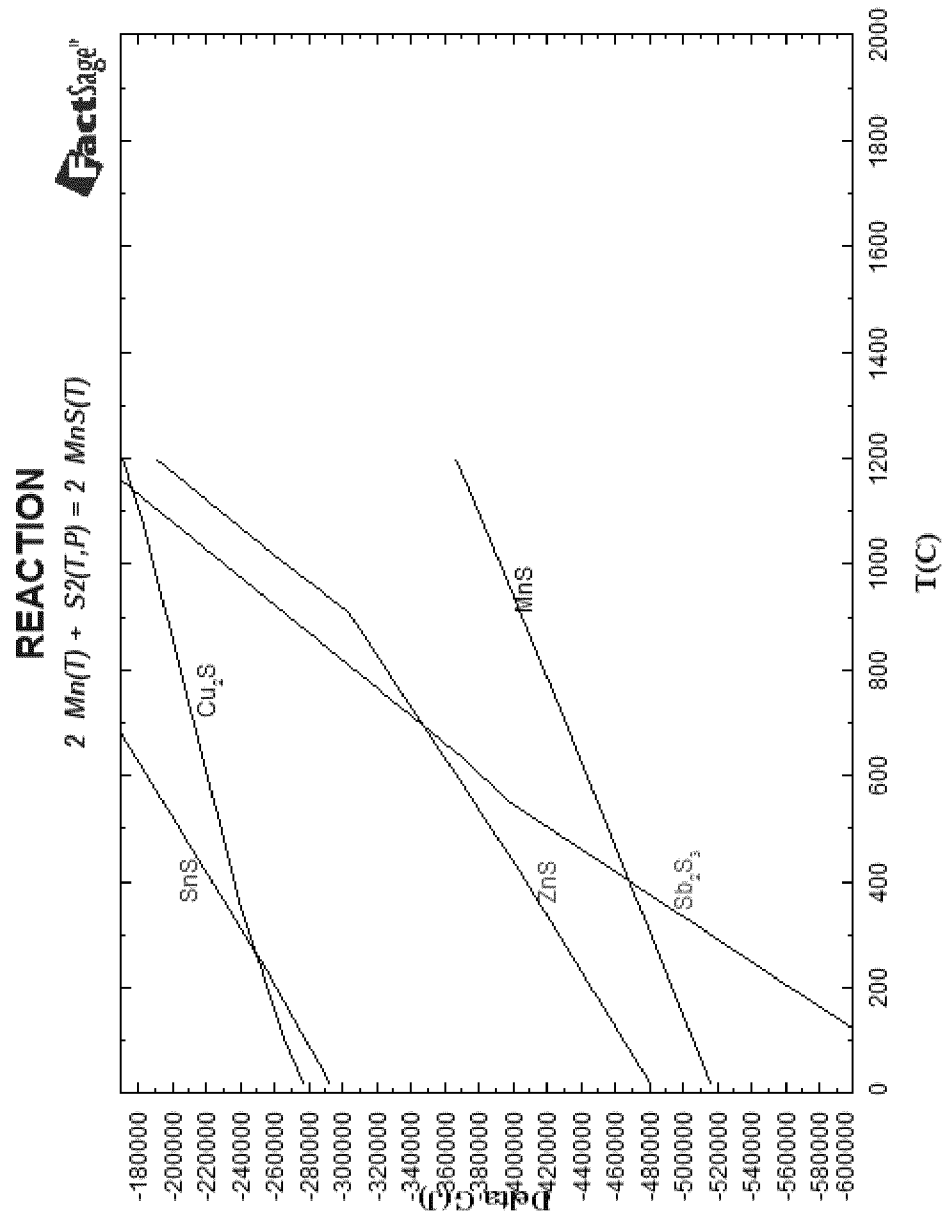


FIGURE 25

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FIGURE 26A

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FIGURE 26B

