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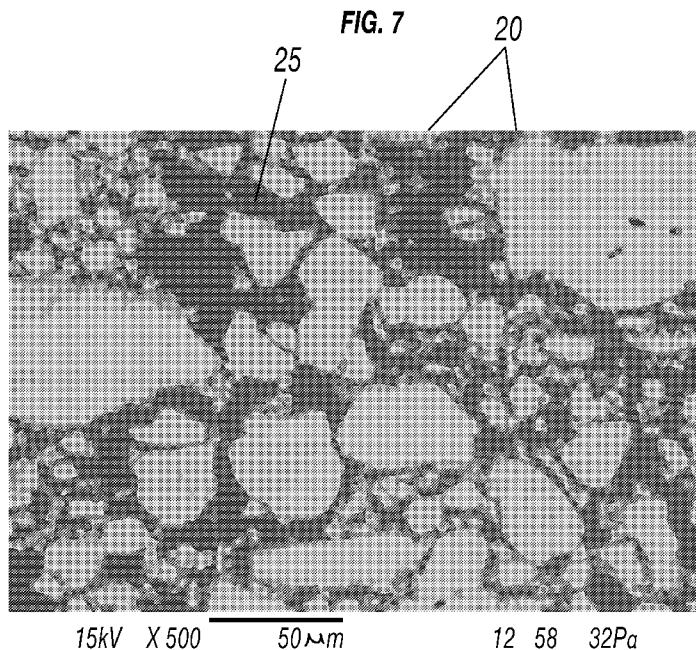
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(54) Title: LOWER MELTING POINT BINDER METALS



(57) Abstract: A copper, manganese, nickel, zinc and tin binder metal composition having a melting point of 1500 °For less that includes zinc and tin at a sum weight of about 26.5% to about 30.5% in which zinc is at least about 12% and Sn is at least about 6.5%.



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LOWER MELTING POINT BINDER METALS

BACKGROUND

[0001] The manufacturing of drill bit bodies involves heating a mixture of hard matrix particles (e.g., tungsten carbide) and a binder metal which are placed in a bit body mold for approximately 75 to 205 minutes at 1875 ° to 2100 ° Fahrenheit (F) causing infiltration of the binder metal through the hard matrix particles. The infiltration process results in a metal-matrix composite that forms the “bit body.” The infiltration occurs when the molten binder metal flows through spaces between the hard matrix particle grains by means of capillary action. Upon cooling, the hard matrix particles and the binder metal form a hard, durable, strong metal-matrix composite. If the infiltration process is not complete, the bit body is often defective and may crack. Infiltration is dependent on the molten binder metal flowing around the grains of the hard matrix particles and attaching to the matrix grains. For a complete infiltration, the binder metal thoroughly melts to allow for good flow and attachment. However, in the case of diamond-impregnated bit bodies, in which diamond is also mixed in or embedded with the matrix particles, the high infiltration temperature (e.g., 1875 ° to 2100 °F) for long periods of time compromises the diamond as well as increases the thermal crack tendency of the bit body.

SUMMARY

[0002] This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter.

[0003] In some embodiments, a binder metal composition has a melting point of about 1500 °F or less, and the binder metal includes zinc (Zn) and tin (Sn) having a sum weight % of about 26.5% to about 30.5% in which Zn is at least about 12% and Sn is at least about 6.5%; nickel (Ni) is at about 4.5 to about 6.5 weight %; manganese (Mn) is at about 11 to about 26 weight %; and copper (Cu) is at about 40 to about 55 weight %. In some embodiments, the binder metal composition does not include manganese (Mn). The binder metal as disclosed is used as an infiltrant for infiltrating hard matrix particles at an infiltration temperature of 1800 °F or less and maintains a strength and toughness that is comparable to matrices made with presently available binder metals.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Embodiments of the binder metal are described with reference to the following figures.

[0005] **FIGURES 1-6** show temperature-dependent heat flow curves calculated from differential scanning calorimetry (DSC) for each of the respective binder metals represented by Formula-2, Formula-3, Formula-4, Formula-5, Formula-6, and Comparative Formula-1, in which the top line represents the heating curve (**5**) and the bottom line represents the cooling curve (**10**), and the measured melting point temperature is the indicated peak (**15**) of the heating curve (**5**), according to one or more embodiments.

[0006] **Figure 7** is a scanning electron micrograph (SEM) image showing the binder structure of an infiltrated metal-matrix composite made from tungsten carbide particles and the Comparative Formula-1 Cu-rich binder metal etched with Spinodal etchant, with tungsten carbide (**20**) and Cu-rich phase (**25**), as indicated.

[0007] **Figure 8** is an energy dispersive spectroscopy (EDS) spectrum showing the single Cu-rich FCC (face-centered cubic) phase (**25**) of the Comparative Formula-1 metal-matrix composite of **Figure 7**.

[0008] **Figure 9** is a scanning electron micrograph (SEM) image showing the binder structure of a metal-matrix composite made of tungsten carbide particles and Formula-4 binder metal, according to one or more embodiments, the metal-matrix composite etched with Spinodal etchant.

[0009] **Figure 10** is an EDS spectrum of the Sn- and Ni-rich FCC phase (**35**) for the Formula-4 metal-matrix composite of **Figure 9**, according to one or more embodiments.

[0010] **Figure 11** is an EDS spectrum of the Cu- and Zn-rich FCC phase (**30**) for the Formula-4 metal-matrix composite of **Figure 9**, according to one or more embodiments.

[0011] **Figure 12** shows three optical microscopic (OM) images of solid matrices of infiltrated tungsten carbide and Formula-4 binder metal, according to one or more embodiments, at three infiltration temperatures of 1950 °F, 1800 °F, and 1700 °F, as shown, in which the eta-phase (**40**), monocrystal tungsten carbide (**20**) and cast tungsten carbide (**22**) are indicated.

[0012] **Figure 13** is a transmission electron microscope (TEM) image of Comparative Formula-1 binder metal, in which the measured FCC lattice parameter is $a = 3.75 \text{ \AA}$ (as a reference, $a_{\text{Cu}} = 3.61 \text{ \AA}$), the single FCC phase Cu-rich binder (**45**) is indicated.

[0013] **Figure 14** shows a selected area diffraction (SAD) pattern for the TEM image of **Figure 13**.

[0014] **Figure 15** is a TEM image of the FCC-1 phase (**50**) of Formula-3, according to one or more embodiments in which the measured FCC lattice parameter is $a = 3.69 \text{ \AA}$.

[0015] **Figure 16** shows a SAD pattern of the TEM image of **Figure 15**.

[0016] **Figure 17** is a TEM image of the FCC-2 phase (**55**) of Formula-3, according to one or more embodiments, in which the measured FCC lattice parameter is $a = 6.15 \text{ \AA}$.

[0017] **Figure 18** shows a selected area diffraction (SAD) pattern of the TEM image of **Figure 17**.

[0018] **Figure 19** shows a SAD pattern of the TEM image of **Figure 17** after tilting the sample to another angle from the TEM image of **Figure 18**.

[0019] **Figure 20** is a TEM image of the FCC-1 (**50**) and FCC-2 (**55**) phases of a Formula-3 binder metal, according to one or more embodiments, at a lower magnification than the TEM images of **Figures 15** and **17**.

DETAILED DESCRIPTION

[0020] An earth-boring drill bit body may be made from a metal-matrix composite which includes a hard particulate phase and a ductile metallic phase. The hard phase includes refractory or ceramic compounds (e.g., nitrides and carbides, such as tungsten carbide), and the metallic phase may be a binder metal, such as a metal made of copper and other nonferrous alloys. The metal-matrix composite may be formed using powder (i.e., particle) metallurgical methods which include hot-pressing, sintering, and infiltration. Drill bit bodies may have at least a portion of their outer surface impregnated with an ultra-hard material. Such bit bodies are referred to as ultra-hard material impregnated bit bodies. For ultra-hard material impregnated drill bit bodies, the metal-matrix composite also serves as a supporting material for supporting the ultra-hard material. In such embodiments, the metal-matrix composite has specifically controlled physical and mechanical properties in order to expose the ultra-hard material. Methods of forming drill bit bodies are described in U.S. Patent No. 6,394,202 and U.S. Patent No. 8,109,177. Some examples of drill bit bodies include

impregnated drill bit bodies, impregnated drill bit bodies having grit hot-pressed inserts (GHIs), and polycrystalline diamond compact (PDC) drill bit bodies.

[0021] As described, infiltration of the metal-matrix composite includes heating the metal-matrix to a temperature that is high enough to allow for the binder metal (also referred to as the infiltrant) to melt and bind to the hard particulate phase. As such, during infiltration of the metal-matrix composite, the binder metal becomes molten and flows and attaches to the grains of the hard particulate. Accordingly, the melting point temperature of the binder metal directly determines the infiltration temperature for forming the metal-matrix composite. As used herein, the melting point or the melting temperature is the liquidus temperature of the particular composition, as described in Hsin Wang and Wallace Porter, *Thermal Conductivity 27 / Thermal Expansion 15*, Oct 2004 (ISBN-10: 1932078347 | ISBN-13: 978-1932078343).

[0022] According to one or more embodiments, a binder having a melting point of 1500 °F or less, allows for an infiltration temperature that is about 1800 °F or lower, and results in improved phases of the metal-matrix composite. In some embodiments, the face centered cubic-1 (FCC-1) phase and FCC-2 phase of the composite formed with such binder metal are in an approximate balance. That is, the FCC-1 to FCC-2 ratio is 1-1.5(FCC-1) to 1.0(FCC-2). In addition, at a lower infiltration temperature of about 1800 °F or less, there is a decrease in the eta-phase of the composite. A drill bit body formed with a composite having a decrease in eta-phase and an approximate (1.0-1.5:1.0) balance of FCC-1 to FCC-2 phases has a decreased thermal cracking tendency.

[0023] Examples of ultra-hard materials used in impregnated drill bit bodies include polycrystalline diamond (PCD) and thermally stable polycrystalline diamond (TSP), both of which are known in the art. Examples of PCD and TSP materials are described in U.S. Patent No. 8,020,644. TSP materials may be formed using any suitable binder, for example, cobalt or silicon carbide binder. Furthermore, a higher density TSP material is formed from a higher density PCD material which utilizes less cobalt binder. In some embodiments, when forming an ultra-hard material impregnated bit body, the metal-matrix composite is formed by infiltrating with the presently disclosed lower melting point temperature binder metal at an infiltration temperature of about 1800 °F. In some embodiments, the metal matrix composite is formed by infiltrating with the presently disclosed lower melting point temperature binder metal at an infiltration temperature of about 1800 °F in forming an impregnated drill bit body which is impregnated with PCD or TSP (sometimes referred to as a diamond impregnated drill bit body), resulting in the diamond being less likely to be compromised in the manufacturing of the diamond-impregnated drilling bit bodies.

[0024] One or more embodiments include a binder metal composition having a melting point temperature of 1500 °F or less, in which the binder metal includes an increased amount of tin (Sn) and zinc (Zn) and a specific sum of these two metals, in addition to copper (Cu), manganese (Mn), and nickel (Ni). As disclosed herein, a binder metal composition for use in making drill bit body components has a melting point temperature of 1500 °F or less and thoroughly melts to allow for good flow and attachment to the hard particulate matrix grains at a lower infiltration temperature (e.g., 1800 °F or lower), thereby effectively lowering the thermal crack tendency of the drill bit body.

[0025] In some embodiments, a binder metal composition having a lower melting point temperature has comparable strength to binder metal compositions having higher melting point temperatures. That is, specific increases in Sn or Zn in the binder metal composition effectively lower the melting point temperature of the binder metal and do not compromise the bonding capability, strength, or toughness of the binder metal.

[0026] Using thermodynamic modeling to perform equilibrium phase diagramming of a multi-component alloy system and to simulate the solidification process (under Gulliver-Scheil non-equilibrium condition), Cu-Mn-Ni-Zn-Sn binder metal alloy compositions having a melting point temperature of 1500 °F or less were determined in which the total weight of Sn and Zn together was increased compared to presently used binder metals without compromising the bonding capability, strength, or toughness. Indeed, the solid metallic matrices made using a binder metal as disclosed herein have two phases compared to the single phased matrices using other binder metals (e.g., a binder metal of Comparative Formula-1 as described in Table 1, having a measured melting point of 1655 °F).

