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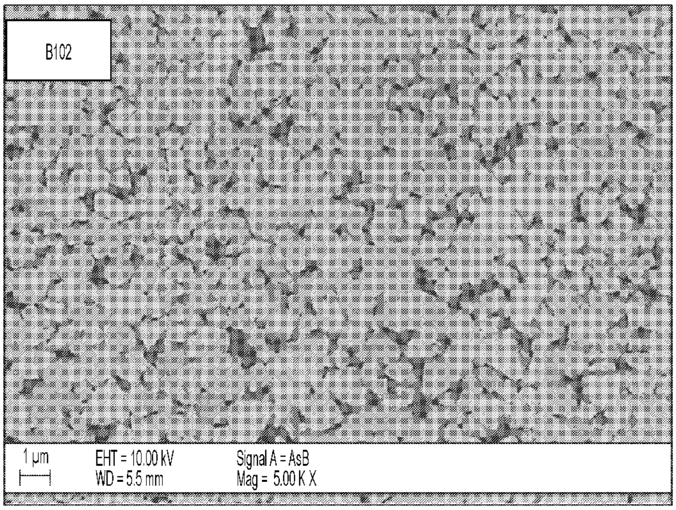

FIG. 3

(57) **Abstract:** Provided are cemented carbides having a hard phase including tungsten carbide (WC), a binder phase including Co, and an additive being a grain growth inhibitor either (I) selected from the group consisting of MO_2C, TiC, TaC, and NbC, and mixtures thereof, the grain growth inhibitor not containing Cr_3C_2 and VC or (II) selected from the group consisting of ZrC, BN, MO_2C, TiC, TaC, NbC, VC, and CrsC and mixtures thereof. The provided cemented carbides have improved properties, such as improved galling resistance, Vickers hardness, Palmqvist fracture toughness and coercive force.

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IMPROVED CEMENTED CARBIDES

TECHNICAL FIELD

[0001] The present application relates to cemented carbides having improved properties, such as improved galling resistance, Vickers hardness, Palmqvist fracture toughness and coercive force.

BACKGROUND

[0002] Cemented carbides are commonly used metallurgical products due to their hardness and fracture toughness. In general, cemented carbides have a hard phase containing hard constituents, such as refractory carbides, nitrides, etc. Cemented carbides also generally have a binder phase that contains a ductile metallic binder, such as Co, Ni, Fe, etc. The hard phase and a metallic binder phase can be processed into a wide variety of microstructures that achieve different mechanical and physical properties. Even though different mechanical and physical properties have been achieved, such properties are generally unpredictable. Thus, cemented carbides continue to be researched and developed in an attempt to achieve further improvements. Such desires for continued improvements are driven, at least in part, by the increased use of hard metal alloys (e.g., INCONEL alloys and other superalloys) that require tools with specialized properties for working. In an effort to improve upon and solve the problems of known cemented carbides, the inventors have discovered the cemented carbides having improved properties disclosed herein.

BRIEF SUMMARY

[0003] In view of the above-mentioned exemplary problems with conventional and known cemented carbides, the present application provides new and improved cemented carbides.

[0004] An embodiment of the present application includes a cemented carbide, including a hard phase composed of WC. The cemented carbide further includes a binder phase including Co, and an additive being a grain growth inhibitor selected from the group consisting of Mo_2C, TiC, TaC, and NbC, and mixtures thereof.

[0005] In one embodiment, the hard phase is 87 wt.% to 91 wt.% of the cemented carbide.

[0006] In another embodiment, the binder phase is 9 wt.% to 11 wt.% of the cemented carbide.

[0007] In another embodiment, the grain growth inhibitor is 0.1 wt.% to 2 wt.% of the cemented carbide.

[0008] In another embodiment, the grain growth inhibitor includes Mo, and the Mo is 0.1 wt.% to 1.50 wt.% of the cemented carbide.

[0009] In another embodiment, the grain growth inhibitor is not Cr_3C_2, VC, or mixtures thereof.

[0010] In another embodiment, the cemented carbide has a HV30 Vickers hardness of at least 1400 HV30.

[0011] In another embodiment, the cemented carbide has a Palmqvist fracture toughness, K_{Ic}, of at least 7.5 MPa√m.

[0012] In another embodiment, the cemented carbide has a coercive force, Hc, of at least 9 kA/m.

[0013] In another embodiment, the Mo is in a range approximately between 0.40 wt.%-0.60 wt.% of the cemented carbide.

[0014] Another embodiment of the present application includes a cemented carbide, including a hard phase composed of WC. The cemented carbide further includes a binder phase including Co, and an additive being a grain growth inhibitor selected from the group consisting of ZrC, and BN, and mixtures thereof.

[0015] In one embodiment, the grain growth inhibitor is 0.1 wt.% to 1 wt.% of the cemented carbide.

[0016] In another embodiment, the additive further includes a grain growth inhibitor selected from the group consisting of Mo_2C, TiC, TaC, NbC, VC, Cr_3C_2, and mixtures thereof.

[0017] In another embodiment, the cemented carbide has a HV30 Vickers hardness of at least 1500 HV30.

[0018] In another embodiment, the cemented carbide has a Palmqvist fracture toughness, K_{Ic}, of at least 9.9 MPa√m.

[0019] Another embodiment of the present application includes a tool including the cemented carbides disclosed herein.

[0020] Another embodiment of the present application includes a method of improving galling resistance, including: providing a cemented carbide sample having a hard phase including WC, a binder phase including Co, and an additive being a grain growth inhibitor including either (I) Mo_2C, TiC, TaC, and NbC, or (II) ZrC, BN, Mo_2C, TiC, TaC, NbC, VC, and Cr_3C_2; measuring an average coefficient of friction (COF) of the cemented carbide sample against INCONEL 718 over a sliding distance from 1 to 18 meters and from 14 to 18 meters; and adjusting the amount of the Mo_2C in the grain growth inhibitor comprising either (I) Mo_2C, TiC, TaC, and NbC, or (II) ZrC, BN, Mo_2C, TiC, TaC, NbC, VC, and Cr_3C_2 based on the measured average coefficient of friction (COF) of the cemented carbide sample against INCONEL 718 over a sliding distance from 1 to 18 meters and from 14 to 18 meters, to obtain the lowest possible coefficient of friction (COF) reflecting the most optimal galling resistance.

[0021] In another embodiment, the cemented carbide sample including Mo_2C in a range approximately between 0.40 wt.%-0.60 wt.% has the most optimal galling resistance.

[0022] Other systems, features and advantages will be, or will become, apparent to one with skill in the art upon examination of the following figures and detailed description. It is intended that all such additional systems, features and advantages be included within this description, be within the scope of the present disclosure, and be protected by the following claims. Nothing in this section should be taken as a limitation on those claims. Further aspects and advantages are discussed below in conjunction with the embodiments of the disclosure. It is to be understood that both the foregoing general description and the following detailed description of the present disclosure are examples and explanatory and are intended to provide further explanation of the disclosure as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] The accompanying drawings, which are included to provide a further understanding of the subject matter and are incorporated in and constitute a part of this specification, illustrate implementations of the subject matter and together with the description serve to explain the principles of the disclosure.

[0024] **FIGS. 1-8** are scanning electron microscope images of the microstructures of particular embodiments of the cemented carbides of the present application.

[0025] **FIGS. 9-15** are scanning electron microscope images of the microstructures of particular embodiments of the cemented carbides of the present application showing the influence of Mo thereon.

[0026] **FIG. 16** is a chart showing the average coefficient of friction (COF) against INCONEL 718 with varied amounts of Mo.

[0027] **FIG. 17** is a chart showing the coefficient of friction against (COF) INCONEL 718 for particular exemplary embodiments.

[0028] **FIG. 18** is a chart showing the coefficient of friction (COF) against INCONEL 718 for the embodiment with 0.47 wt.% Mo and the embodiment with 0.1 wt.% Mo.

[0029] **FIG. 19** is a chart showing the coefficient of friction (COF) against INCONEL 718 for the embodiment with 0.47 wt.% Mo and the embodiment with 0.25 wt.% Mo.

[0030] **FIG. 20** is a chart showing the coefficient of friction (COF) against INCONEL 718 for the embodiment with 0.47 wt.% Mo and the embodiment with 0.75 wt.% Mo.

[0031] **FIG. 21** is a chart showing the coefficient of friction (COF) against INCONEL 718 for the embodiment with 0.47 wt.% Mo and the embodiment with 1 wt.% Mo.

[0032] **FIG. 22** is a chart showing the coefficient of friction (COF) against INCONEL 718 for the embodiment with 0.47 wt.% Mo and the embodiment with 1.25 wt.% Mo.

[0033] **FIG. 23** is a chart showing the coefficient of friction (COF) against INCONEL 718 for the embodiment with 0.47 wt.% Mo and the embodiment with 1.50 wt.% Mo.

[0034] **FIGS. 24-28** are scanning electron microscope images of the microstructures of particular embodiments of the cemented carbides of the present application containing ZrC, BN, or a mixture thereof.

[0035] **FIG. 29** is a chart showing the galling resistance of particular embodiments of the cemented carbides of the present application by measuring the average coefficient of friction (COF) against a reference-grade material.

[0036] **FIG. 30** shows the milling performance on INCONEL 718 of a grade composed of 0.47 wt.% Mo compared to a reference grade.

DETAILED DESCRIPTION

[0037] Unless defined otherwise all technical and scientific terms used herein have the same meaning as commonly understood to one of ordinary skill in the art to which the presently described subject matter pertains.

[0038] Where a range of values is provided, for example, concentration ranges, percentage ranges, or ratio ranges, it is understood that each intervening value, to the tenth of the unit of the lower limit, unless the context clearly dictates otherwise, between the upper and lower limit of that range and any other stated or intervening value in that stated range, is encompassed within the described subject matter. The upper and lower limits of these smaller ranges may independently be included in the smaller ranges, and such embodiments are also encompassed within the described subject matter, subject to any specifically excluded limit in the stated range. Where the stated range includes one or both of the limits, ranges excluding either or both of those included limits are also included in the described subject matter.