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FIGURE 27A

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FIGURE 27B

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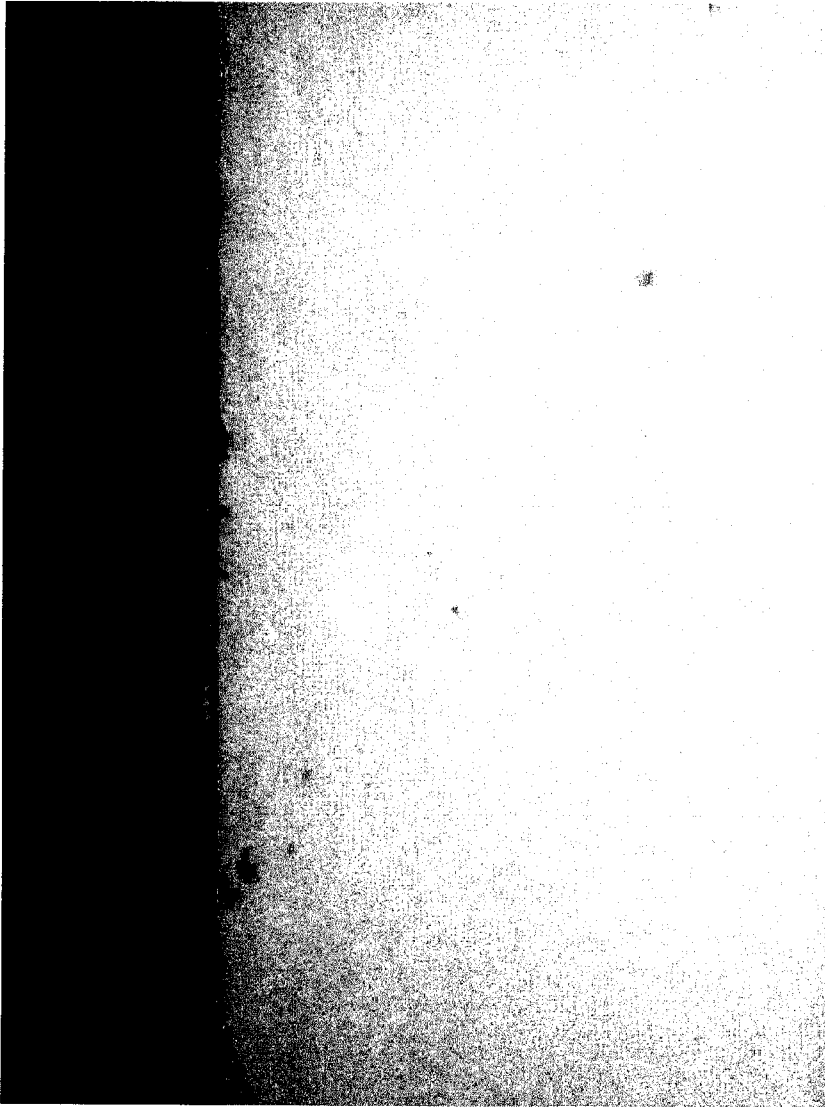