[0027] As used herein, the term “about” preceding a value refers to the value including 0.5 less than the value and 0.5 more than the value.

[0028] In some embodiments, a binder metal composition has a melting point of 1500 °F or less and includes Cu, Mn, Ni, Zn, and Sn in which Sn is at least at about 6.5 weight %, and Sn and Zn together equal a total weight amount of about 26.5% to about 30.5%; Ni is present at about 4.5 to about 6.5 weight %; Mn is present at about 11 to about 26 weight %; and Cu is present at about 40 to about 55 weight %.

[0029] In other embodiments, the composition does not include manganese and is weight balanced with copper. For example, Sn is at least at about 6.5 weight %, and Sn and Zn together equal a total weight amount of about 26.5% to about 30.5%; Ni is present at about 4.5 to about 6.5 weight %; and Cu is present at about 51 to about 81 weight %.

[0030] In some embodiments, a binder metal composition has a melting point of 1500 °F or less and includes Cu, Mn, Ni, Zn, and Sn in which Sn is at least at about 6.75 weight %, and Sn and Zn together equal a total weight amount of about 26.5% to about 30.5%; Ni is present at about 4.5 to about 6.5 weight %; Mn is present at about 14 to about 21 weight %; and Cu is present at about 45 to about 52 weight %.

[0031] In some embodiments, a binder metal composition has a melting point of 1500 °F or less and includes Cu, Mn, Ni, Zn, and Sn in which Sn is at least at about 6.75 weight %, and Sn and Zn together equal a total weight amount of about 26.5% to about 30.5%; Ni is present at about 4.5 to about 6.5 weight %; Mn is present at about 17 weight %; and Cu is present at about 49%.

[0032] In some embodiments, a binder metal composition has a melting point of 1500 °F or less and includes Cu, Mn, Ni, Zn, and Sn in which Sn is present in a weight amount of about 6.75% to about 16%; Zn is present in a weight amount of about 12% to about 22.75%; Ni is present in a weight amount of about 4.5% to about 6.5%; Mn is present in a weight amount of about 11 to about 26%; and Cu is present in a weight amount of about 40 to about 55%.

[0033] In other embodiments, a binder metal composition has a melting point of 1500 °F or less and includes Cu, Mn, Ni, Zn, and Sn represented herein by **Formula 2** (For-2), in which Sn is present in a weight amount of about 16%; Zn is present in a weight amount of about 12%; Ni is present in a weight amount of about 6%; Mn is present in a weight amount of about 17%; and Cu is present in a weight amount of about 49%. **Figure 1** shows the DSC temperature curves for a Formula-2 binder metal, with the measured melting point at the peak (15) of the heating curve (5). As shown in **Figure 1**, the measured melting point for a binder metal of Formula 2 is 771 °C (1420 °F).

[0034] In other embodiments, a binder metal composition has a melting point of 1500 °F or less and includes Cu, Mn, Ni, Zn, and Sn represented herein by **Formula 3** (For-3), in which Sn is present in a weight amount of about 10%; Zn is present in a weight amount of about 19%; Ni is present in a weight amount of about 5%; Mn is present in a weight amount of about 17%; and Cu is present in a weight amount of about 49%. **Figure 2** shows the DSC temperature curves for a Formula-3 binder metal with the measured melting point at the peak (15) of the heating curve (5). As shown in **Figure 2**, the measured melting point for a binder metal of Formula 3 is 798 °C (1468 °F).

[0035] In other embodiments, a binder metal composition has a melting point of 1500 °F or less and includes Cu, Mn, Ni, Zn, and Sn represented herein by **Formula 4** (For-4), in

which Sn is present in a weight amount of about 13%; Zn is present in a weight amount of about 15.5%; Ni is present in a weight amount of about 5.5%; Mn is present in a weight amount of about 17%; and Cu is present in a weight amount of about 49%. **Figure 3** shows the DSC temperature curves for a Formula-4 binder metal, with the measured melting point at the peak (15) of the heating curve (5). As shown in **Figure 3**, the measured melting point for a binder metal of Formula 4 is 779 °C (1434 °F).

[0036] In other embodiments, a binder metal composition has a melting point of 1500 °F or less and includes Cu, Mn, Ni, Zn, and Sn represented herein by **Formula 5** (For-5), in which Sn is present in a weight amount of about 15%; Zn is present in a weight amount of about 12.5%; Ni is present in a weight amount of about 6.5%; Mn is present in a weight amount of about 17%; and Cu is present in a weight amount of about 49%. **Figure 4** shows the DSC temperature curves for a Formula-5 binder metal, with the measured melting point at the peak (15) of the heating curve (5). As shown in **Figure 4**, the measured melting point for a binder metal of Formula 5 is 779 °C (1434 °F).

[0037] In other embodiments, a binder metal composition has a melting point of 1500 °F or less and includes Cu, Mn, Ni, Zn, and Sn represented herein by **Formula 6** (For-6), in which Sn is present in a weight amount of about 6.75%; Zn is present in a weight amount of about 22.75%; Ni is present in a weight amount of about 4.5%; Mn is present in a weight amount of about 17%; and Cu is present in a weight amount of about 49%. **Figure 5** shows the DSC temperature curves for a Formula-6 binder metal, with the measured melting point at the peak (15) of the heating curve (5). As shown in **Figure 5**, the measured melting point for a binder metal of Formula 6 is 811 °C (1492 °F).

[0038] **Figure 6** shows the DSC temperature curve for Comparative Formula-1, with the measured melting point at the peak (15) of the heating curve (5). As shown in **Figure 6**, the measured melting point for a binder metal of Comparative Formula-1 is 902 °C (1655 °F).

[0039] Table 1 below shows the formulae and the measured melting point temperatures (from DSC curves of **Figures 1-6**) for Formulae 2, 3, 4, 5, and 6, and Comparative Formula-1, as well as the crystallographic properties (based on the thermodynamic calculation). The crystallographic properties as indicated include the face-centered cubic (FCC) data for each alloy.

Table 1

Sample Binder Metal Alloy	Chemistry (weight percentage)	Calculated mole fraction of solid solution	Calculated MP (°F)	Measured MP (°F) by DSC
Comparative Formula-1	55Cu12Ni23Mn4Zn6Sn	0.980FCC-1-0.013FCC-2	1702	1655
Formula-2	49Cu6Ni17Mn12Zn16Sn	0.503FCC-1-0.458FCC-2	1482	1420
Formula-3	49Cu5Ni17Mn19Zn10Sn	0.592FCC-1-0.395FCC-2	1518	1468
Formula-4	49Cu5.5Ni17Mn15.5Zn13Sn	0.559FCC-1-0.419FCC-2	1502	1434
Formula-5	49Cu6.5Ni17Mn12.5Zn15Sn	0.594FCC-1-0.375FCC-2	1500	1434
Formula-6	49Cu4.5Ni17Mn22.75Zn6.75Sn	0.594FCC-1-0.398FCC-2	1530	1492

[0040] According to some embodiments, binder metals having a melting point temperature of 1500 °F or less have balanced solid solution FCC-1/FCC-2 microstructure properties which are not found in other binder metals, e.g., a binder metal of Comparative Formula-1. The balance of FCC-1 (30) and FCC-2 (35) phases in a metal-matrix composite made from a binder metal of Formula-4 is shown in the SEM images (**Figure 9**), and the corresponding semi-quantitative chemistry is provided in the energy dispersion spectroscopy (EDS) (**Figures 10 and 11**). This dual phase metal matrix (FCC-1 (50) and FCC-2 (55)) for the Formula -3 binder is also resolved in the TEM images of **Figures 15, 17 and 20**. In contrast, the binder metal of Comparative Formula-1 is resolved in the SEM and EDS images of **Figures 7 and 8**, in which the single FCC-1 (25) binder metal phase dominates the metal-matrix composite. The single FCC-1 phase (45) of the binder metal of Comparative Example 1 is also resolved in a TEM image as shown in **Figure 13**. These observations are in agreement with the multi-component thermodynamic modeling, as shown in Table 1. (The difference in the calculated melting point and the measured values is due to the extrapolated thermodynamic database employed in this research and the variation in chemistry.)

[0041] According to some embodiments, binder metals having a melting point temperature of 1500 °F or less are infiltrated into the matrix particles (e.g. tungsten carbide) at lower infiltration temperatures to form the metal-matrix composite used in drill bit bodies. The optical microscopy (OM) images of **Figure 12** show the formation of a reaction layer around the cast tungsten carbide (20) at an infiltration temperature of 1950 °F, 1800 °F and

1700 °F, as indicated. The lower infiltration temperature reduces the dissolution of cast tungsten carbide (22) and suppresses the formation of brittle phases, such as the carbon-deficient eta-phases (40). Furthermore, lower infiltration temperature preserves the integrity of diamond.

[0042] In some embodiments, the binder metal composition includes an additive element in which the additive element is up to about 5% of the binder metal composition by weight. For example, an additive element includes boron, silicon, iron, cobalt, aluminum, titanium, niobium, molybdenum, tungsten and or combinations thereof. For example, the binder metal composition may include both boron and silicon. In some embodiments, boron and silicon are added together up to about 5% of the binder metal composition by weight. In some embodiments boron and silicon are added together up to about 0.5% by weight. In some embodiments, boron is included from 0.05 to 0.07% by weight and silicon is added from 0.15 to 0.18% by weight.

[0043] In some embodiments, the metal-matrix composite having the lower melting point binder metal as disclosed herein is used in the fabrication of drill bit bodies having a plurality of blades (e.g., ribs) disposed on the drill bit body and cutting elements, for example, as described in detail in U.S. Patent No. 8,020,644. As described in this reference, the metal-matrix materials may be combined with varying hard particles to make various aspects of the drill bit body having blades and cutting elements. The metal-matrix composite for the disclosed components in U.S. Patent No. 8,100,203 may include the disclosed lower melting point binder metal, having a melting point of 1500 °F or less. For example, in some embodiments, a bit body made using a metal-matrix composite made with the presently disclosed lower melting point binder metal, includes a blade or blades having diamond grit. In other embodiments, polycrystalline diamond compact (PDC) inserts having a substrate made from a metal-matrix composite made with the presently disclosed lower melting point binder metal are attached to a drill bit body. In other embodiments, thermally stable polycrystalline diamond (TSP) cutting elements include a substrate made from a metal-matrix composite made with the presently disclosed lower melting point binder metal. Methods using PCD or TSP cutting elements are known in the art, and for example, are described in U.S. Patent No. 6,892,836 and U.S. Patent Publication No. 2010/0126779. In another example, the presently disclosed lower melting point binder metal is used as the infiltrant in forming grit hot pressed inserts (GHIs), as described, for example, in U.S. Patent No. 6,394,202 and U.S. Patent No. 8,109,77. In all of the aforementioned embodiments, the lower melting point metal binders disclosed herein may be used in lieu of the binder metals disclosed in the cited references.

[0044] The following Examples are presented for illustrative purposes only, and do not limit the scope or content of the present application.

EXAMPLES

Example 1. Properties of Binder Metal of Formulae 2-6.

[0045] As shown below in Table 2, the mechanical and energetic properties of binder metals of Formulae 2-6 were analyzed and the data is shown in comparison to the binder metal of Comparative Formula-1.