[0039] The following definitions set forth the parameters of the described subject matter.

[0040] As used herein this disclosure, “wt.%” refers to a given weight percent of the total weight of a cemented carbide composition, unless specifically indicated otherwise.

[0041] As used herein this disclosure, the terms “about” and “approximately” are used interchangeably. It is meant to mean plus or minus 1% of the numerical value of the number with which it is being used. Thus, “about” and “approximately” are used to provide flexibility to a numerical range endpoint by providing that a given value may be “above” or “below” the given value. As such, for example a value of 50% is intended to encompass a range defined by 49.5%-50.5%.

[0042] As used herein this disclosure, the term “predominantly” is meant to encompass at least 95% of a given entity.

[0043] As used herein, the term “substantially” refers to the complete or nearly complete extent or degree of an action, characteristic, property, state, structure, item, or result.

[0044] As used herein, the term “lowest possible” refers to the least quantity of a value that is determined as the minimum from a set of values that are recorded.

[0045] As used herein, the term “most optimal” refers to the amount or degree of something that is most favorable, satisfactory or desirable.

[0046] Wherever used throughout the disclosure, the term “generally” has the meaning of “approximately”, “typically” or “closely” or “within the vicinity or range of”.

[0047] As used herein this disclosure, the term “Palmqvist fracture toughness” i.e. K_{Ic}, refers to the ability of a material with pre-cracks to resist further fracture propagation upon absorbing energy.

[0048] As used herein this disclosure, the term “HV30 Vickers hardness” (i.e. applying a 30 kgf load) is a measure of the resistance to localized plastic deformation, which is obtained by indenting the sample with a Vickers tip at 30 kgf.

[0049] As used herein this disclosure, the ISO 28079-2009 standard specifies a method for measuring the fracture toughness and hardness of hardmetals, cermets and cemented carbides at room temperature by an indentation method. The ISO 28079-2009 standard applies to a measurement of fracture toughness and hardness calculated by using the diagonal lengths of indentations and cracks emanating from the corners of a Vickers hardness indentation, and it is intended for use with metal-bonded carbides and carbonitrides (e.g. hardmetals, cermets or cemented carbides). The test procedures proposed in the ISO 28079:2009 standard are intended for use at ambient temperatures but can be extended to higher or lower temperatures by agreement. The test procedures proposed in the ISO 28079:2009 standard are also intended for use in a normal laboratory-air environment. They are typically not intended for use in corrosive environments, such as strong acids or seawater. The ISO 28079-2009 standard is directly comparable to the standard ASTM B771 as disclosed for example in “Comprehensive Hard Materials book”, 2014, Elsevier Ltd. Page 312, which is incorporated herein by reference in its entirety. Thus, it can be assumed that the measured fracture toughness and hardness using the ISO 28079-2009 standard will be the same as the measured values employing the ASTM B771 standard.

[0050] As used herein this disclosure, the term “coercive force” i.e. Hc, also called coercivity or magnetic coercivity, is a measure of the ability of a ferromagnetic material to withstand an external magnetic field without becoming demagnetized.

[0051] As used herein this disclosure, the term “coefficient of friction” i.e. μ is a ratio that is used to quantify the frictional force resisting the motion of two surfaces in contact between two objects, taken in relation to the normal force that is pressing and keeping the two objects together.

[0052] As used herein this disclosure, the term “galling” is a form of wear of a material typically caused by friction and adhesion between sliding surfaces. When a material galls, some of it is pulled with the contacting surface, especially if there is a large amount of force compressing the surfaces together. Thus, galling is caused by a combination of friction and adhesion between the surfaces that is followed by slipping and tearing of crystal structures beneath the surfaces. This will generally leave some material stuck or even friction-welded to the adjacent surface, whereas the galled material may appear gouged with balled-up or torn lumps of material stuck to its surface.

[0053] As used herein this disclosure, the term INCONEL 718 is a common superalloy based on nickel typically in an amount between 50.0 wt.%-55.0 wt.%, chromium generally in an amount between 17.0 wt.%-21.0 wt.%, molybdenum typically in an amount between 2.8 wt.%-3.3 wt.%, niobium and tantalum generally in an amount between 4.75 wt.%-5.50 wt.% with a balance of iron. INCONEL 718 is also known in the art as Nicrofer 5219, Superimphy 718, Haynes 718, Pyromet 718, Supermet 718, and Udimet 718.

[0054] Cemented carbide grades can be classified according to the WC grain size. Different types of grades have been defined as nano, ultrafine, submicron, fine, medium, medium coarse, coarse and extra coarse. As used herein this disclosure, the term (I) “nano grade” is defined as a material with a grain size of less than about 0.2 μm; (II) “ultrafine grade” is defined as a material with a grain size between about 0.2 μm and about 0.5 μm; (III) “submicron grade” is defined as a material with a grain size between about 0.5 μm and about 0.9 μm; (IV) “fine grade” is defined as a material with a grain size between about 1.0 μm and about 1.3 μm; (V) “medium grade” is defined as a material with a grain size between about 1.4 μm and about 2.0 μm; (VI) “medium coarse grade” is defined as a material with a grain size between about 2.1 μm and about 3.4 μm; (VII) “coarse grade” is defined as a material with a grain size between about 3.5 µm and about 5.0 µm; and (VIII) “extra coarse grade” is defined as a material with a grain size greater than about 5.0 µm.

[0055] Cemented carbides of the present application are now described by reference to the embodiments. The description provided herein is not intended to limit the scope of the claims, but to exemplify the variety encompassed by the present application. The embodiments are described more fully hereinafter with reference to the accompanying drawings in which like numerals represent like elements throughout the several figures, and in which example embodiments are shown. Embodiments of the claims may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. The examples set forth herein are non-limiting examples and are merely examples among other possible examples.

The Cemented Carbides

[0056] The present application includes a cemented carbide including a hard phase having WC, a binder phase including a binder material such as, for example, Co, and/or an additive.

[0057] The hard phase includes WC. In certain embodiments, the grade of the WC is submicron, fine, or mixtures thereof. The cemented carbide primarily contains WC with WC being present in the cemented carbide typically in a range of 87 wt.% to 91 wt.% relative to the total weight of the cemented carbide. In some embodiments, the WC is present in the cemented carbide in a range of 88 wt.% to 91 wt.% relative to the total weight of the cemented carbide. In other embodiments, the WC is present in the cemented carbide in a range of 89 wt.% to 91 wt.% relative to the total weight of the cemented carbide. In still other embodiments, the WC is present in the cemented carbide in a range of 90 wt.% to 91 wt.% relative to the total weight of the cemented carbide. In certain particular embodiments, the WC is present in the cemented carbide in a range of 88 wt.% to 89.5 wt.%, 88 wt.% to 90 wt.%, 89 wt.% to 89.5 wt.%, 89 wt.% to 90 wt.%, 90 wt.% to 90.5 wt.%, or in a range of 90.5 wt.% to 91 wt.% all of which are relative to the total weight of the cemented carbide. The hard phase can additionally include additional hard phase components, such as carbides, carbonitrides, and/or nitrides of Ti, Nb, V, Ta, Cr, Zr, and Hf, and mixtures thereof.

[0058] The binder phase includes a binder component such as, e.g., Co. In certain embodiments, the binder is Co such that the cemented carbide is a WC-Co cemented carbide. The binder is typically present in the cemented carbide in a range of 9 wt.% to 11 wt.% relative to the total weight of the cemented carbide. In some embodiments, the binder is present in the cemented carbide in a range of 9 wt.% to 10 wt.% relative to the total weight of the cemented carbide. In other embodiments, the binder is present in the cemented carbide in a range of 9.5 wt.% to 11 wt.% relative to the total weight of the cemented carbide. In still other embodiments, the binder is present in the cemented carbide in a range of 10 wt.% to 11 wt.% relative to the total weight of the cemented carbide. In yet other embodiments, the binder is present in the cemented carbide in a range of 10.5 wt.% to 11 wt.% relative to the total weight of the cemented carbide. In certain particular embodiments, the binder is present in an amount of 9.5 wt.% to 10.5 wt.% and approximately 10 wt.%, all of which are relative to the total weight of the cemented carbide. The term “approximately” is understood to mean +/- 1% of the numerical value of the number with which it is being used.

[0059] The additive can be a grain growth inhibitor that can be selected from the group consisting of Mo_2C, TiC, TaC, NbC, and mixtures thereof. The grain growth inhibitor phase is typically present in the cemented carbide in a range of 0.1 wt.% to 2 wt.% relative to the total weight of the cemented carbide. In some embodiments, the grain growth inhibitor phase is present in the cemented carbide in a range of 0.25 wt.% to 2 wt.% relative to the total weight of the cemented carbide. In other embodiments, the grain growth inhibitor phase is present in the cemented carbide in a range of 0.5 wt.% to 2 wt.% relative to the total weight of the cemented carbide. In yet other embodiments, the grain growth inhibitor phase is present in the cemented carbide in a range of 0.75 wt.% to 2 wt.% relative to the total weight of the cemented carbide. In still other embodiments, the grain growth inhibitor phase is present in the cemented carbide in a range of 1 wt.% to 2 wt.% relative to the total weight of the cemented carbide. In further embodiments, the grain growth inhibitor phase is present in the cemented carbide in a range of 1.25 wt.% to 2 wt.% relative to the total weight of the cemented carbide. In further other embodiments, the grain growth inhibitor phase is present in the cemented carbide in a range of 1.50 wt.% to 2 wt.% relative to the total weight of the cemented carbide. In even other embodiments, the grain growth inhibitor phase is present in the cemented carbide in a range of 1.75 wt.% to 2 wt.% relative to the total weight of the cemented carbide. In certain particular embodiments, the grain growth inhibitor phase is present in the cemented carbide in a range of 0.4 wt.% to 1 wt.% and approximately 0.5 wt.%, all of which are relative to the total weight of the cemented carbide. The term "approximately" is understood to mean +/- 1% of the numerical value of the number with which it is being used.