FIGURE 28A

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FIGURE 28B

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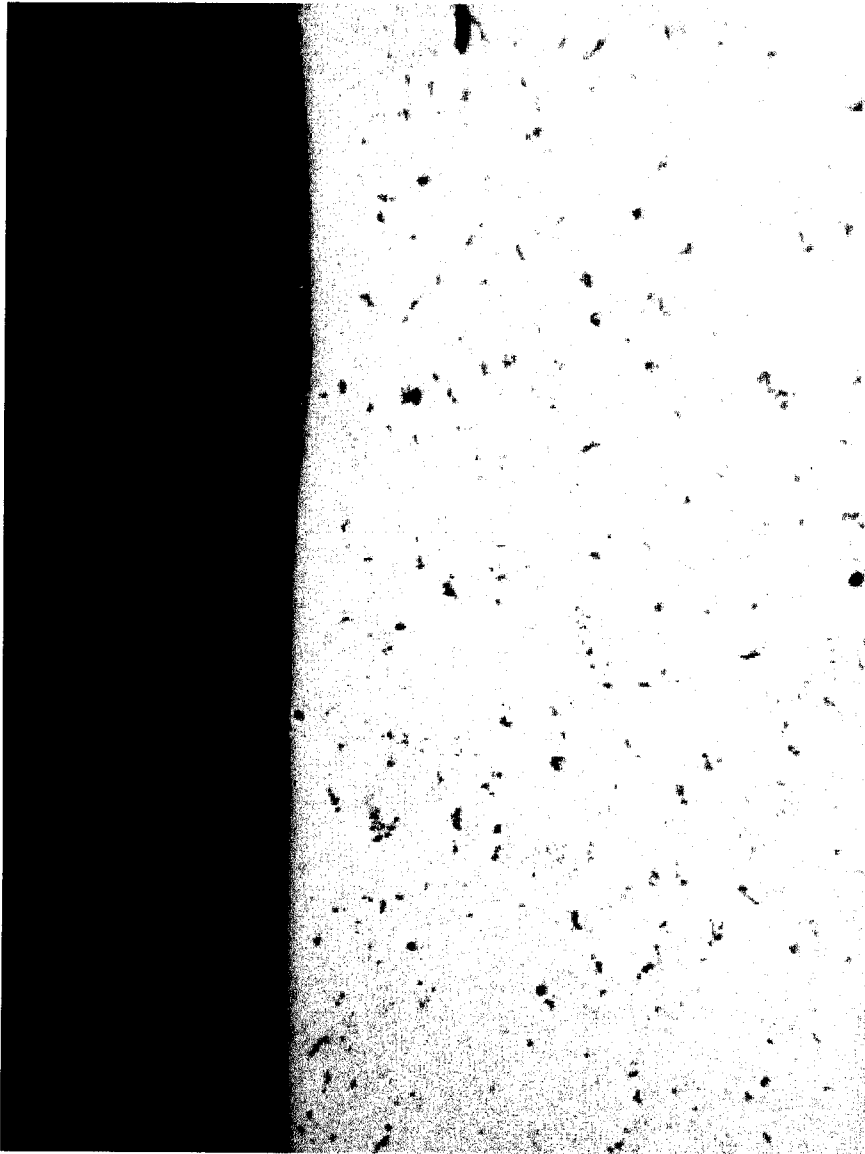