Table 2

	Comparative Formula-1	Formulae-2, 3, 4, 5, 6
Melting point (°F)	1655	1420-1492
Infiltration Temp (°F)	1950	≤1800
TRS (GM15 infiltrated at 1800 °F) (ksi)	137±6	121±5
K _{IC} (GM15 infiltrated at 1800 °F) (ksi·in ^{1/2})	18.6±1.8	16.1±1.1

[0046] The infiltration temperature is the temperature required to melt the binder metal and allow for good flow of the binder metal and attachment to the hard particulate grains (e.g. the tungsten carbide grains). As shown in Table 2, the binder metals of Formulae 2, 3, 4, 5 and 6, have an infiltration temperature of 1800 °F, which is approximately 300 degrees higher than the melting point temperature of each of the binder metals of Formulae 2, 3, 4, 5 and 6. Comparatively, a binder metal of Comparative Formula-1, having a melting point of 1655 °F, has an infiltration temperature of 1950 °F. The infiltration temperature for a binder metal of Formulae 2-6 having a melting point of 1500 °F or less, can be infiltrated with the hard phase matrix particles (e.g., tungsten carbide) at 1800 °F or less. In some embodiments, a binder metal as disclosed herein is used for infiltrating at an infiltration temperature of about 1790 °F. In some embodiments, a binder metal as disclosed herein is used for infiltrating at an infiltration temperature of about 1780 °F. In other embodiments, a binder metal as disclosed herein is used for infiltrating at an infiltration temperature of about 1770 °F.

[0047] The transverse rupture strength (TRS) was measured on solid matrices of tungsten carbide and binder metal for each of the binder metals of Formula 2-6 and Comparative Formula-1. In Table 2, the solid matrices using a binder metal of Formulae 2, 3, 4, 5 or 6 had a TRS of 121 ± 5 ksi (one thousand pounds per square inch), which is comparable to the TRS of a solid metal-matrix composite made from a binder metal of Comparative Formula-1.

[0048] Linear-Elastic Plane-Strain Fracture Toughness K_{IC} of the solid metal-matrix composite is measured using a uniaxial bending method and reported in inch pounds or $\text{ksi}\cdot\text{in}^{1/2}$. The solid matrices using a binder metal of Formulae 2, 3, 4, 5 or 6 have comparable toughness to the toughness of a solid metal-matrix composite made from a binder metal of Comparative Formula-1.

[0049] Example 2. *Differential Scanning Calorimetry (DSC)*. DSC analysis was performed following standard methods known in the art. In brief, the melting of each binder metal was analyzed using the NETZSCH model DSC 404 F1 Pegasus® differential scanning calorimeter to measure the transformation energies of the binder metals.

[0050] Example 3. *Preparation of solid metal-matrix composite for OM and SEM*. The solid metal matrix composite made of tungsten carbide particles and the binder metal was formed by infiltrating the tungsten carbide particles and the binder metal to form the solid metal-matrix composite. A binder TEM sample was prepared by standard procedures and a final thinning process was completed by a Gatan Precision Ion Polishing System (PIPS™). TEM observations and analysis were performed on a JEOL 2010 Transmission Electron Microscope at an accelerating voltage of 200kV. Selected area diffraction (SAD) patterns were obtained for each TEM image. The SAD pattern corresponding to the TEM image of **Figure 13** is shown in **Figure 14**. The SAD pattern corresponding to the TEM image of **Figure 15** is shown in **Figure 16**, and the two SAD patterns at two different angles corresponding to the TEM image of **Figure 17** are shown in **Figures 18 and 19**.

[0051] As disclosed throughout, a binder metal including Cu, Mn, Ni, Zn and Sn, in which Zn and Sn have a sum weight % of 26.5% to 30.5% in which Zn is at least 12% and Sn is at least 6.75%; Ni is at 4.5 to 6.5 weight %; Mn is at 11 to 26 weight %; and Cu is at 40 to 55 weight %, has a melting point of about 1500 °F or less and has a transverse rupture strength of 90-140 ksi varying with the hard phase matrix particles. As discussed and shown in the figures herein, the binder metal according to the disclosed embodiments is infiltrated into the hard matrix particles at an infiltration temperature of about 1800 °F or less.

[0052] Although only a few example embodiments have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible without

materially departing from this disclosure, and all such modifications are intended to be included within the scope of this disclosure. It is the express intention of the applicant not to invoke 35 U.S.C. 112, paragraph 6 for any limitations of any of the claims herein, except for those in which the claim expressly uses the words 'mean for' together with an associated function.

WHAT IS CLAIMED IS:

1. A binder metal composition having a melting point of 1500 °F or less, the binder metal composition, comprising:
 - zinc (Zn) at about at least 12 weight %;
 - tin (Sn) at about at least 6.5 weight %;
 - nickel (Ni) at about 4.5 weight % to about 6.5 weight %;
 - manganese (Mn) at about 11 weight % to about 26 weight %;
 - copper (Cu) at about 40 weight % to about 55 weight %; and
 - the total weight of Zn and Sn is about 26.5 weight % to about 30.5 weight %.
2. The binder metal composition of claim 1, wherein Mn is present at about 14 weight % to about 21 weight % and Cu is present at about 40 weight % to about 55 weight %.
3. The binder metal composition of claim 1, wherein Mn is present at about 17 weight % and Cu is present at about 49 weight %.
4. The binder metal composition of claim 1, further comprising an additive selected from the group consisting of boron, silicon, iron cobalt, aluminum, titanium, niobium, molybdenum, tungsten and combinations thereof.
5. An infiltrated metal-matrix composite comprising:
 - hard matrix particles which are infiltrated with the binder metal composition of claim 1.
6. The infiltrated metal-matrix composite of claim 5, wherein the infiltrated metal-matrix has a transverse rupture strength (TRS) of 90-140 ksi.
7. A drill bit body comprising a plurality of blades, the plurality of blades comprising the infiltrated metal-matrix composite of claim 5.
8. An infiltrated metal-matrix composite comprising the binder metal composition of claim 1, wherein the infiltrated binder metal has a mixture of a first face-centered cubic (FCC) phase and a second FCC phase, and the first FCC phase has different chemistry and lattice parameters than the second FCC phase.
9. The infiltrated metal-matrix composite of claim 8, wherein the ratio of the first FCC phase to the second FCC phase is about 1 to 1.5: 1.
10. A drill bit body comprising:

- hard matrix particles which are infiltrated with the binder metal composition of claim 1.
11. A binder metal composition having a melting point of 1500 °F or less, the binder metal composition, comprising:
- Sn at about 6.5 weight % to about 16 weight %;
 - Zn at about 12 weight % to about 22.75 weight %;
 - Ni at about 4.5 weight % to about 6.5 weight %;
 - Mn at about 11 weight % to about 26 weight %; and
 - Cu at about 40 weight % to about 55 weight %.
12. The binder metal composition of claim 11, wherein Mn is present at about 17 weight % and Cu is present at about 49 weight %.
13. The binder metal composition of claim 12, wherein Sn is present at about 16 weight %; Zn is present at about 12 weight %, and Ni is present at about 6 weight %.
14. The binder metal composition of claim 12, wherein Sn is present at about 10 weight %, Zn is present at about 19 weight %, and Ni is present at about 5 weight %.
15. The binder metal composition of claim 12, wherein Sn is present at about 13 weight %, Zn is present at about 15.5 weight %, and Ni is present at about 5.5 weight %.
16. The binder metal composition of claim 12, wherein Sn is present at about 15 weight %, Zn is present at about 12.5 weight %, and Ni is present at about 6.5 weight %.
17. The binder metal composition of claim 12, wherein Sn is present at about 6.75 weight %, Zn is present at about 22.75 weight %, and Ni is present at about 4.5 weight %.
18. A method of forming an infiltrated metal-matrix composite, comprising:
- infiltrating tungsten carbide particles using a binder metal, the binder metal comprising:
 - zinc (Zn) at about at least 12 weight %;
 - tin (Sn) at about at least 6.5 weight %;
 - nickel (Ni) at about 4.5 weight % to about 6.5 weight %;
 - manganese (Mn) at about 11 weight % to about 26 weight %;
 - copper (Cu) at about 40 weight % to about 55 weight %; and
 - the total weight of Zn and Sn is about 26.5 weight % to about 30.5 weight %.

19. The method of claim 18, wherein infiltrating comprises infiltrating at a temperature of about 1800 °F or less.
20. A binder metal composition having a melting point of 1500 °F or less, the binder metal composition, comprising:
- zinc (Zn) at about at least 12 weight %;
 - tin (Sn) at about at least 6.5 weight %;
 - nickel (Ni) at about 4.5 to about 6.5 weight %;
 - copper (Cu) at about 51 to about 81 weight %; and
 - the total weight of Zn and Sn is about 26.5 weight % to about 30.5 weight %.

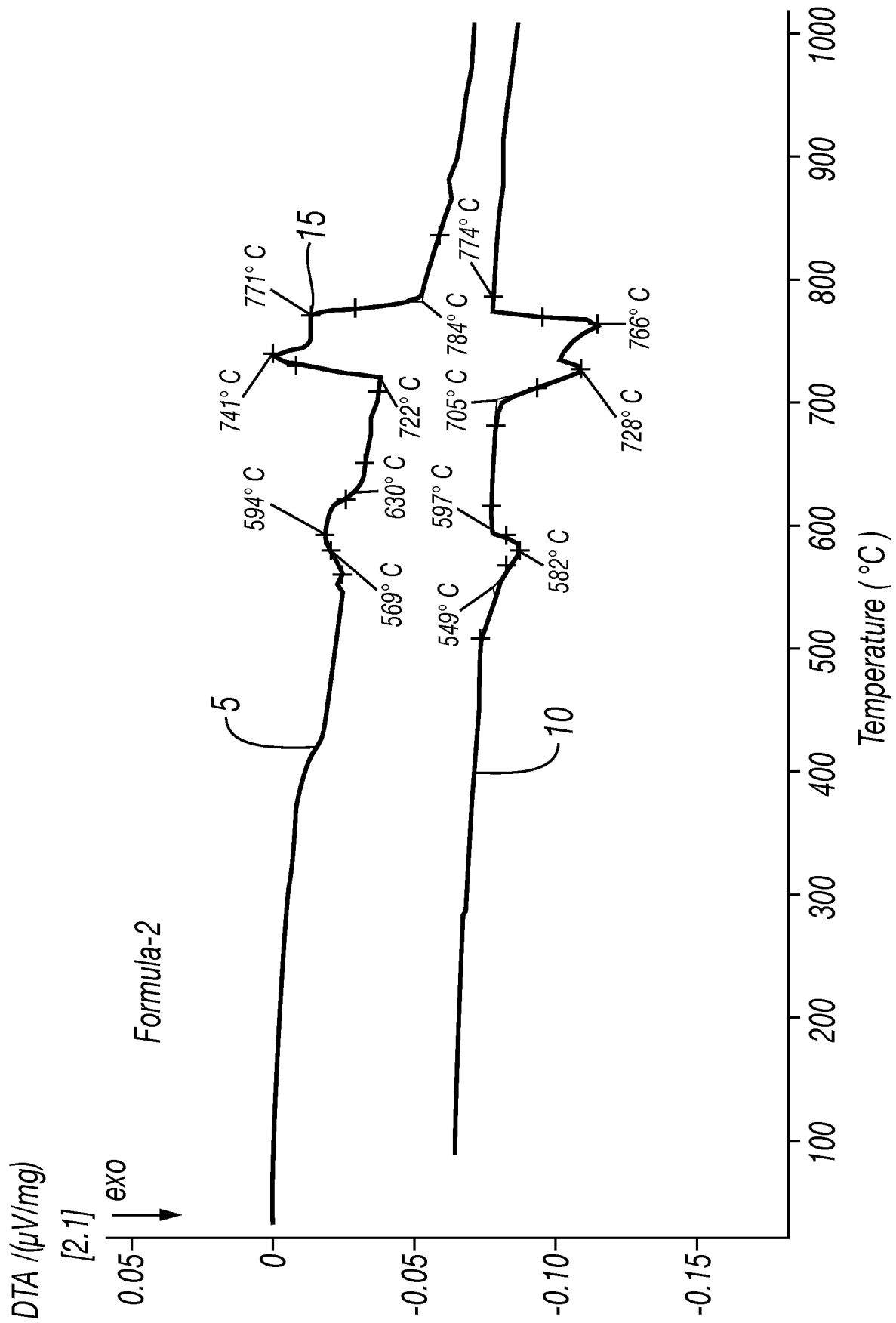
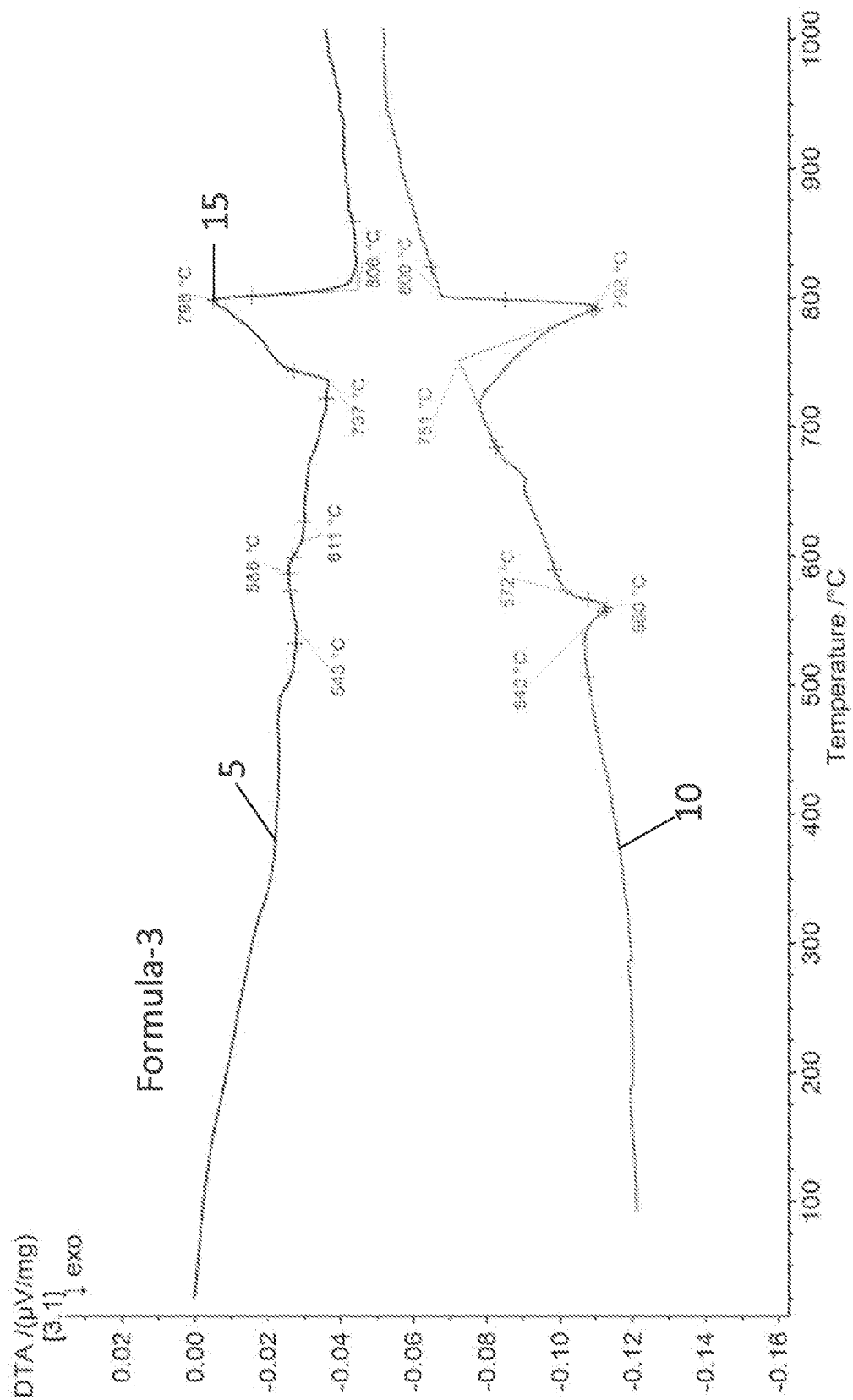
**FIG. 1**