[0060] In certain embodiments, the grain growth inhibitor does not include Cr_3C_2 and/or VC. In this regard, the cemented carbides of the present application can inhibit WC grain growth during sintering with refractory carbides other than the commonly used Cr_3C_2 and/or VC. By controlling the WC grain size growth, excellent hardness and fracture toughness can be achieved even without the addition of Cr_3C_2 and/or VC. Indeed, the excellent hardness and fracture toughness achieved by the cemented carbides of the present application are similar to WC-Co cemented carbides that utilize Cr_3C_2 and/or VC as a grain growth inhibitor. Obtained coercive force, H_c, values for the cemented carbides of the present application may for example range from 9 kA/m to 16 kA/m. Corresponding coercive force, H_c, values for a WC-10Co submicron grade (i.e. 10Co refers to 10 wt.% Co of the cemented carbide composition and the grade can contain Cr_3C_2 and/or VC) typically range from 17 kA/m to 23 kA/m, whereas a WC-10Co coarse grade has coercive force, H_c, values which generally range from 6 kA/m to 8.5 kA/m.

[0061] As explained in Farag, *et al.*, "The influence of grain growth inhibitors on the microstructure and properties of submicron, ultrafine and nano-structured hardmetals – A review, Int. J. Refract. Met. Hard Mater. 77. 12-30 (2018) and Wittmann, *et al.*, "WC grain growth inhibition in nickel and iron binder hardmetals," Int. J. Refract. Met. Hard

Mater. 20. 51-60 (2002), the inhibition of WC grain growth is usually done by adding Cr_3C_2 and/or VC, which are known to be more effective in comparison with other refractory carbides. However, by using other refractory carbides and/or Fe in the appropriate proportion, the grain growth of WC is limited, thereby obtaining cemented carbides with hardness and fracture toughness on the range of those expected when using Cr_3C_2 as a grain growth inhibitor.

[0062] In particular, the cemented carbides of the present application have an HV30 Vickers hardness of at least 1400 HV30. In certain embodiments, the cemented carbides generally have an HV30 Vickers hardness in the range of 1400 HV30 to 1700 HV30. In certain particular embodiments, the cemented carbides have an HV30 Vickers hardness in the range of 1400 HV30 to 1500 HV30, 1400 HV30 to 1600 HV30, 1500 HV30 to 1550 HV30, 1500 HV30 to 1600 HV30, 1500 HV30 to 1700 HV30, 1550 HV30 to 1600 HV30, 1600 HV30 to 1700 HV30, or in the range of 1650 HV30 to 1700 HV30.

[0063] The cemented carbides of the present application typically have a Palmqvist fracture toughness, K_{Ic}, of at least 7.5 MPa√m. In some embodiments, the cemented carbides have a Palmqvist fracture toughness, K_{Ic}, of 7.5 MPa√m to 12.5 MPa√m. In other embodiments, the cemented carbides have a Palmqvist fracture toughness, K_{Ic}, of 8.5 MPa√m to 12.5 MPa√m. In yet other embodiments, the cemented carbides have a Palmqvist fracture toughness, K_{Ic}, of 9.5 MPa√m to 12.5 MPa√m. In still other embodiments, the cemented carbides have a Palmqvist fracture toughness, K_{Ic}, of 10.5 MPa√m to 12.5 MPa√m. In further other embodiments, the cemented carbides have a Palmqvist fracture toughness, K_{Ic}, of 11.5 MPa√m to 12.5 MPa√m. In certain particular embodiments, the cemented carbides have a Palmqvist fracture toughness, K_{Ic}, of 9 MPa√m to 11 MPa√m or 9.5 MPa√m to 10.5 MPa√m.

[0064] The cemented carbides of the present application have a coercive force, Hc, of at least 9 kA/m. In some embodiments, the cemented carbides have a coercive force, Hc, of 9 kA/m to 25 kA/m. In other embodiments, the cemented carbides have a coercive force, Hc, of 11 kA/m to 25 kA/m. In yet other embodiments, the cemented carbides have a coercive force, Hc, of 13 kA/m to 25 kA/m. In still other embodiments, the cemented carbides have a coercive force, Hc, of 15 kA/m to 25 kA/m. In further embodiments, the cemented carbides have a coercive force, Hc, of 17 kA/m to 25 kA/m. In even other embodiments, the cemented carbides have a coercive force, Hc, of 19 kA/m to 25 kA/m. In certain embodiments, the cemented carbides have a coercive force, Hc, of 21 kA/m to 25 kA/m. In certain particular embodiments, the cemented carbides have a coercive force, Hc, of 12 kA/m to 20 kA/m, or 17 kA/m to 20 kA/m. The coercivity generally has an inversely proportional relationship with the microstructure of the carbide. That is, as the coercivity increases, the carbide grain size decreases. A high coercivity, therefore, indicates a small carbide grain size.

[0065] The following TABLE 1 shows certain embodiments of the cemented carbides of the present application, including the HV30 Vickers hardness, Palmqvist fracture toughness, K_{Ic}, and coercive force, Hc. **FIGS. 1-8** show scanning electron microscope images of the grades identified in TABLE 1.

[0066] [TABLE 1]

Grade	WC (wt.%)		Co (wt.%)	$Fe(Cr_3Cr_2)$ (wt.%)	TaC (wt.%)	Mo_2C (wt.%)	TiC (wt.%)	NbC (wt.%)	Total (wt.%)	HV30	K_{Ic} (MPa√m)	Hc (kA/m)
B69	Submicron	89.5	10	0	0.50	0.00	0.0	0.00	100.0	1573	10.4	20.60
B76	Submicron	89.5	10	0	0.00	0.50	0.0	0.00	100.0	1523	10.4	17.46
B102	Fine	90.5	9	0	0.00	0.50	0.0	0.00	100.0	1533	9.8	17.88
B98	Fine	89.5	10	0	0.00	0.20	0.3	0.00	100.0	1557	9.9	20.76
B87	Submicron	89.5	10	0	0.30	0.20	0.0	0.00	100.0	1486	11.0	18.69
B88	Fine	89.5	10	0	0.30	0.20	0.0	0.00	100.0	1508	11.4	17.34

B99	Fine	89.5	10	0	0.00	0.30	0.2	0.00	100.0	1547	10.1	20.65
B100	Fine	89.6	10	0	0.00	0.30	0.1	0.00	100.0	1658	9.0	24.66

[0067] Further, the grain growth inhibitor phase generally includes Mo in an amount of 0.1 wt.% to 1.50 wt.% of the cemented carbide. In certain embodiments, the grain growth inhibitor phase includes Mo in an amount of 0.1 wt.% to 1 wt.% of the cemented carbide. In certain particular embodiments, the grain growth inhibitor phase includes Mo in an amount of 0.25 wt.% to 1.50 wt.%, 0.50 wt.% to 1.50 wt.%, 0.75 wt.% to 1.50 wt.%, 0.90 wt.% to 1.50 wt.%, 1.00 wt.% to 1.50 wt.%, 1.10 wt.% to 1.50 wt.%, 1.25 wt.% to 1.50 wt.%, or 1.40 wt.% to 1.50 wt.% of the cemented carbide.

[0068] That is, in the present embodiments, the grain growth inhibitor phase is added as Mo_2C, such that the cemented carbides contain Mo therein. If the amount of Mo exceeds 1.25 wt.%, the precipitation of the third phase can occur. To avoid such precipitation, the upper limit for the amount of Mo in the carbide composition can be limited to 1.25 wt.% or even 1 wt.%. Even further, in certain embodiments, the cemented carbides of the present application do not form and do not contain a cubic Co and Mo phase.

[0069] The presence of a third phase was experimentally verified by preparing the samples shown in TABLE 2 (below). Each of the samples contained the amount of Mo in wt.% shown in TABLE 2 together with 10 wt.% Co and a balance of WC.

[0070] [TABLE 2]

Sample	**Mo (wt.%)**	**HV30**	**K_{Ic} (MPa√m)**	**COF from 1 to 18 m**	**COF from 14 to 18 m**
0.10Mo	0.10	1489	12.2	0.582	0.541

0.25Mo	0.25	1465	12.4	0.553	0.526
0.47Mo	0.47	1481	11.3	0.415	0.378
0.75Mo	0.75	1505	11.8	0.551	0.520
1.00Mo	1.00	1514	11.7	0.604	0.537
1.25Mo	1.25	1549	10.6	0.595	0.536
1.50Mo	1.50	1533	11.0	0.569	0.520

[0071] **FIGS. 9-15** show scanning electron microscope images of the microstructure of the embodiments from TABLE 2. The aforementioned third phase is visible in **FIGS. 14-15**, which show the microstructure when the amount of Mo is 1.25 wt.% and 1.50 wt.%. TABLE 2 indicates that the presence of the third phase negatively influences the Palmqvist fracture toughness, K_{Ic}, which decreases when the amount of Mo is 1.25 wt.% relative to the amount of Mo being in the range of 0.1 wt.% to 1 wt.%.

[0072] The coefficient of friction (COF) against INCONEL 718 was measured for each of the samples shown in TABLE 2. The coefficient of friction (COF) was measured from 1 to 18 meters of sliding distance. The coefficient of friction (COF) was further measured from 14 to 18 meters of sliding distance when the coefficient of friction (COF) showed a stable behavior. The results are shown in TABLE 2.

[0073] Additionally, the galling resistance for the samples from TABLE 2 was measured by a reciprocating sliding test at 20 N of constant load over a total sliding distance of 18 meters. **FIG. 16** shows the results, where the average coefficient of friction (COF) against INCONEL 718 is plotted against the content of Mo in wt.%. The results presented in **FIG. 16** show that galling resistance is generally favorable spanning a range approximately between 0.40 wt.% Mo-0.60 wt.% (i.e. the lowest possible point on the graph depicting an average COF measurement over a sliding distance from 1 to 18 meters in **FIG. 16**).