FIGURE 29A

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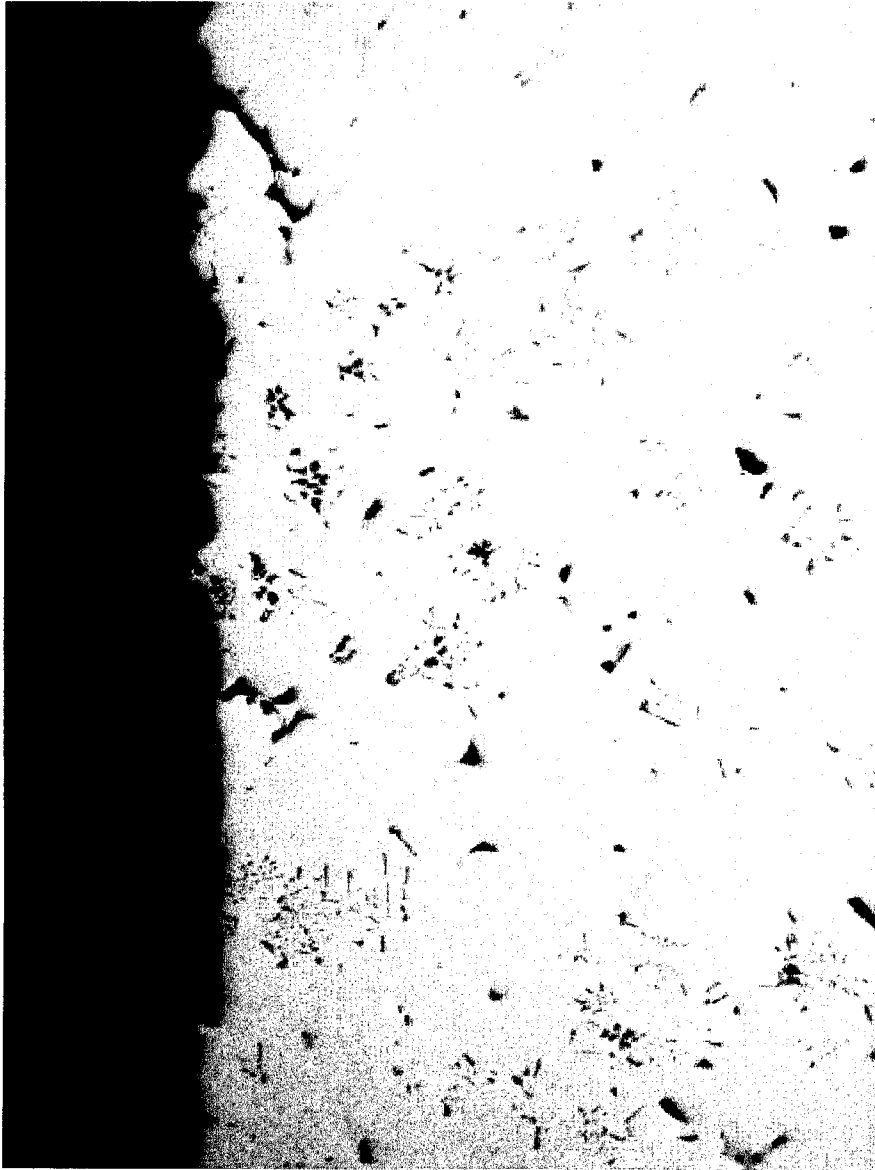


FIGURE 29B

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FIGURE 30

Heat No	Cu	Sn	Zn	Ni	S	P	Mn	Pb	Fe	Sb	Al	Si	C	Comments
84030-021313-P3H1A-7	94.36	.889	4.35	.126	.050	.032	.009	.005	.117	.052	.001	.001	.003	0.05% CCG
84030-022213-P3H1B-7	93.36	.865	4.30	.265	.060	.022	.002	.003	0.60	.049	.	.001	.002	0.05% CCG
84030-021513-P3H2A-7	77.41	5.75	14.05	2.66	.024	.028	.001	.004	.023	.040	.001	.001	.002	0.05% CCG
84030-022213-P3H2B-7	77.38	5.82	13.77	2.76	.057	.032	.001	.004	.119	.047	.001	.001	.001	0.05% CCG
84030-032713-P3H3-9	80.81	1.03	14.97	.240	.331	.037	.005	.006	.139	2.42	.001	.001	.003	0.05% CCG
84030-032713-P3H4-7	84.91	5.71	4.28	1.98	.781	.032	.0008	.008	.159	2.12	.002	.001	.006	0.05% CCG
84030-032713-P3H5-7	87.34	5.88	4.15	.233	.072	.035	.0006	.006	.107	2.16	.001	.001	.004	1.7% CCG
84030-032713-P3H6-9	78.74	1.02	15.46	2.15	.051	.036	.001	.005	.114	2.15	.001	.001	.001	1.7% CCG
84030-022213-P3H7A-7	79.80	5.62	13.81	.212	.234	.034	.001	.003	.189	.074	.001	.001	.007	1.7% CCG
84030-022613-P3H7B-7	80.18	5.88	13.13	.229	.321	.035	.0006	.005	.16	.049	.001	.002	.001	1.7% CCG
84030-022213-P3H8A-7	91.75	.900	3.98	2.49	.589	.033	.001	.003	.176	.062	.001	.001	.006	1.7% CCG