FIGURE 2



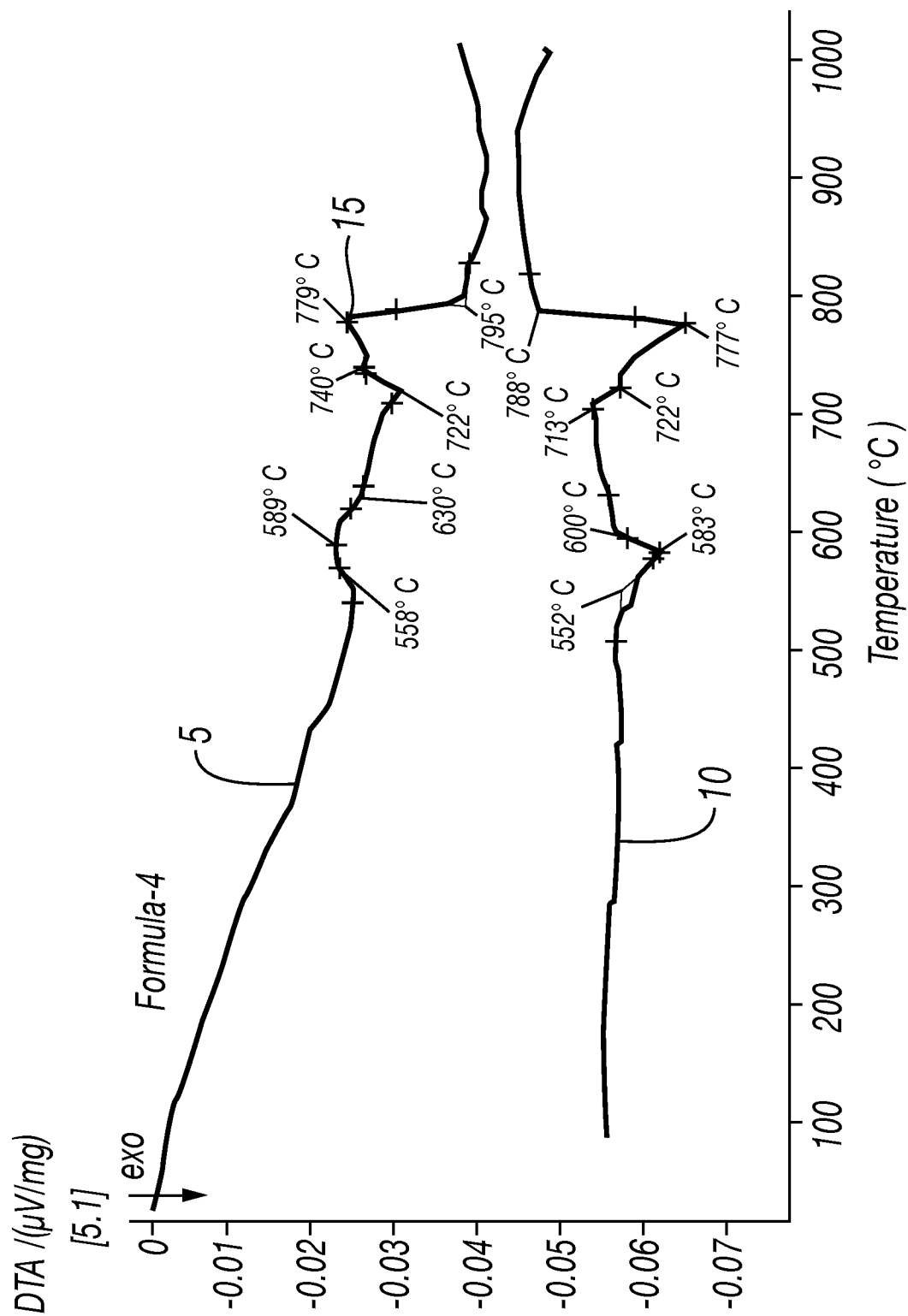


FIG. 3

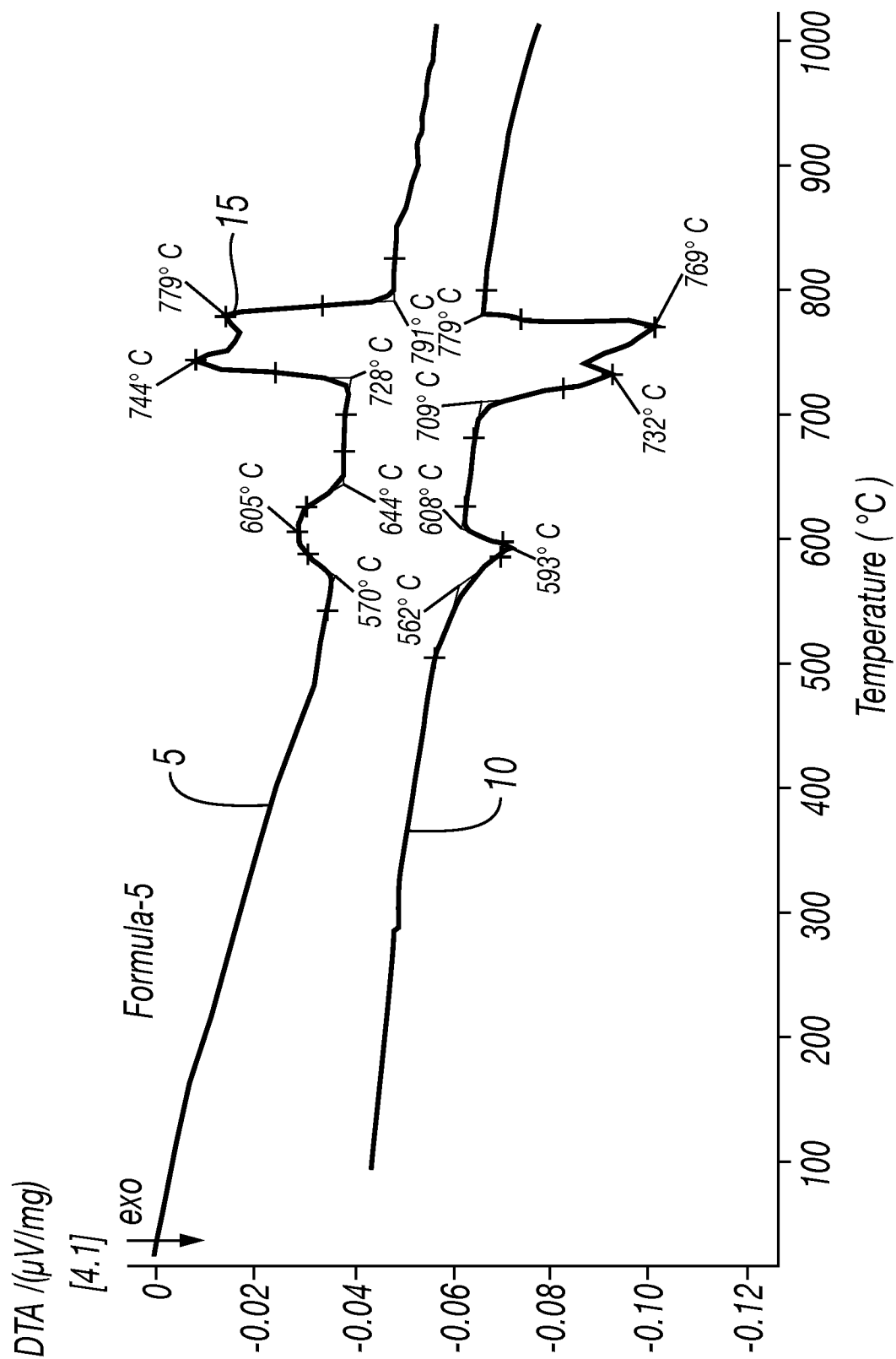


FIG. 4

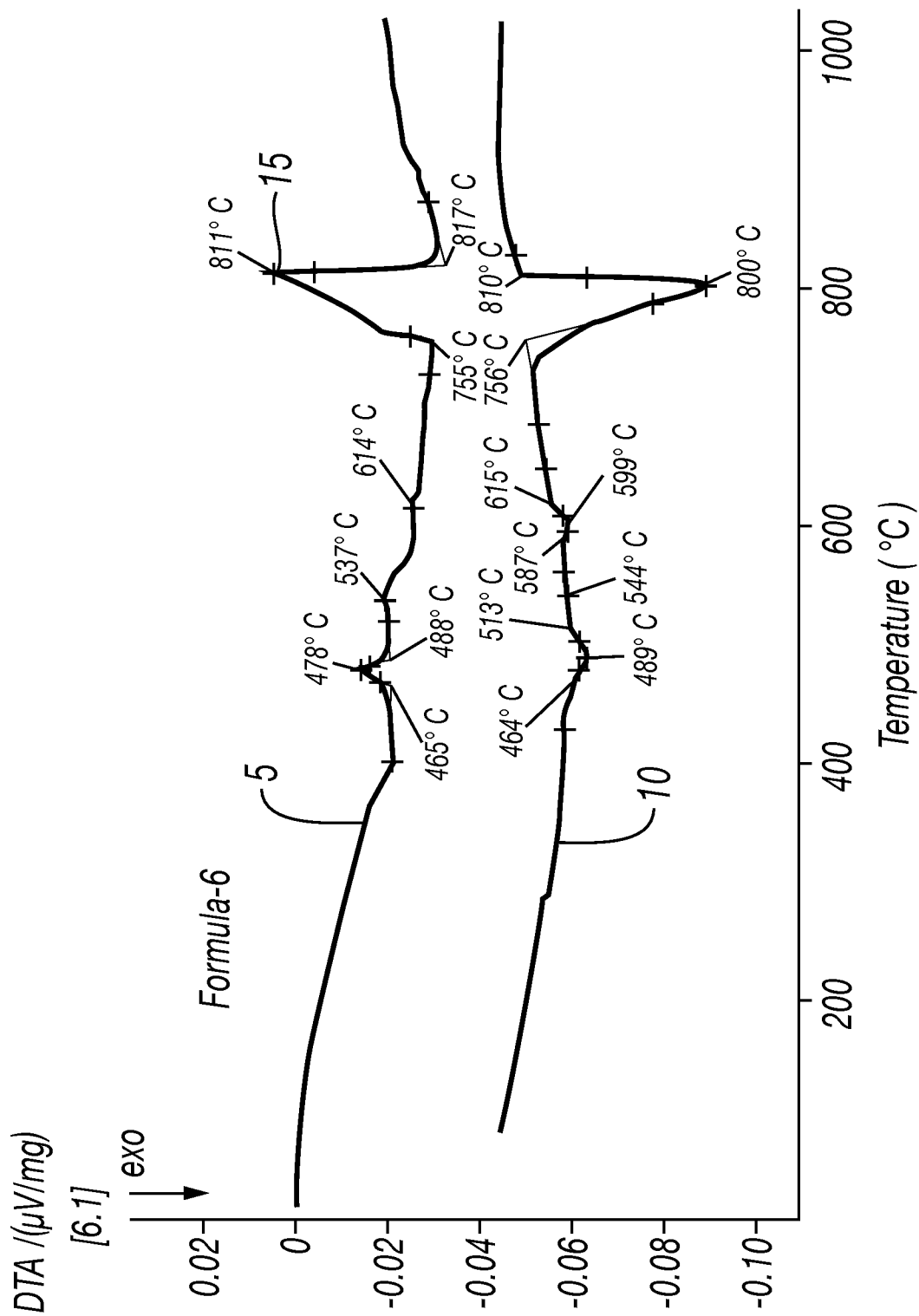