[0074] **FIG. 16** shows the coefficient of friction (COF) against INCONEL 718 plotted against the sliding distance for all the samples from TABLE 2. The coefficient of friction (COF) for the embodiment with 0.47 wt.% Mo is depicted as the line having the lowest coefficient of friction (COF). That is, each of the other samples has an elevated coefficient of friction (COF) as compared to the embodiment with 0.47 wt.% Mo. The galling resistance, however, is not merely a function of the coefficient of friction (COF), but also considers the presence of galling events, which are depicted as peaks and valleys in the lines of **FIG. 17**. As seen in **FIG. 17**, the samples that showed more galling events are the ones composed with 0.25 wt.% Mo, 1 wt.% Mo, and 1.25 wt.% Mo, respectively. For additional clarity, **FIGS. 19, 21** and **22** extract the lines from **FIG. 17** for the embodiments composed with 0.25 wt.% Mo, 1 wt.% Mo, and 1.25 wt.% Mo and provide the lines together with the embodiment composed with 0.47 wt.% Mo. The increase in galling events shown in **FIGS. 19, 21** and **22** coincides with the elevated average coefficient of friction (COF) shown in **FIG. 16**.

[0075] In contrast, **FIG. 18** shows only the embodiment composed with 0.47 wt.% Mo and the embodiment composed with 0.1 wt.% Mo. **FIG. 20** shows only the embodiment composed with 0.47 wt.% Mo and the embodiment composed with 0.75 wt.% Mo. **FIG. 23** shows only the embodiment composed with 0.47 wt.% Mo and the embodiment composed with 1.50 wt.% Mo. **FIGS. 18, 20** and **23** depict fewer galling events (i.e., fewer peaks and valleys). Thus, in sum the results presented in **FIGS. 16-23** show that galling resistance is favorable generally in a range approximately between 0.40 wt.% Mo-0.60 wt.%. Even though it is possible that samples with 0.1 wt.% Mo, 0.75 wt.% Mo, and 1.50 wt.% Mo present a good galling resistance against INCONEL 718 due to the stable coefficient of friction (COF), favorable results of satisfactory low coefficient of friction (COF) and a decrease in galling events (i.e. improvement in galling resistance) were observed for samples generally spanning a range typically between approximately 0.40 wt.%-0.60 wt.% Mo.

[0076] The present application also includes methods of preparing the cemented carbides. The method of preparing the cemented carbides includes: first, mixing and/or milling the hard phase and the binder phase; second, pressing the mixture of the hard phase and the binder phase; third, sintering the pressed mixture of the hard phase and the binder phase. If necessary, the sintered product can be ground and coated to obtain a product (e.g., a tool or insert) from the cemented carbides. The coating can be provided by chemical vapor deposition (CVD) and/or physical vapor deposition (PVD). As discussed above, the cemented carbides can achieve excellent hardness and fracture toughness even without the addition of Cr_3C_2 and/or VC as a grain growth inhibitor. Additionally, the methods of preparing the cemented carbides can proceed to avoid the formation of a cubic Co and Mo phase.

ZrC and/or BN

[0077] The cemented carbides of the present application can include ZrC and/or BN as the additive. The addition of ZrC or BN helps decrease metal build-up events when machining Ni alloys. In this regard, metal build-up is a critical damage mechanism for cemented carbide tools when machining any metallic alloy. It is usually solved by using a coating on top of standard grades of cemented carbides. However, the cemented carbides of the present application that include ZrC and/or BN as the additive can decrease the adhesion of the machined material to the bulk material when the coating is completely removed from the surface.

[0078] When the additive is ZrC and/or BN, the ZrC and/or BN can be present in an amount of 0.1 wt.% to 0.2 wt.% of the cemented carbide. The addition of large amounts of ZrC (i.e., over 5 wt.%) is avoided because of the high activity of Zr with oxygen, which can produce highly porous materials. Additionally, when the additive is ZrC and/or BN, the additive can further include a grain growth inhibitor selected from the group consisting of Mo_2C, TiC, TaC, NbC, VC, Cr_3C_2, and mixtures thereof. That is, when the additive is ZrC and/or BN, the cemented carbides can be prepared with and without Cr_3C_2.

[0079] TABLE 3 (below) shows certain embodiments of the cemented carbides of the present application when the additive is ZrC and/or BN and includes the HV30 Vickers hardness and Palmqvist fracture toughness, K_{Ic}. **FIGS. 24-28** show scanning electron microscope images of the grades identified in TABLE 3. The reference grade in TABLE 3 refers to a 10% Co grade with submicron WC (i.e. 10Co refers to 10 wt.% Co of the cemented carbide composition).

[0080] [TABLE 3]

Grade	WC (wt.%)		Co (wt.%)	Cr_3Cr_2 (wt.%)	ZrC (wt.%)	Mo_2C (wt.%)	VC (wt.%)	BN (wt.%)	Total (wt.%)	HV30	K_{Ic} (MPa√m)
B61	Submicron	89.5	10	0.3	0.2	0.0	0.0	0.0	100.0	1589	10.4
B105	Submicron	89.0	10	0.5	0.2	0.3	0.0	0.0	100.0	1506	10.3
B107	Fine	89.1	10	0.5	0.1	0.3	0.0	0.0	100.0	1525	10.6
B67	Submicron	89.7	10	0.0	0.0	0.0	0.3	0.2	100.2	1623	9.9
B75	Submicron	89.9	10	0.0	0.0	0.0	0.1	0.0	100.0	1486	10.2
Reference (WC-10Co)	Submicron	89.5	10	0.5					100.0	1548	10.9

[0081] As seen in TABLE 3, the cemented carbides containing ZrC and/or BN have an HV30 Vickers hardness of at least 1500 HV30. In some embodiments, the cemented carbides have an HV30 Vickers hardness in the range of 1500 HV30 to 1650 HV30. In certain embodiments, the cemented carbides have an HV30 Vickers hardness of 1550 HV30 to 1650 HV30. In certain particular embodiments, the cemented carbides have an HV30 Vickers hardness of 1600 HV30 to 1650 HV30.

[0082] Additionally, the cemented carbide ZrC and/or BN have a Palmqvist fracture toughness, K_{Ic}, of at least 9.9 MPa√m. In certain particular embodiments, the cemented carbides have a Palmqvist fracture toughness, K_{Ic}, of 9.9 MPa√m to 10.6 MPa√m.

[0083] The addition of ZrC is not a common practice in cemented carbides, because it is understood to be less effective than common grain growth inhibitors. However, the small addition of ZrC affects the interaction of the binder with nickel alloys, thereby improving galling resistance by decreasing metal build-up. The addition of BN in small quantities decreases the chemical affinity of the Co binder with nickel alloys, thereby also decreasing galling. In this regard, metal build-up was measured in terms of "galling" by observing the change in time of the friction coefficient against Ni superalloys/INCONEL 718. A common WC-Co (with Cr_3C_2 addition) exhibits abrupt changes in friction coefficient along the sliding distance, and thus causes elevated metal build-up. **FIG. 29** shows that such abrupt changes were not observed for grades of the cemented carbides containing ZrC and/or BN shown in TABLE 3. In this regard, **FIG. 29** shows the curves for the friction coefficient against the sliding distance of the reference-grade and grades of the cemented carbides containing ZrC and/or BN shown in TABLE 3. **FIG. 29** shows that that abrupt changes associated with galling events are not observed on the grades of the cemented carbides containing ZrC and/or BN shown in TABLE 3. Even though the addition of ZrC and/or BN decreases metal build-up, it does not affect hardness and fracture toughness in the range of a common WC-Co material used for machining.

[0084] As discussed above, the present application also includes methods of preparing the cemented carbides. The method of preparing the cemented carbides includes: first, mixing and/or milling the hard phase and the binder phase; second, pressing the mixture of the hard phase and the binder phase; third, sintering the pressed mixture of the hard phase and the binder phase. If necessary, the sintered product can be ground and coated to obtain a product (e.g., a tool or insert) from the cemented carbides. The coating can be provided by chemical vapor deposition (CVD) and/or physical vapor deposition (PVD). Small amounts of ZrC and/or BN can be added to the cemented carbides. In particular, the small amounts of ZrC and/or BN can be added to the mixture of the hard phase and the binder phase in the methods of preparing the cemented carbides.

Tools

[0085] The cemented carbides disclosed herein can be used to prepare tools. The present application relates to a tool including the disclosed cemented carbides. For example, the tool can be, but is not limited to end mills, inserts, drills or saw tips. In certain particular embodiments, the tool is an end mill.

[0086] **FIG. 30** shows the milling performance on INCONEL 718 of a grade composed of 0.47 wt.% Mo compared to a reference grade. As depicted in **FIG. 30**, the average number of passes is increased by about 35% for the grade composed of 0.47 wt.% Mo in comparison to the reference grade. Thus, the results demonstrated in **FIG. 30** are in alignment with the favorable low coefficient of friction (COF) and a decrease in galling events (i.e. improvement in galling resistance), which were observed for samples generally spanning a range typically between approximately 0.40 wt.% and 0.60 wt.% Mo.

[0087] Although the present disclosure has been described in connection with embodiments thereof, it will be appreciated by those skilled in the art that additions, deletions, modifications, and substitutions not specifically described may be made without departure from the spirit and scope of the disclosure as defined in the appended claims.

[0088] With respect to the use of substantially any plural and/or singular terms herein, those having skill in the art can translate from the plural to the singular and/or from the singular to the plural as is appropriate to the context and/or application. The various singular/plural permutations are not expressly set forth herein for sake of clarity.