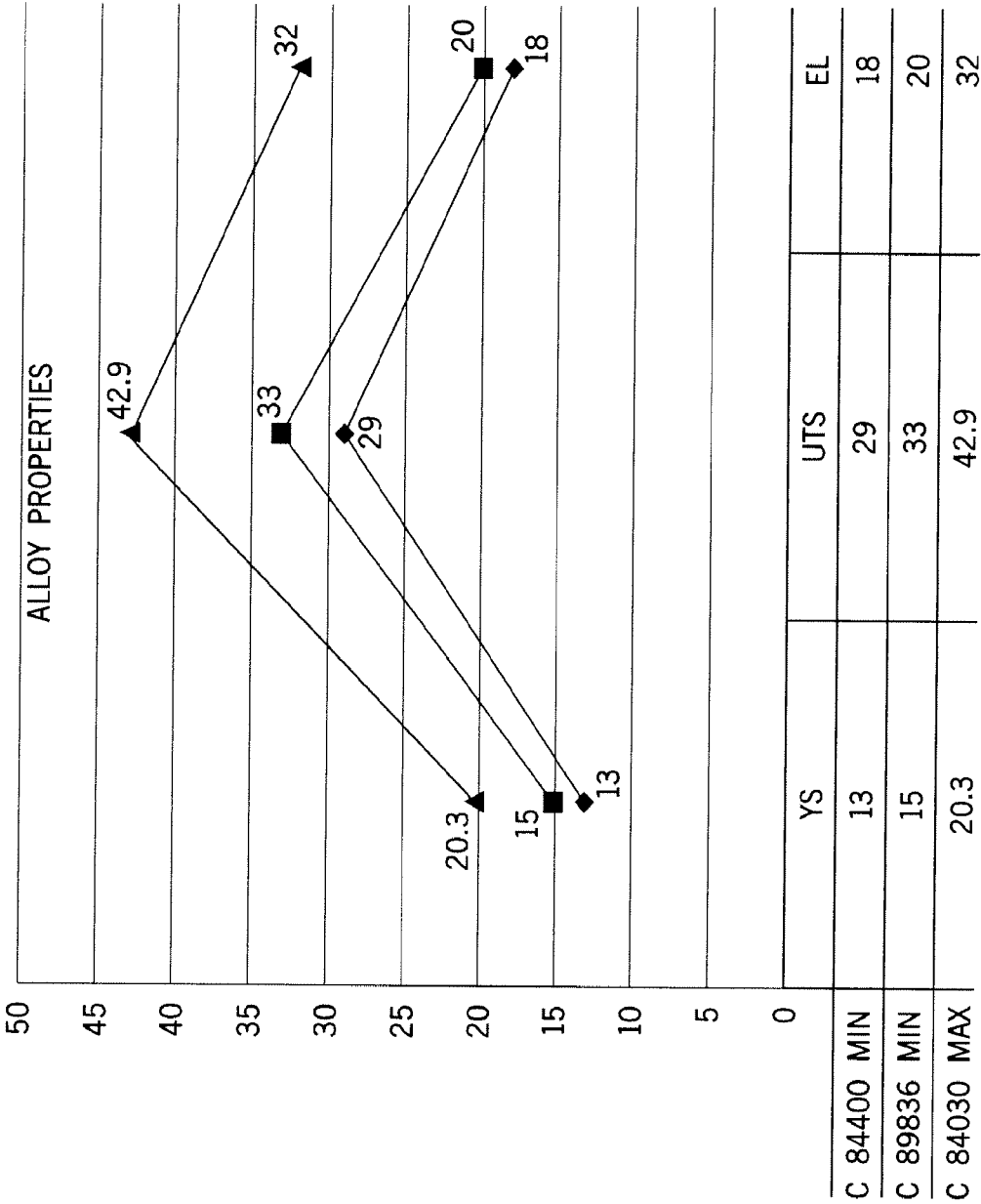


FIG. 31

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FIGURE 32

Heat No	Cu	Sn	Zn	Ni	S	Sb	UTS Ksi	YS ksi	% Elong	BHN	MoE Mpsi	Comments
84030-021313-P3H1A-9A	94.36	.889	4.35	.126	.050	.052	36.20	14.07	33	57	14.3	0.05 CCG
84030-021313-P3H1A-9B	94.36	.889	4.35	.126	.050	.052	37.60	14.86	37	57	14.4	0.05 CCG
84030-022213-P3H1B-9A	93.36	.865	4.30	.265	.060	.049	38.2	16.00	31	61	15.2	0.05 CCG
84030-022213-P3H1B-9B	93.36	.865	4.30	.265	.060	.049	38.4	15.92	31	65	15.115	0.05 CCG
84030-021513-P3H2A-9A	77.41	5.75	14.05	2.66	.024	.040	35.00	19.84	17	74	15.0	0.05 CCG
84030-021513-P3H2A-9B	77.41	5.75	14.05	2.66	.024	.040	35.10	19.48	18	74	14.9	0.05 CCG
84030-022613-P3H2B-9A	93.36	.865	4.30	.265	.060	.047	34.20	18.41	18	69	15.1	0.05 CCG
84030-022613-P3H2B-9B	93.36	.865	4.30	.265	.060	.047	34.80	18.04	19	65	15.0	0.05 CCG
84030-032713-P3H3-1A	80.81	1.03	14.97	.240	.331	2.42	24.40	16.02	8	61	14.6	0.05 CCG
84030-032713-P3H3-2B	80.81	1.03	14.97	.240	.331	2.42	24.00	16.15	9	69	14.5	0.05 CCG
84030-032713-P3H4-1B	84.91	5.71	4.28	1.98	.781	2.12	40.50	23.10	19	86	15.3	1.7% CCG