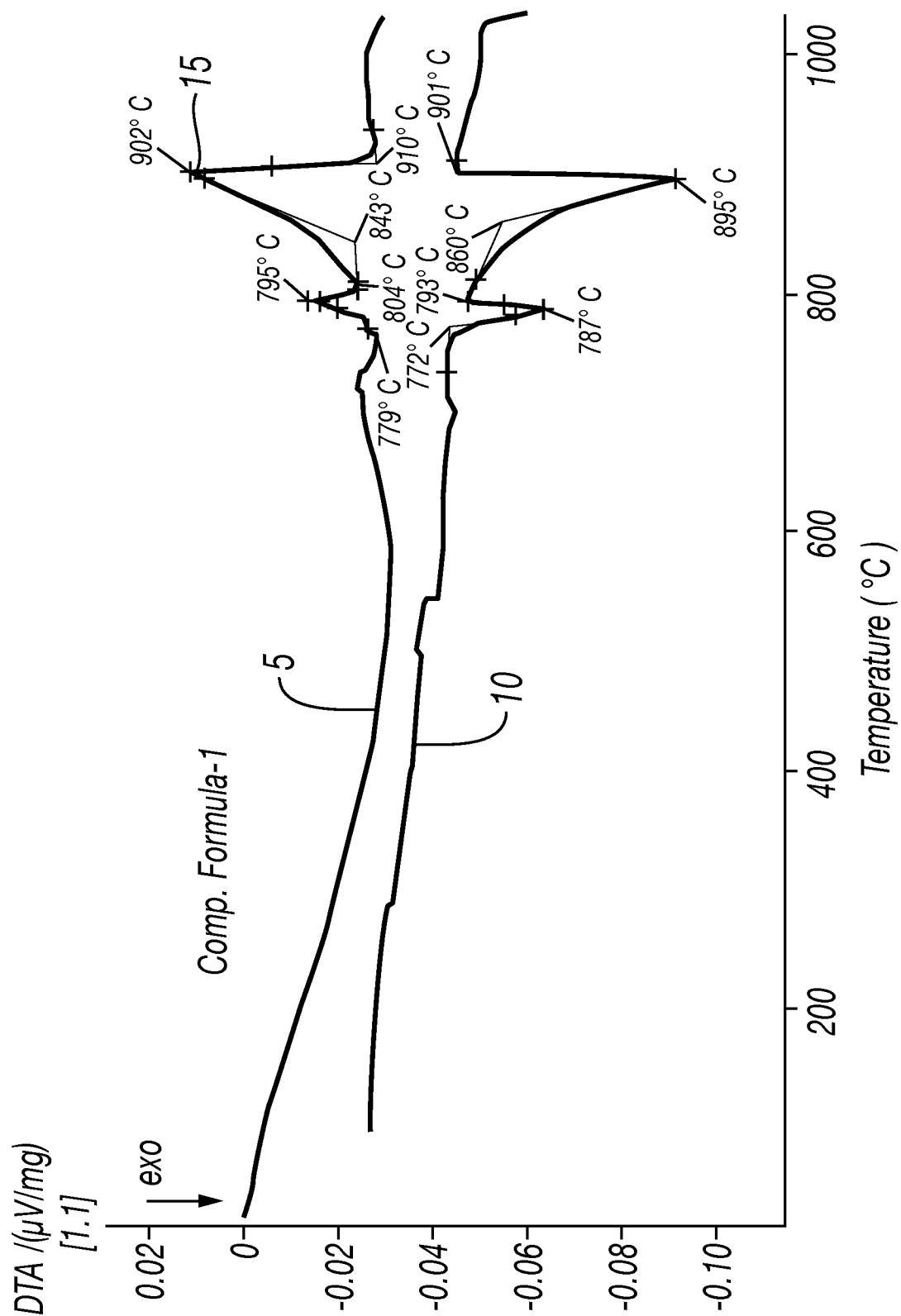
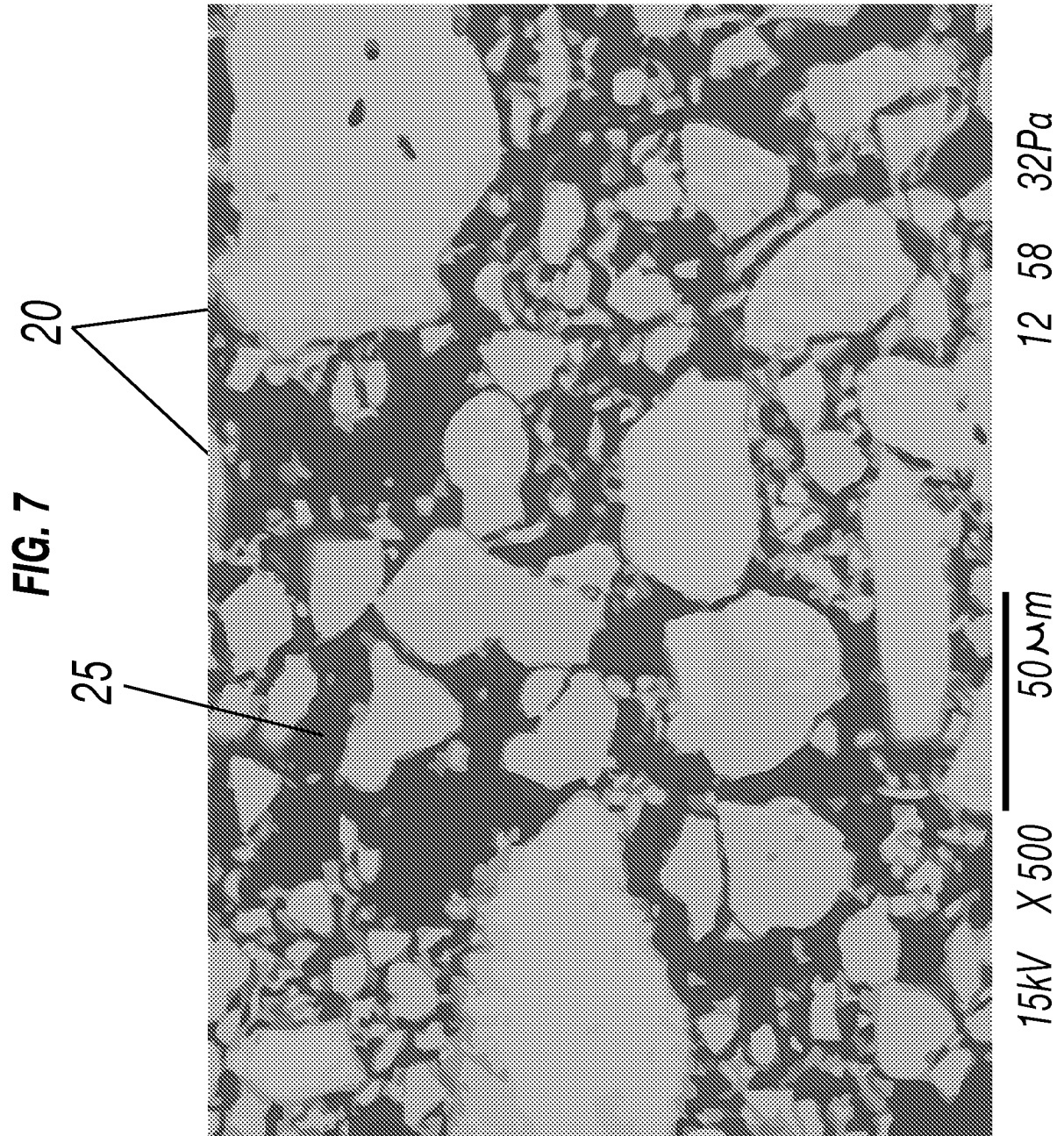
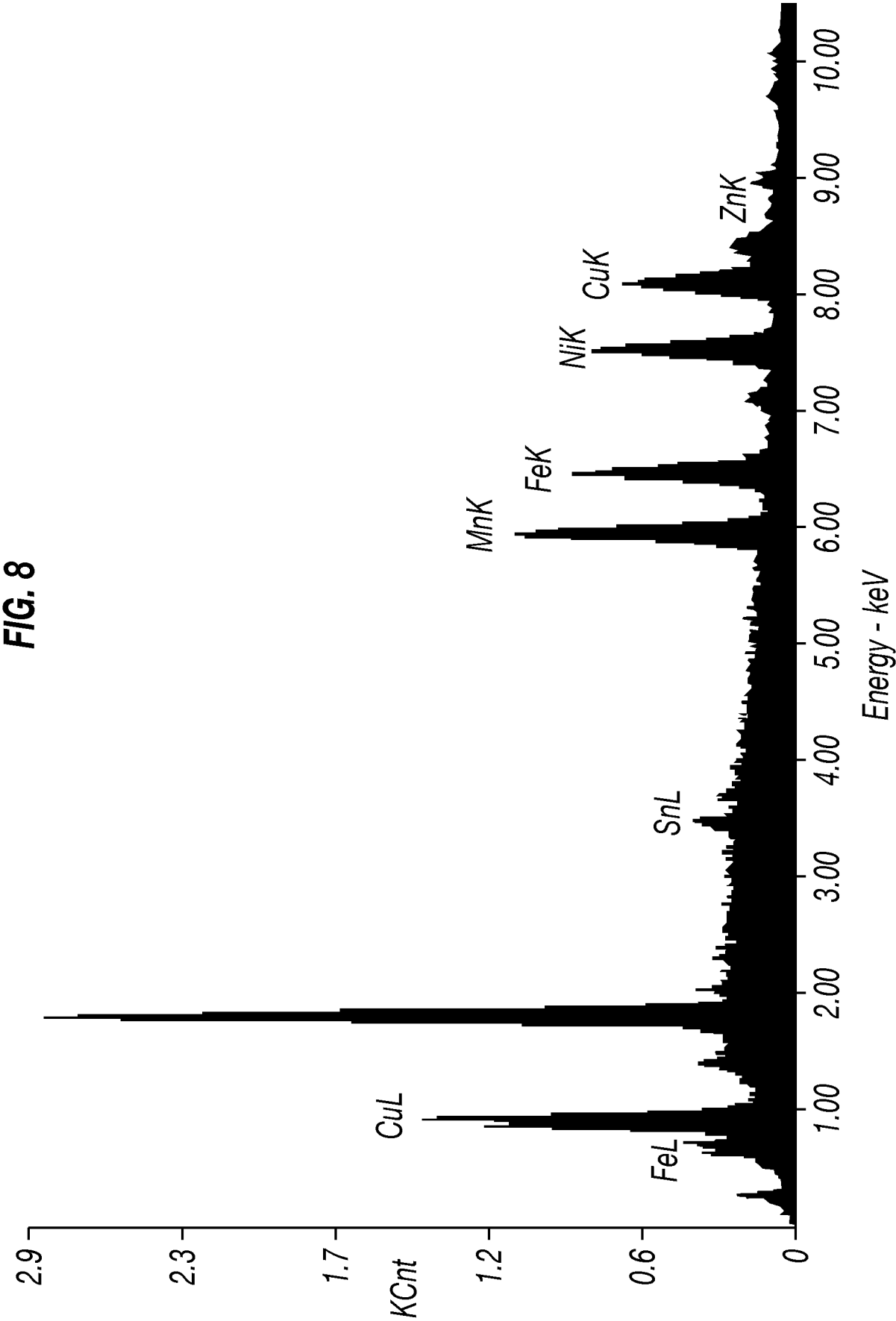
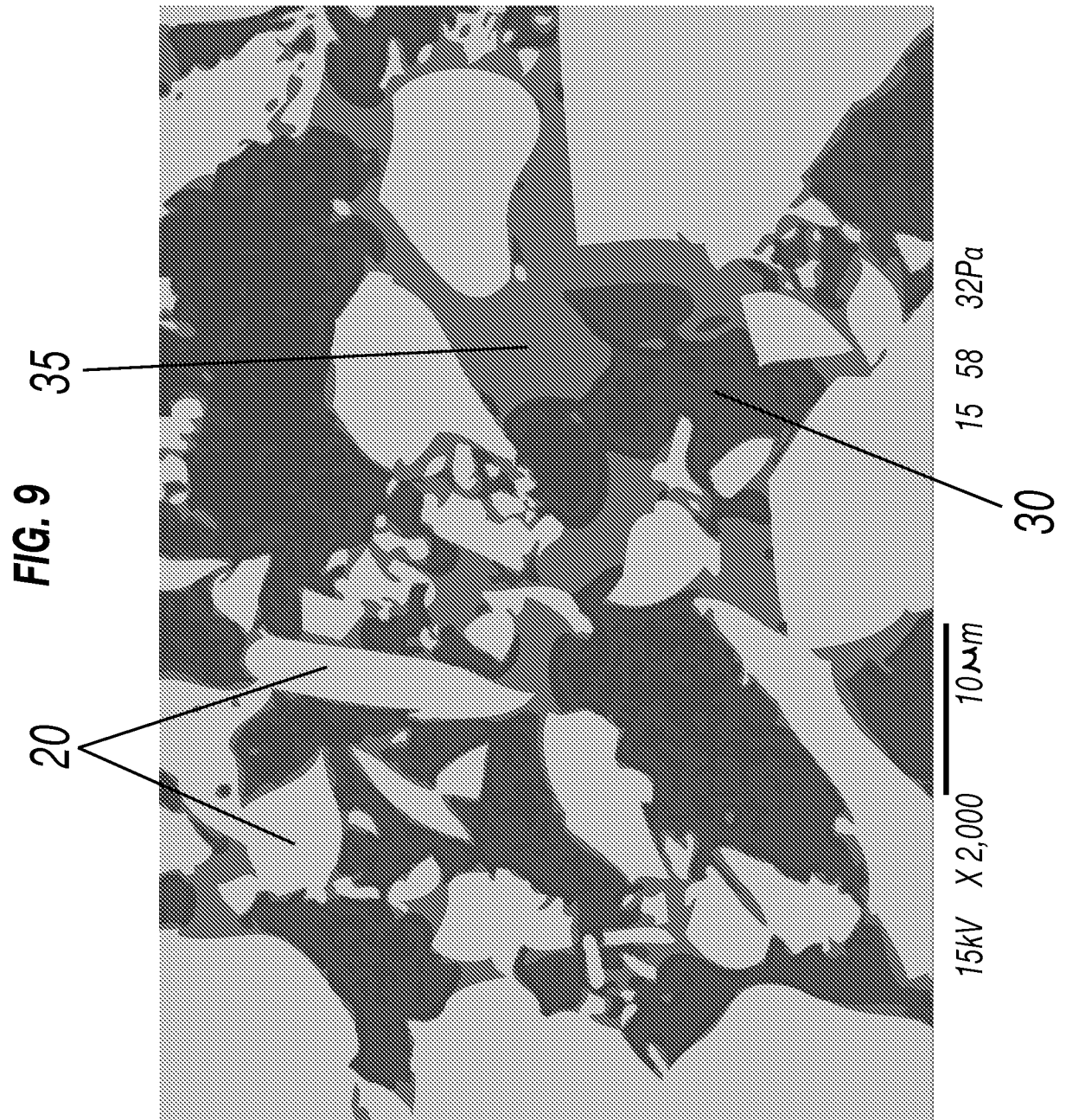