[0089] The herein described subject matter sometimes illustrates different components contained within, or connected with, different other components. It is to be understood that such depicted architectures are merely exemplary, and that in fact many other architectures may be implemented which achieve the same functionality. In a conceptual sense, any arrangement of components to achieve the same functionality is effectively “associated” such that the desired functionality is achieved. Hence, any two components herein combined to achieve a particular functionality can be seen as “associated with” each other such that the desired functionality is achieved, irrespective of architectures or intermedial components. Likewise, any two components so associated can also be viewed as being “operably connected”, or “operably coupled,” to each other to achieve the desired functionality, and any two components capable of being so associated can also be viewed as being “operably couplable,” to each other to achieve the desired functionality. Specific examples of operably couplable include but are not limited to physically mateable and/or physically interacting components, and/or wirelessly interactable, and/or wirelessly interacting components, and/or logically interacting, and/or logically interactable components.

[0090] In some instances, one or more components may be referred to herein as “configured to,” “configured by,” “configurable to,” “operable/operative to,” “adapted/adaptable,” “able to,” “conformable/conformed to,” etc. Those skilled in the art will recognize that such terms (e.g., “configured to”) can generally encompass active-state components and/or inactive-state components and/or standby-state components, unless context requires otherwise.

[0091] While particular aspects of the present subject matter described herein have been shown and described, it will be apparent to those skilled in the art that, based upon the teachings herein, changes and modifications may be made without departing from the subject matter described herein and its broader aspects and, therefore, the appended claims are to encompass within their scope all such changes and modifications as are within the true spirit and scope of the subject matter described herein. It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as “open” terms (e.g., the term “including” should be interpreted as “including but not limited to,” the term “having” should be interpreted as “having at least,” the term “includes” should be interpreted as “includes but is not limited to,” etc.).

[0092] It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases “at least one” and “one or more” to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles “a” or “an” limits any particular claim containing such introduced claim recitation to claims containing only one such recitation, even when the same claim includes the introductory phrases “one or more” or “at least one” and indefinite articles such as “a” or “an” (e.g., “a” and/or “an” should typically be interpreted to mean “at least one” or “one or more”); the same holds true for the use of definite articles used to introduce claim recitations.

[0093] In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should typically be interpreted to mean at least the recited number (e.g., the bare recitation of “two recitations,” without other modifiers, typically means at least two recitations, or two or more recitations).

[0094] Furthermore, in those instances where a convention analogous to “at least one of A, B, and C, etc.” is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., “ a system having at least one of A, B, and C” would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to “at least one of A, B, or C, etc.” is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., “ a system having at least one of A, B, or C” would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that typically a disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms unless context dictates otherwise. For example, the phrase “A or B” will be typically understood to include the possibilities of “A” or “B” or “A and B.”

[0095] With respect to the appended claims, those skilled in the art will appreciate that recited operations therein may generally be performed in any order. Also, although various operational flows are presented in a sequence(s), it should be understood that the various operations may be performed in other orders than those which are illustrated, or may be performed concurrently. Examples of such alternate orderings may include overlapping, interleaved, interrupted, reordered, incremental, preparatory, supplemental, simultaneous, reverse, or other variant orderings, unless context dictates otherwise. Furthermore, terms like “responsive to,” “related to,” or other past-tense adjectives are generally not intended to exclude such variants, unless context dictates otherwise.

[0096] Those skilled in the art will appreciate that the foregoing specific exemplary processes and/or devices and/or technologies are representative of more general processes and/or devices and/or technologies taught elsewhere herein, such as in the claims filed herewith and/or elsewhere in the present application.

[0097] While various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

[0098] 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.

[0099] Where a range of values is provided, it is understood that each intervening value, to the tenth of the unit of the lower limit unless the context clearly dictates otherwise, between the upper and lower limit of that range and any other stated or intervening value in that stated range is encompassed within the disclosure. The upper and lower limits of these smaller ranges which can independently be included in the smaller ranges is also encompassed within the disclosure, subject to any specifically excluded limit in the stated range. Where the stated range includes one or both of the limits, ranges excluding either both of those included limits are also included in the disclosure.

[00100] One skilled in the art will recognize that the herein described components (e.g., operations), devices, objects, and the discussion accompanying them are used as examples for the sake of conceptual clarity and that various configuration modifications are contemplated. Consequently, as used herein, the specific exemplars set forth and the accompanying discussion are intended to be representative of their more general classes. In general, use of any specific exemplar is intended to be representative of its class, and the non-inclusion of specific components (e.g., operations), devices, and objects should not be taken as limiting.

[00101] Additionally, for example any sequence(s) and/or temporal order of sequence of the system and method that are described herein this disclosure are illustrative and should not be interpreted as being restrictive in nature. Accordingly, it should be understood that the process steps may be shown and described as being in a sequence or temporal order, but they are not necessarily limited to being carried out in any particular sequence or order. For example, the steps in such processes or methods generally may be carried out in various different sequences and orders, while still falling within the scope of the present disclosure.

[00102] Finally, the discussed application publications and/or patents herein are provided solely for their disclosure prior to the filing date of the described disclosure. Nothing herein should be construed as an admission that the described disclosure is not entitled to antedate such publication by virtue of prior disclosure.

What is claimed is:

1. A cemented carbide, comprising:

a hard phase comprising WC;

a binder phase comprising Co; and

an additive being a grain growth inhibitor selected from the group consisting of Mo_2C, TiC, TaC, and NbC, and mixtures thereof.

2. The cemented carbide of claim 1, wherein the hard phase is 87 wt.% to 91 wt.% of the cemented carbide.

3. The cemented carbide of claim 1, wherein the binder phase is 9 wt.% to 11 wt.% of the cemented carbide.

4. The cemented carbide of claim 1, wherein the grain growth inhibitor is 0.1 wt.% to 2 wt.% of the cemented carbide.

5. The cemented carbide of claim 1, wherein the grain growth inhibitor comprises Mo, and the Mo is 0.1 wt.% to 1.50 wt.% of the cemented carbide.

6. The cemented carbide of claim 1, wherein the grain growth inhibitor is not Cr_3C_2, VC, or mixtures thereof.

7. The cemented carbide of claim 1, wherein the cemented carbide has a HV30 Vickers hardness of at least 1400 HV30.

8. The cemented carbide of claim 1, wherein the cemented carbide has a Palmqvist fracture toughness, K_{Ic}, of at least 7.5 MPa√m.

9. The cemented carbide of claim 1, wherein the cemented carbide has a coercive force, Hc, of at least 9 kA/m.

10. The cemented carbide of claim 5, wherein the Mo is in a range approximately between 0.40 wt.%-0.60 wt.% of the cemented carbide.

11. A cemented carbide, comprising:

a hard phase comprising WC;

a binder phase comprising Co; and

an additive being a grain growth inhibitor selected from the group consisting of ZrC, and BN, and mixtures thereof.

12. The cemented carbide of claim 11, wherein the grain growth inhibitor is 0.1 wt.% to 1 wt.% of the cemented carbide.

13. The cemented carbide of claim 11, wherein the additive further comprises a grain growth inhibitor selected from the group consisting of Mo_2C, TiC, TaC, NbC, VC, Cr_3C_2, and mixtures thereof.

14. The cemented carbide of claim 11, wherein the cemented carbide has a HV30 Vickers hardness of at least 1500 HV30.

15. The cemented carbide of claim 11, wherein the cemented carbide has a Palmqvist fracture toughness, K_{Ic}, of at least 9.9 MPa√m.

16. A tool, comprising the cemented carbide of claim 1.

17. A tool, comprising the cemented carbide of claim 11.

18. A method of improving galling resistance, comprising:

providing a cemented carbide sample comprising a hard phase comprising WC, a binder phase comprising Co, and an additive being a grain growth inhibitor comprising either (I) Mo_2C, TiC, TaC, and NbC, or (II) ZrC, BN, Mo_2C, TiC, TaC, NbC, VC, and Cr_3C.

19. The method according to claim 18, further comprising measuring an average coefficient of friction (COF) of the cemented carbide sample against INCONEL 718 over a sliding distance from 1 to 18 meters and from 14 to 18 meters; and

adjusting the amount of the Mo_2C in the grain growth inhibitor comprising either (I) Mo_2C, TiC, TaC, and NbC, or (II) ZrC, BN, Mo_2C, TiC, TaC, NbC, VC, and Cr_3C based on the measured average coefficient of friction (COF) of the cemented carbide sample against INCONEL 718 over a sliding distance from 1 to 18 meters and from 14 to 18 meters, to obtain the lowest possible coefficient of friction (COF) reflecting the most optimal galling resistance.

20. The method of claim 18, wherein the cemented carbide sample comprising Mo_2C in a range approximately between 0.40 wt.%-0.60 wt.% has the most optimal galling resistance.