84030-032713-P3H5-1A	87.34	5.88	4.15	.233	.072	2.16	32.00	21.30	10	74	15.1	1.7% CCG
84030-032713-P3H6-1B	78.74	1.02	15.46	2.15	.051	2.15	32.00	16.12	19	61	14.7	1.7% CCG
84030-022213-P3H7A-9A	79.80	5.62	13.81	.212	.234	.074	34.60	17.64	18	69	14.9	1.7% CCG
84030-022713-P3H7B-9A	80.18	5.88	13.13	.229	.321	.049	34.10	18.02	16*	72	14.9	1.7% CCG
84030-022213-P3H8A-9A	91.75	.900	3.98	2.49	.589	.062	36.20	16.96	28	69	15.1	1.7% CCG
84030-022213-P3H8A-9B	91.75	.900	3.98	2.49	.589	.062	36.20	17.09	23	69	15.0	1.7% CCG

	Cu	Sn	Pb	Zn	Fe	Sb	Ni	S	P	Al	Si	Mn	Zr	B	C	Ti
Lead-Free Semi-Red Brass - Sand Cast																
C84030	82.0-89.0	2.0-4.0	0.09	5.0-14.0	0.4	0.1-1.5	0.5-2.0	0.01-0.65	0.05	0.005	0.005	0.20	0.20	0.20	0.1	0.30
Lead-Free Tin Bronze - Sand Cast																
C90430	86.0-89.0	7.5-8.5	0.09	1.0-5.0	0.4	0.1-1.5	1.0	0.01-0.65	0.05	0.010	0.010	0.2	0.20	0.20	0.1	0.30
Lead-Free Yellow Brass - Permanent Mold Cast																
C85930	58.0-62.0	1.5	0.09	31.0-41.0	0.50	0.1-1.5	1.5	0.01-0.65	0.01	0.1-0.6	0.25	0.2	0.20	0.20	0.1	0.30
Lead-Free Yellow Brass Wrought																
C28330	58.0-62.0	--	0.09	31.0-41.0	0.35	0.1-1.5	--	0.01-0.65	--	--	--	0.2	0.20	0.20	0.1	0.3 0