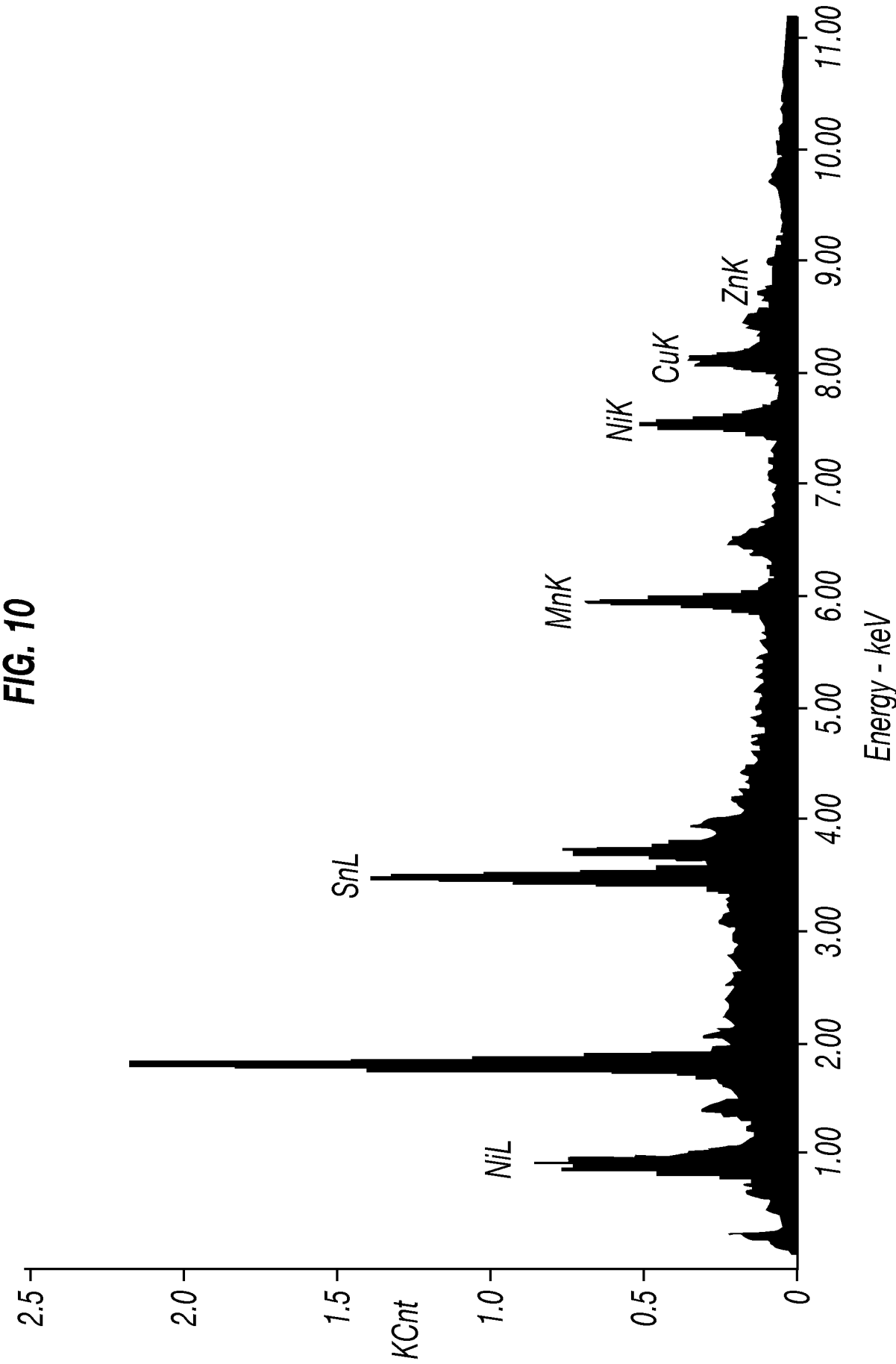
FIG. 5

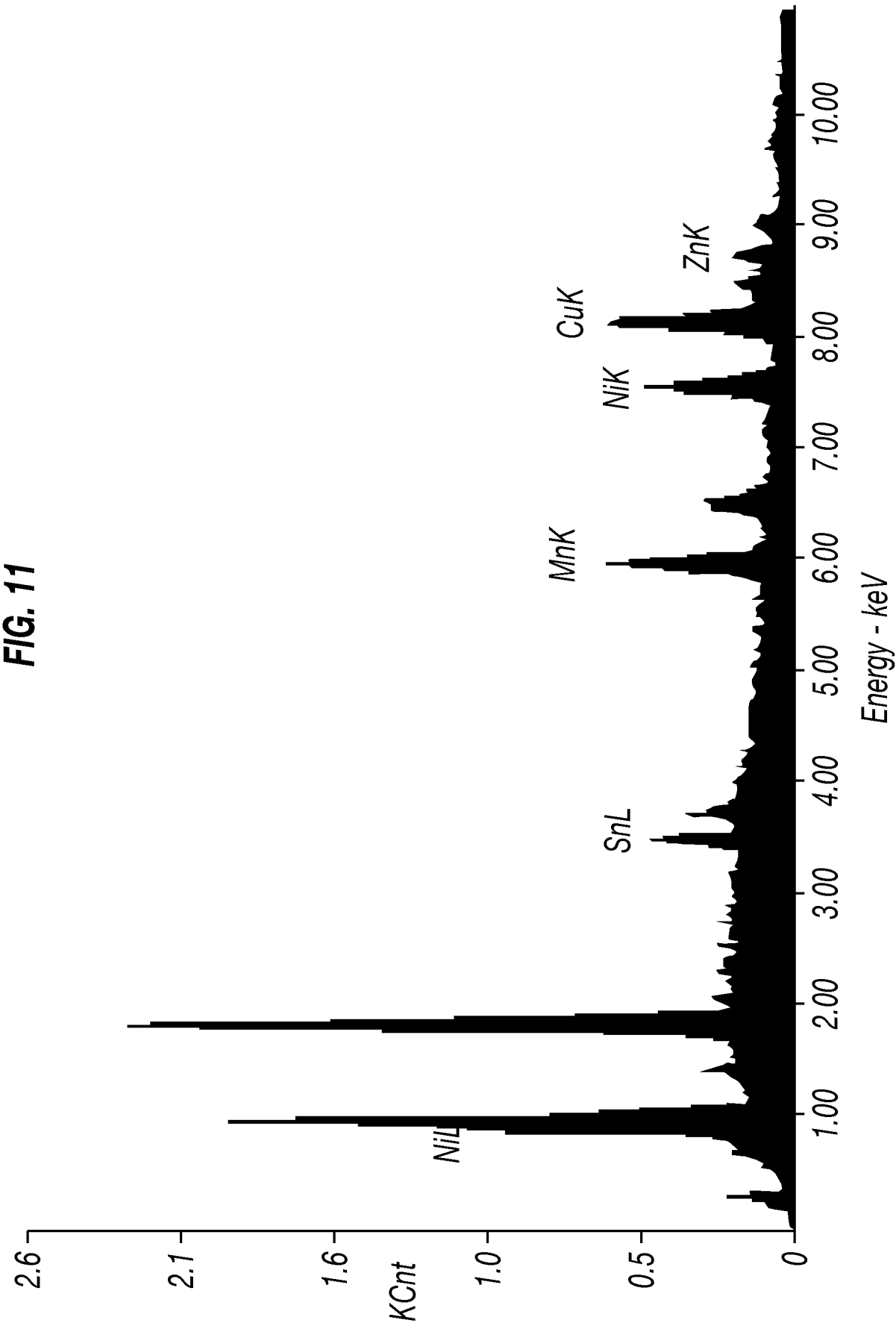
**FIG. 6**











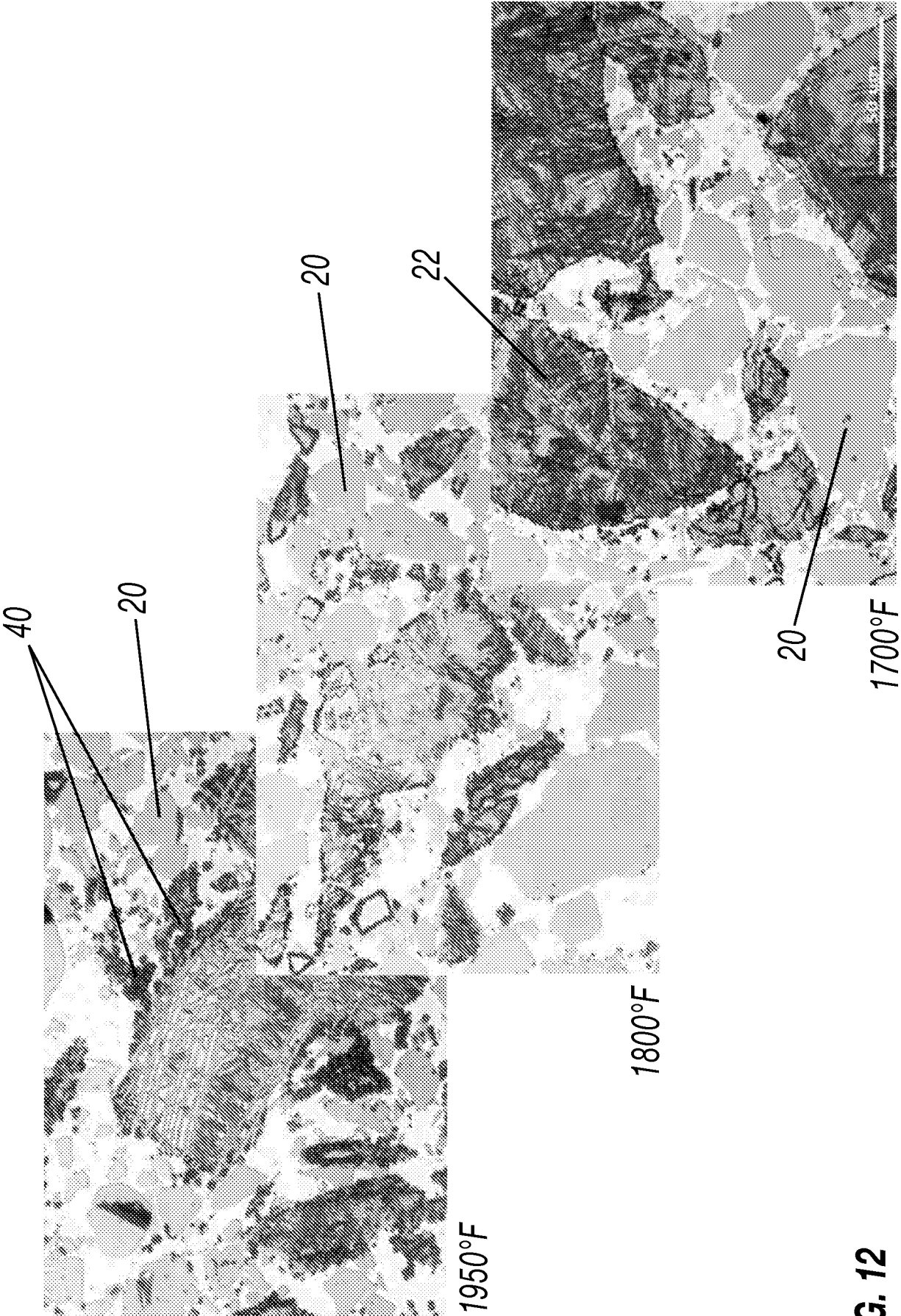


FIG. 12



FIG. 13

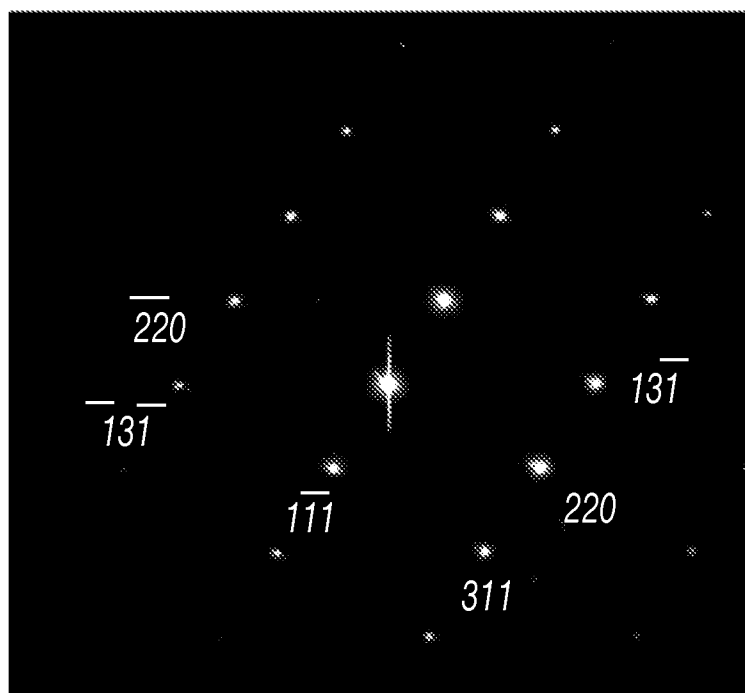
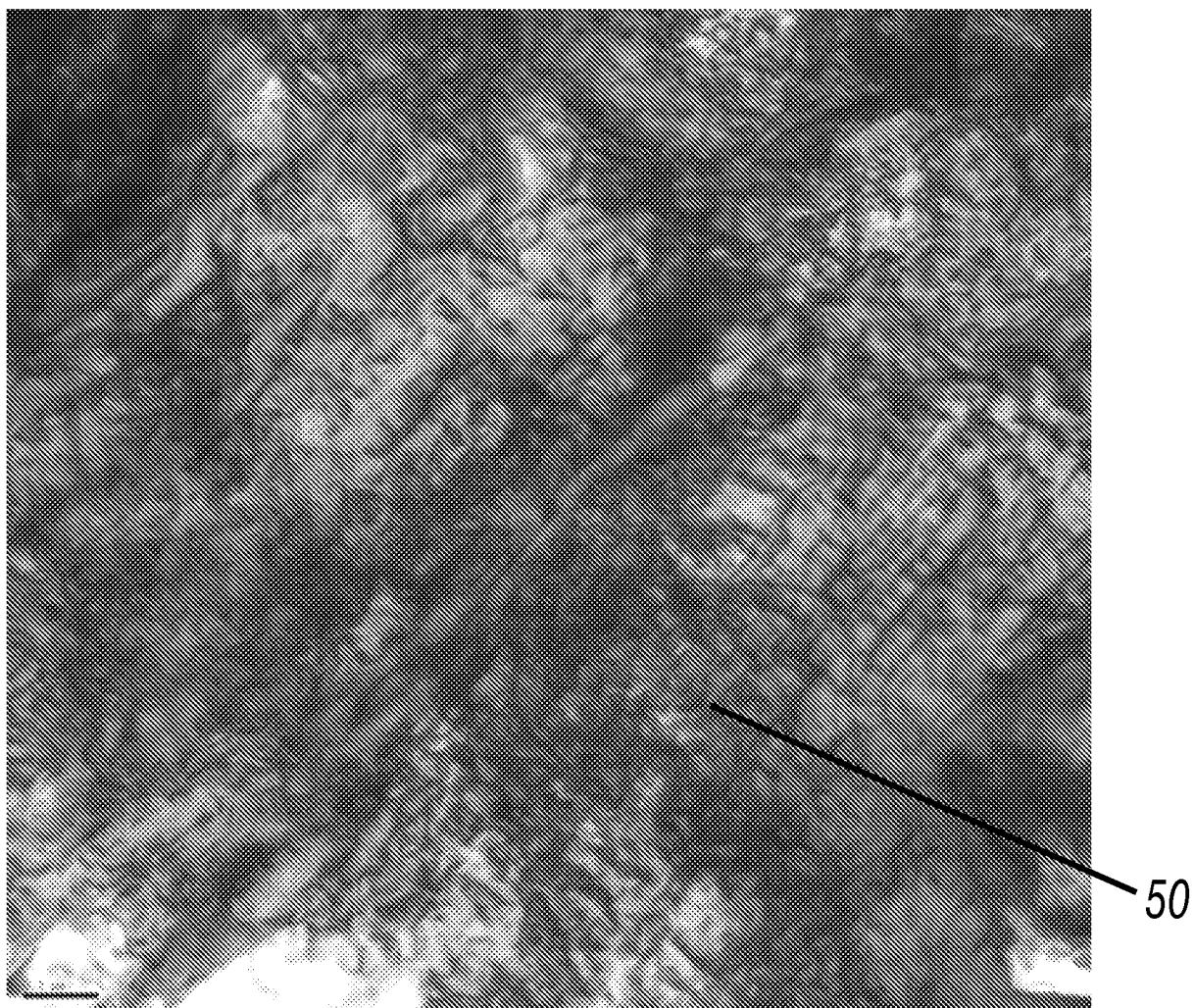
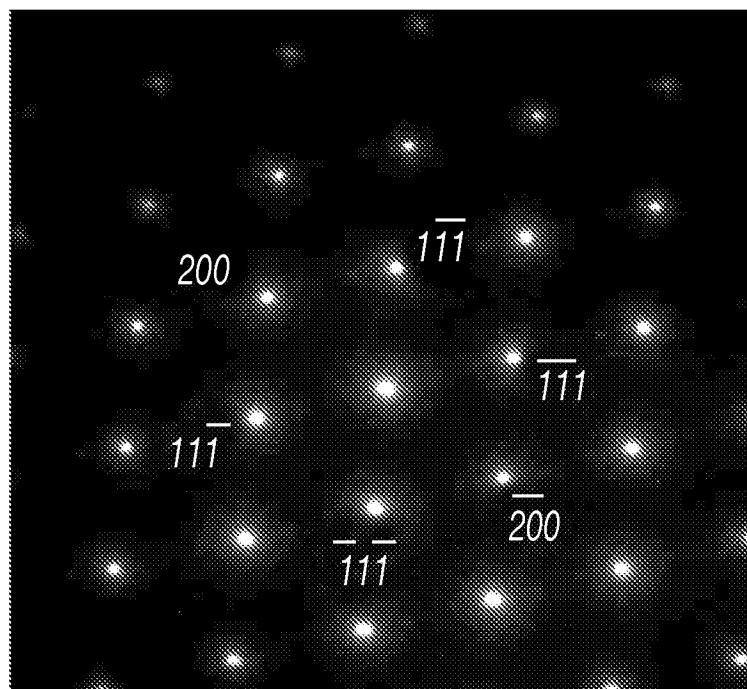
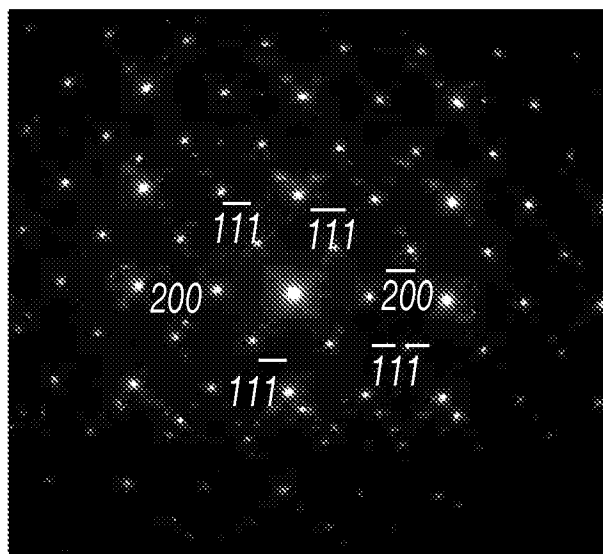
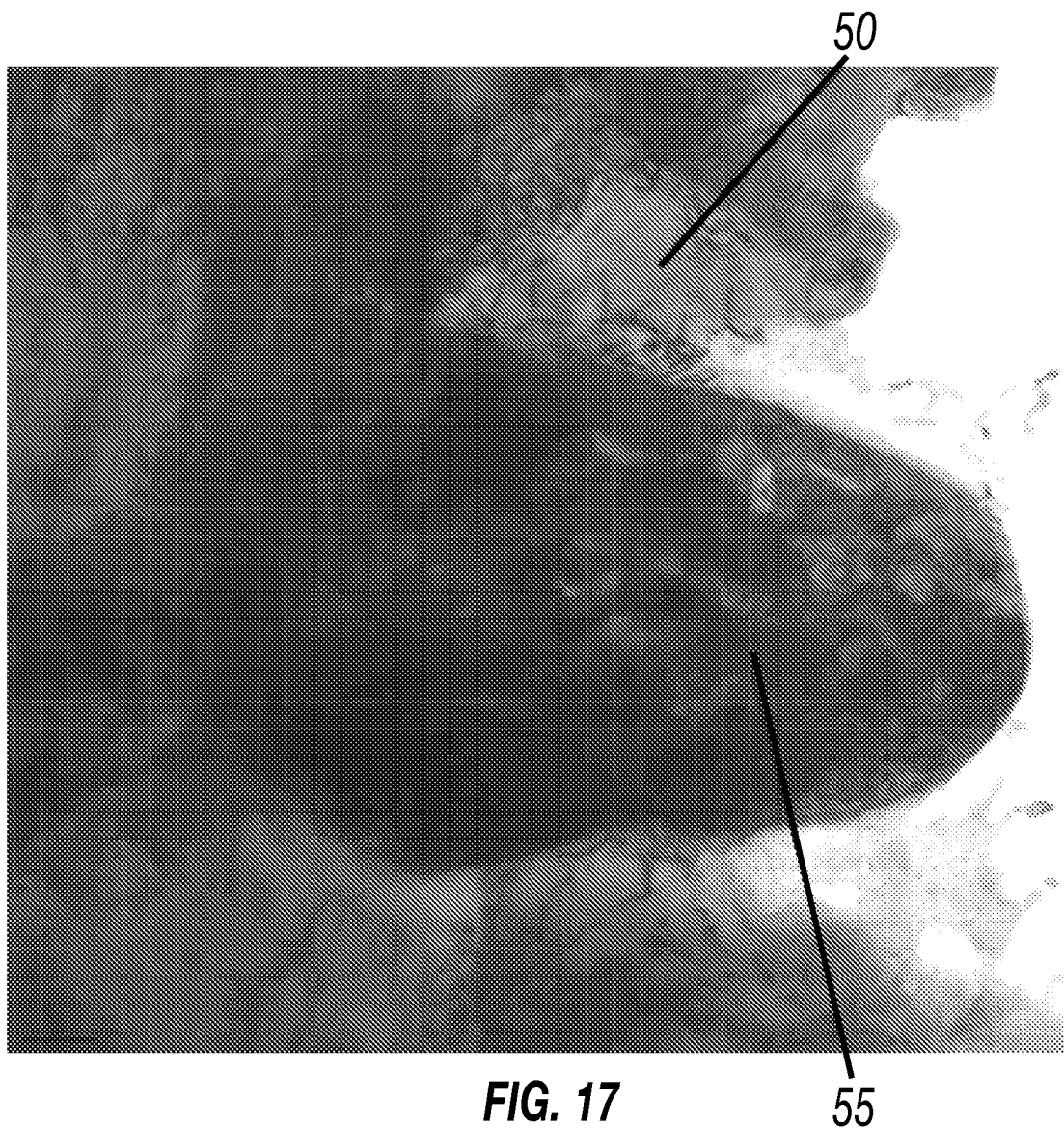
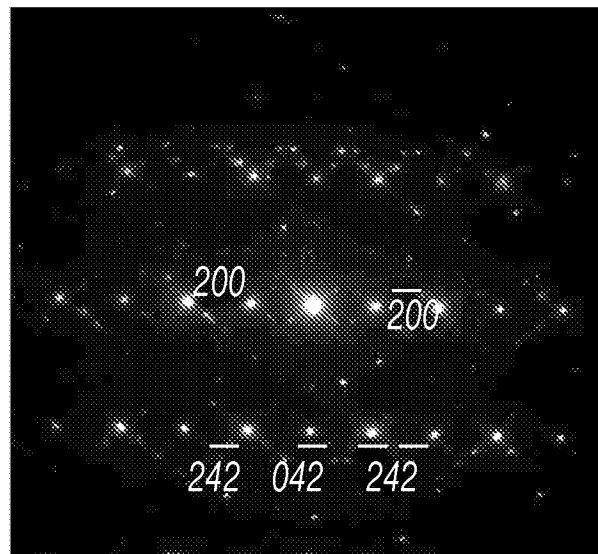


FIG. 14

**FIG. 15****FIG. 16**

**FIG. 18****FIG. 19**

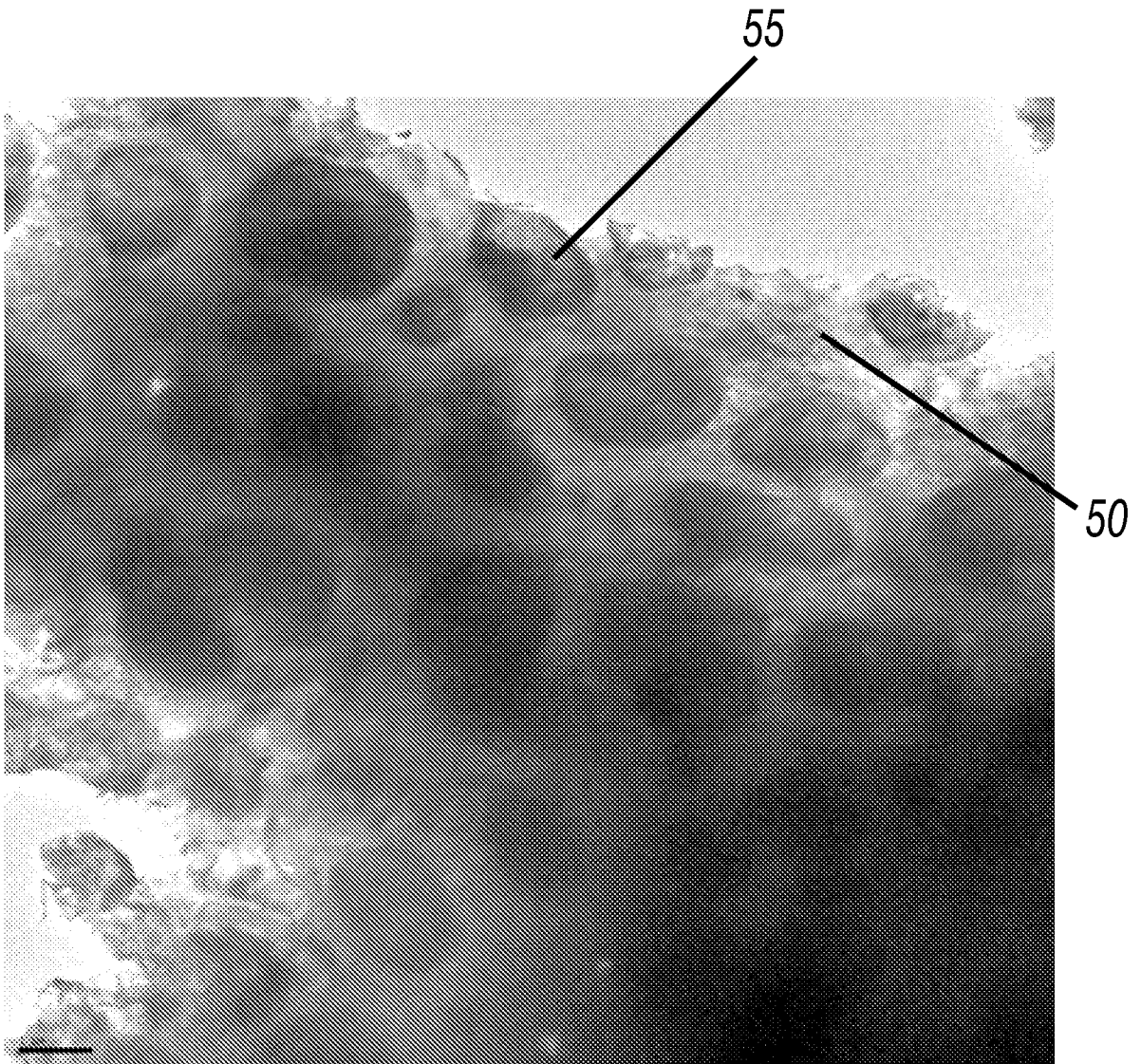


FIG. 20

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/076356**A. CLASSIFICATION OF SUBJECT MATTER****C22C 9/00(2006.01)i, C22C 