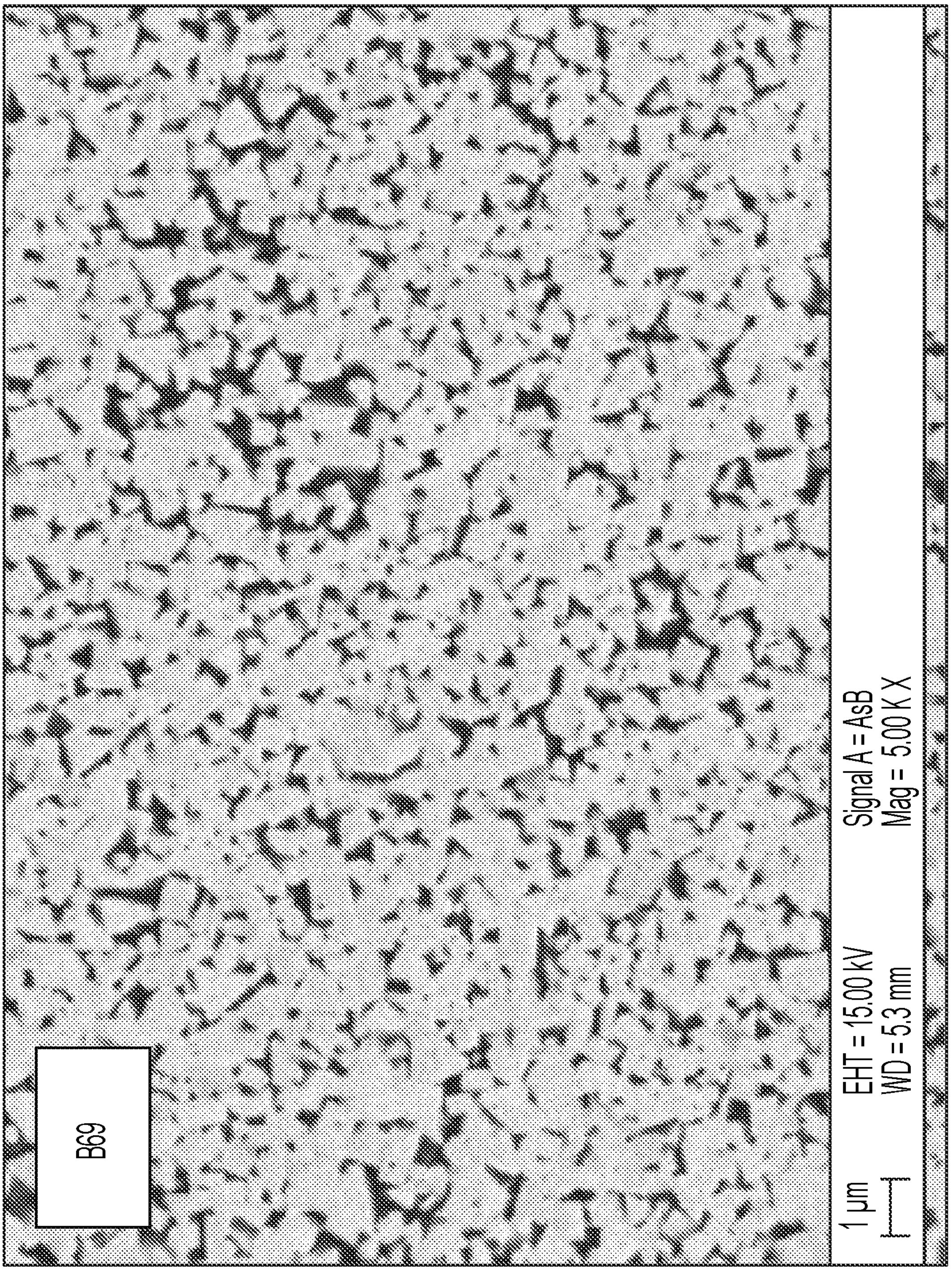


FIG. 1

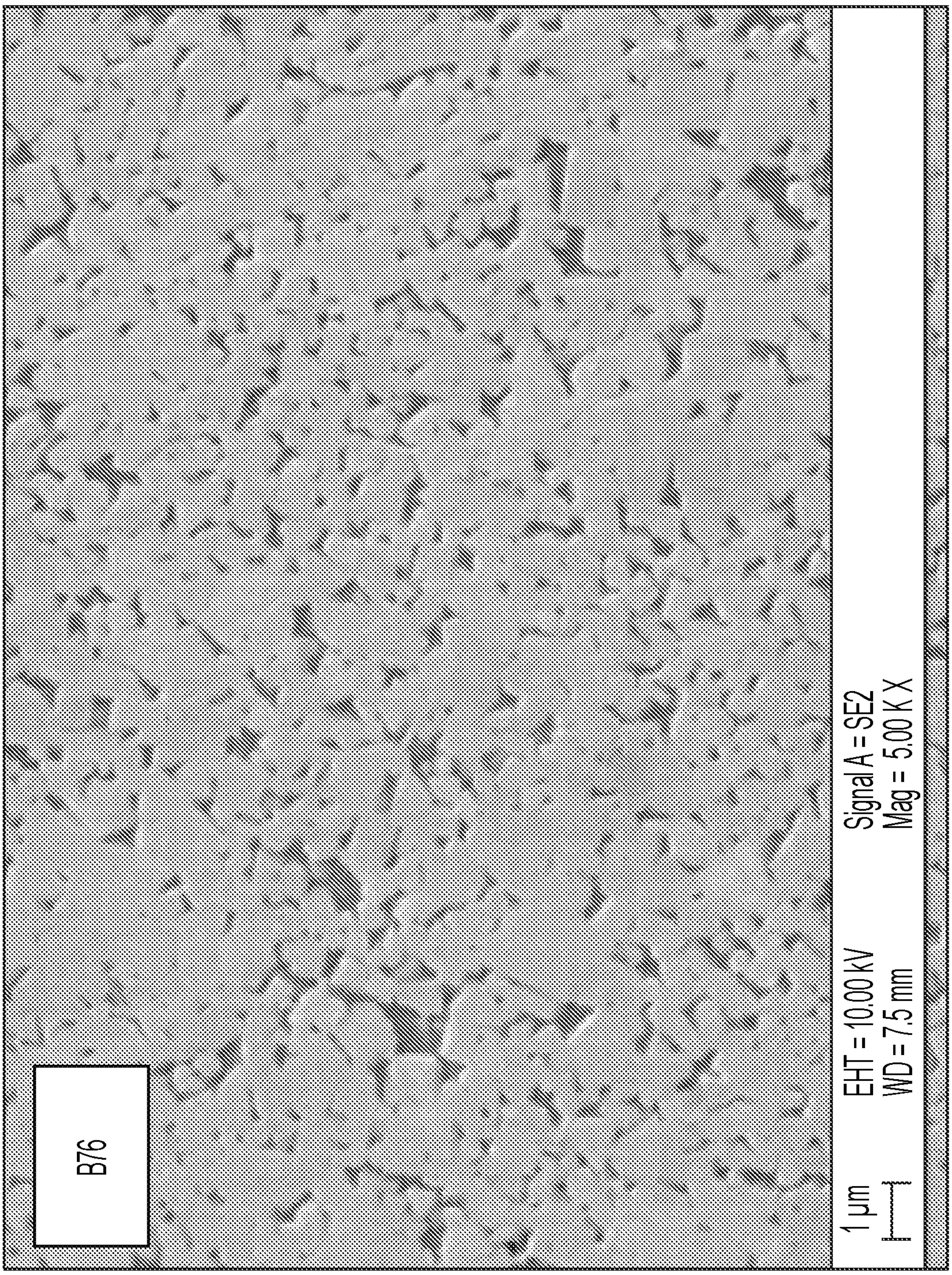


FIG. 2

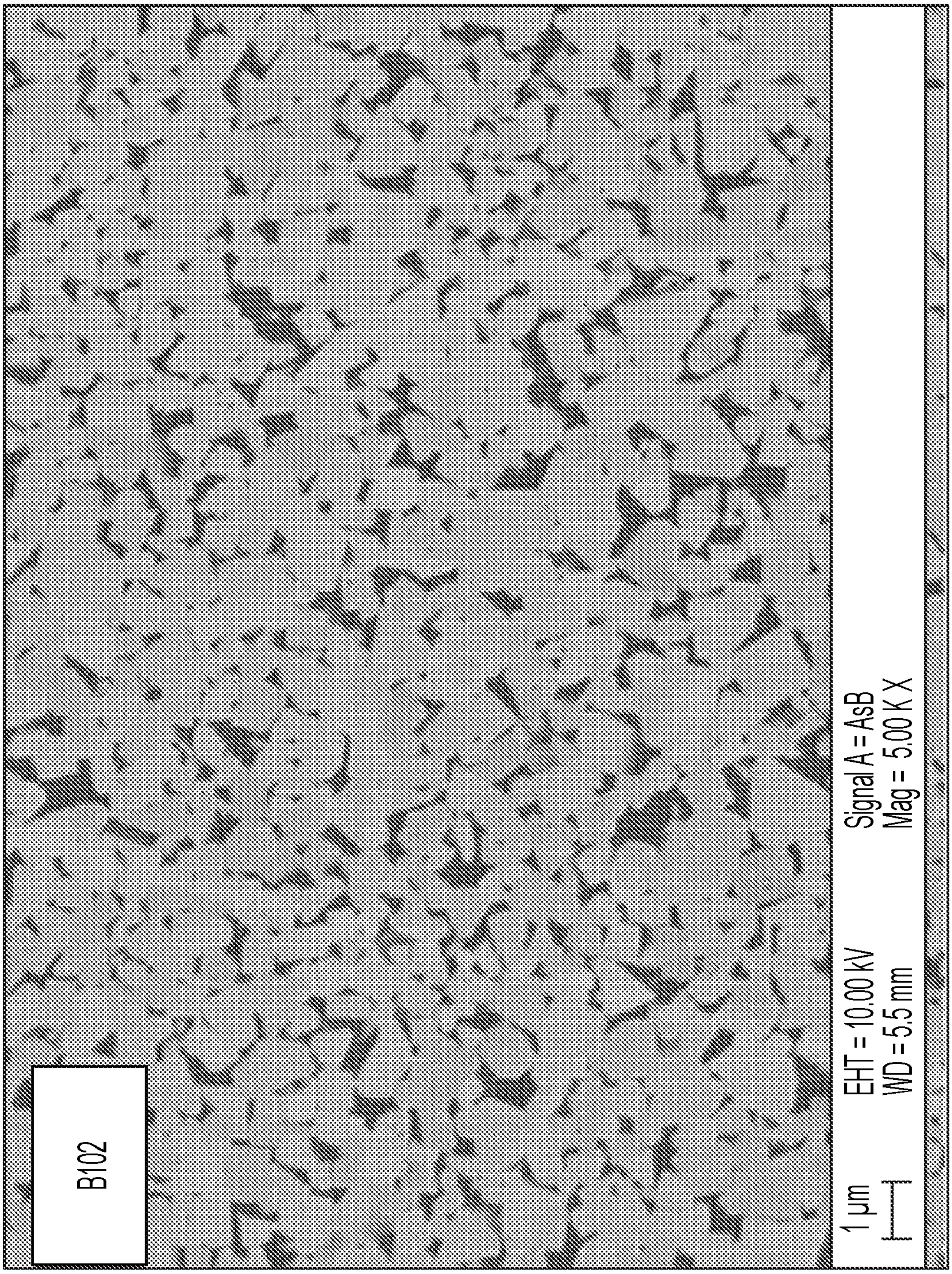


FIG. 3

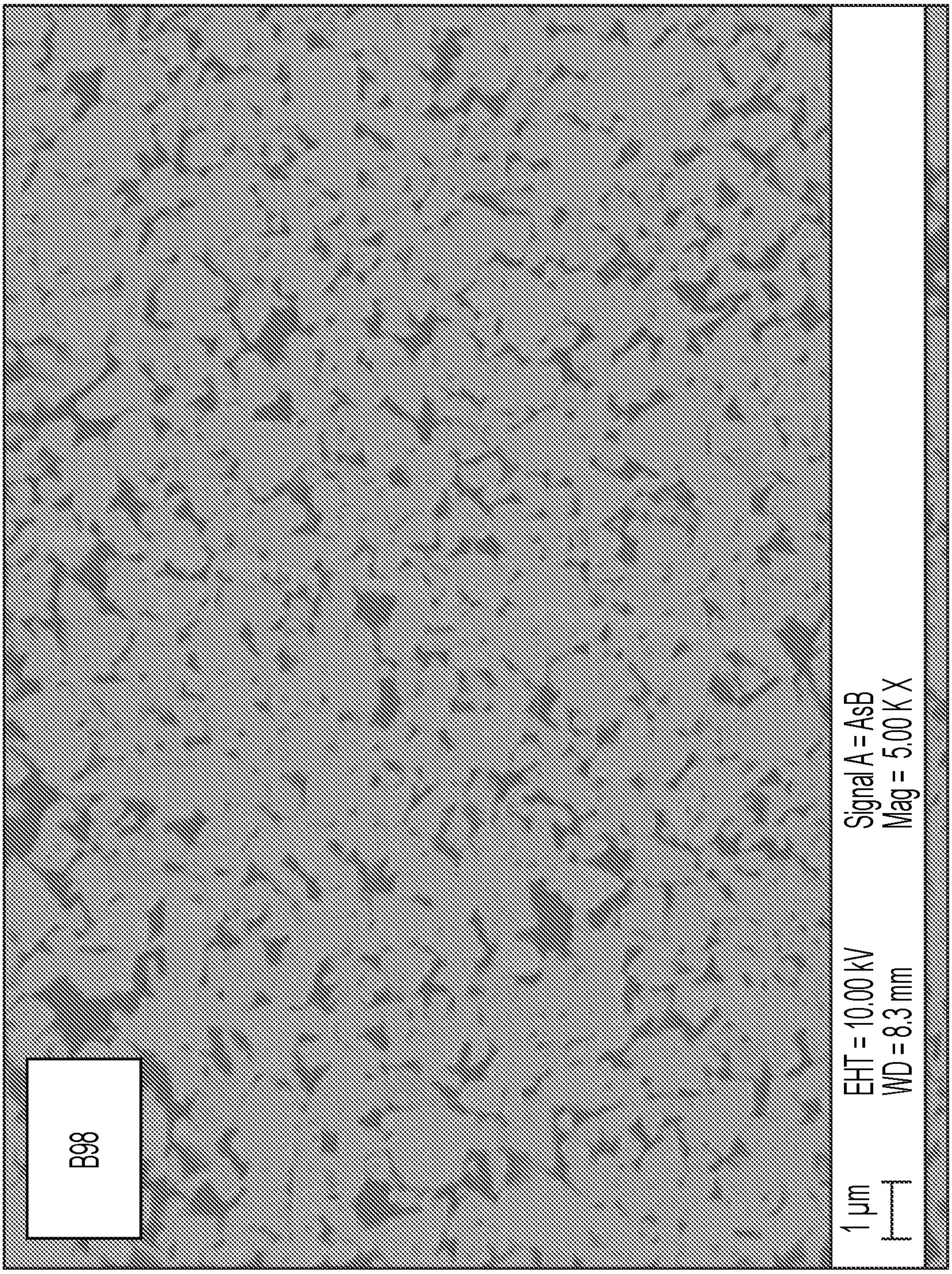


FIG. 4

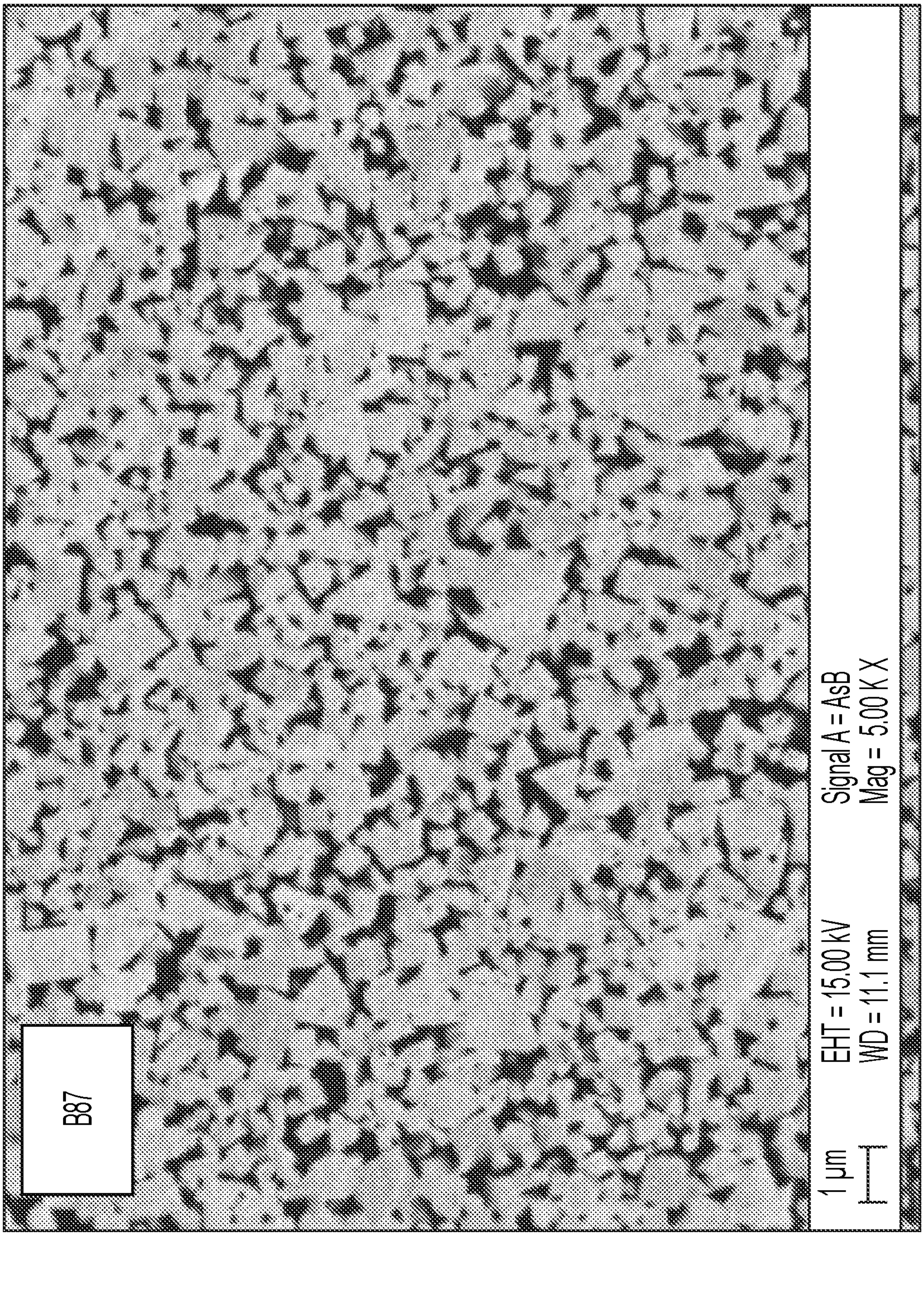


FIG. 5