9/04(2006.01)i, C22C 9/05(2006.01)i, C22C 30/00(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 9/00; A61M 25/09; C22C 9/02; E21B 10/46; C22C 29/00; C22C 1/05; C22C 1/04; C22C 9/01; B21K 5/04; C22C 9/04; C22C 9/05; C22C 30/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & keywords: melting point, binder metal, copper, zinc, tin, infiltrate, temperature, and nickel

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6375706 B2 (KEMBAIYAN et al.) 23 April 2002	1-3,5-7,10-20
Y	See abstract; column 2, lines 60-67, column 3, lines 15-41; and claims 1,5.	4,8-9
Y	US 5000273 A (HORTON et al.) 19 March 1991	4
	See abstract; column 4, lines 1-14; and claims 1-11.	
Y	US 6328822 B1 (ISHIDA et al.) 11 December 2001	8-9
	See abstract and column 4, lines 45-56.	
A	WO 2008-103688 A1 (KENNAMEDAL INC.) 28 August 2008	1-20
	See abstract; paragraphs [0032]-[0034]; and claims 1,3,13.	
A	US 2004-0244540 A1 (OLDHAM et al.) 09 December 2004	1-20
	See paragraphs [0021],[0031] and claims 12,16.	



Further documents are listed in the continuation of Box C.



See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

15 April 2014 (15.04.2014)

Date of mailing of the international search report

18 April 2014 (18.04.2014)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2013/076356

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