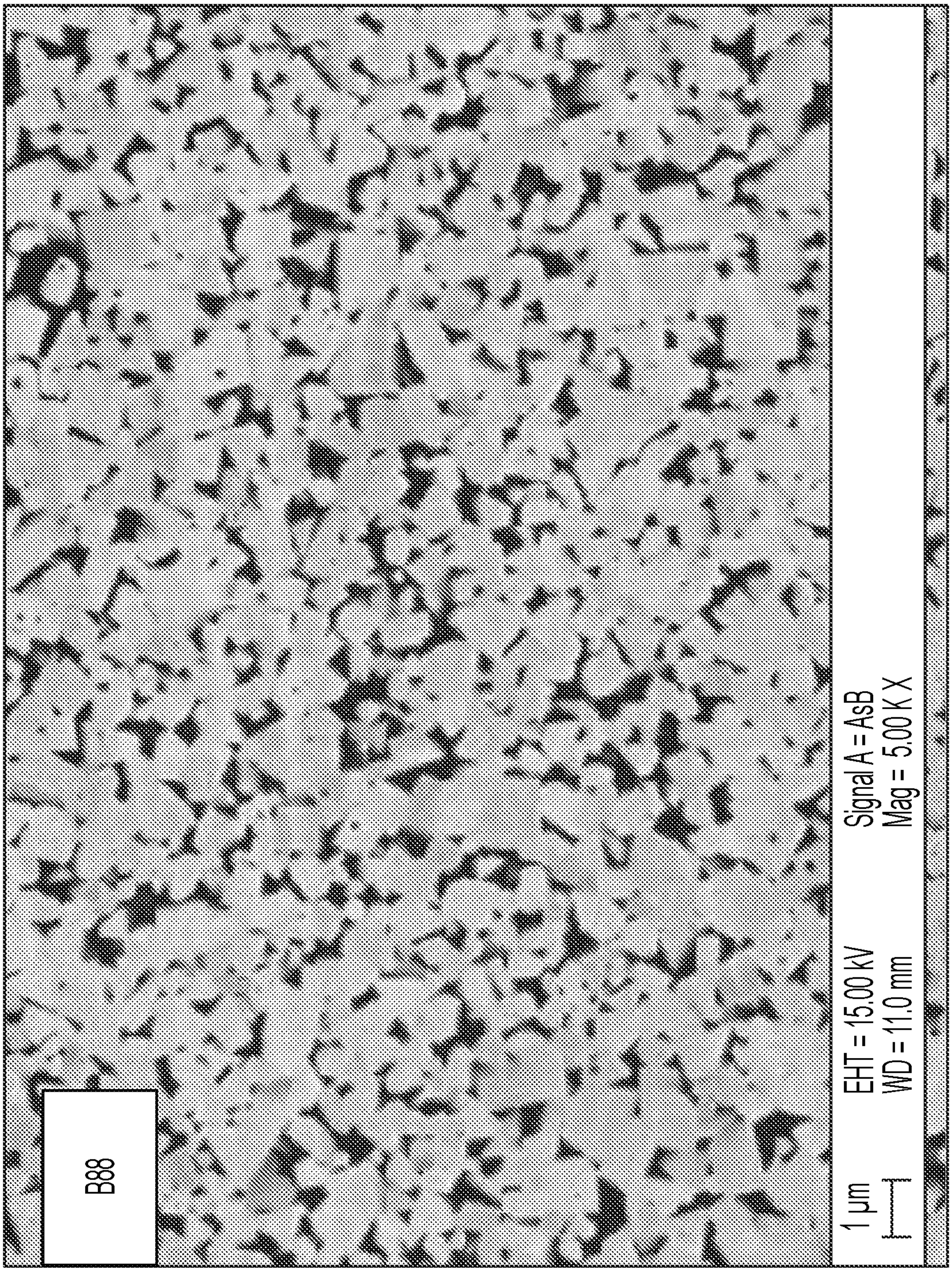


FIG. 6

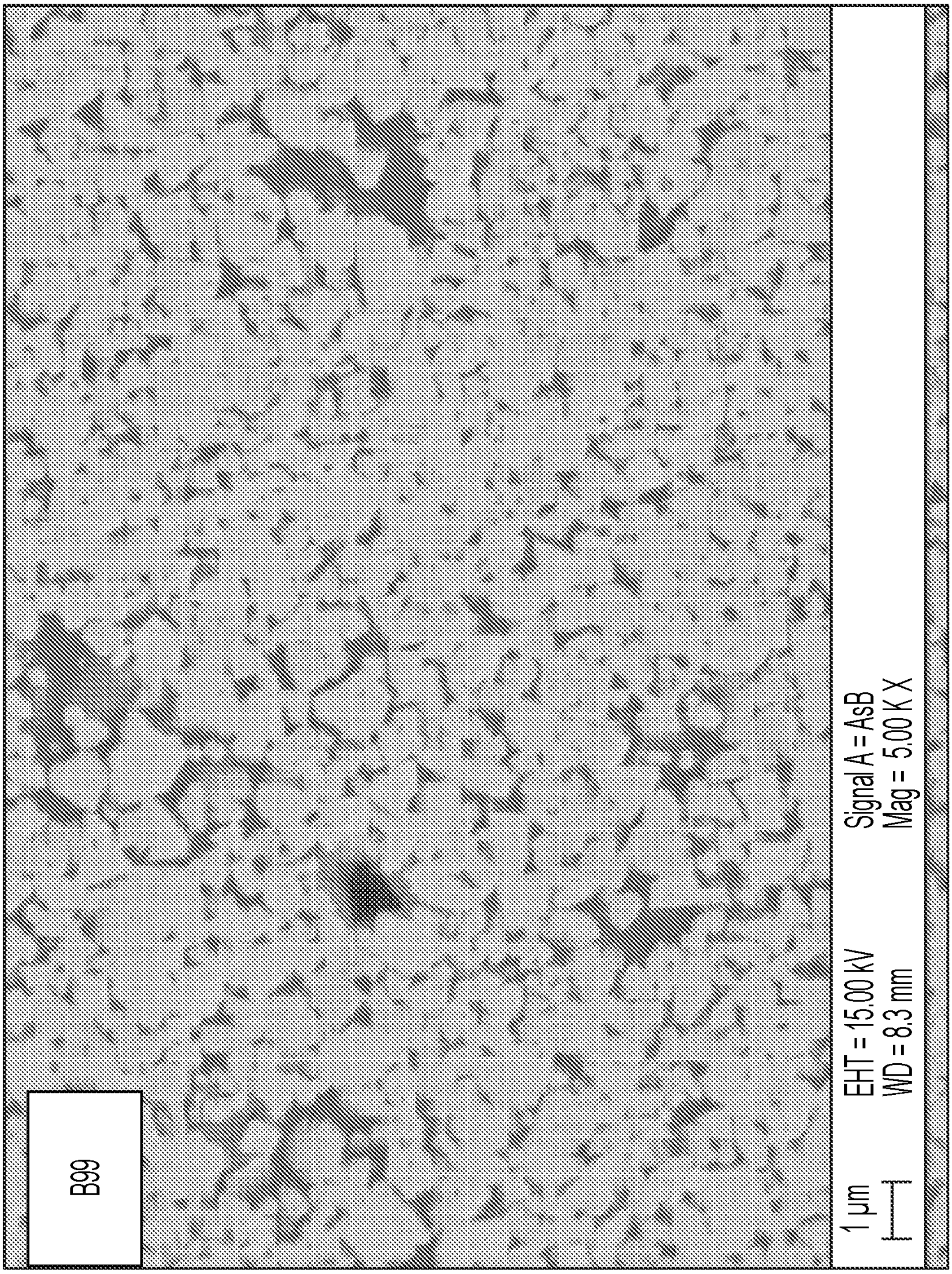


FIG. 7

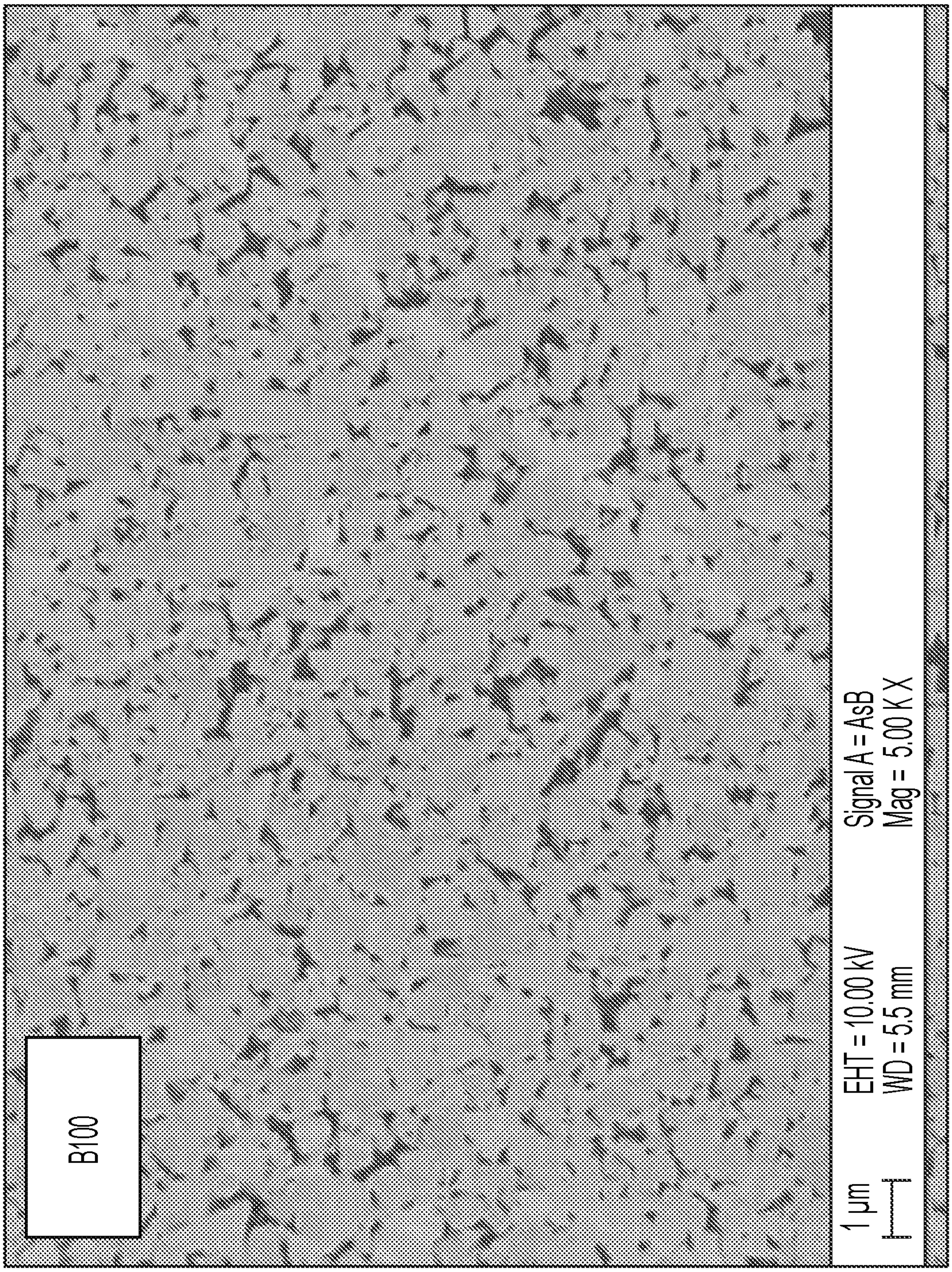


FIG. 8

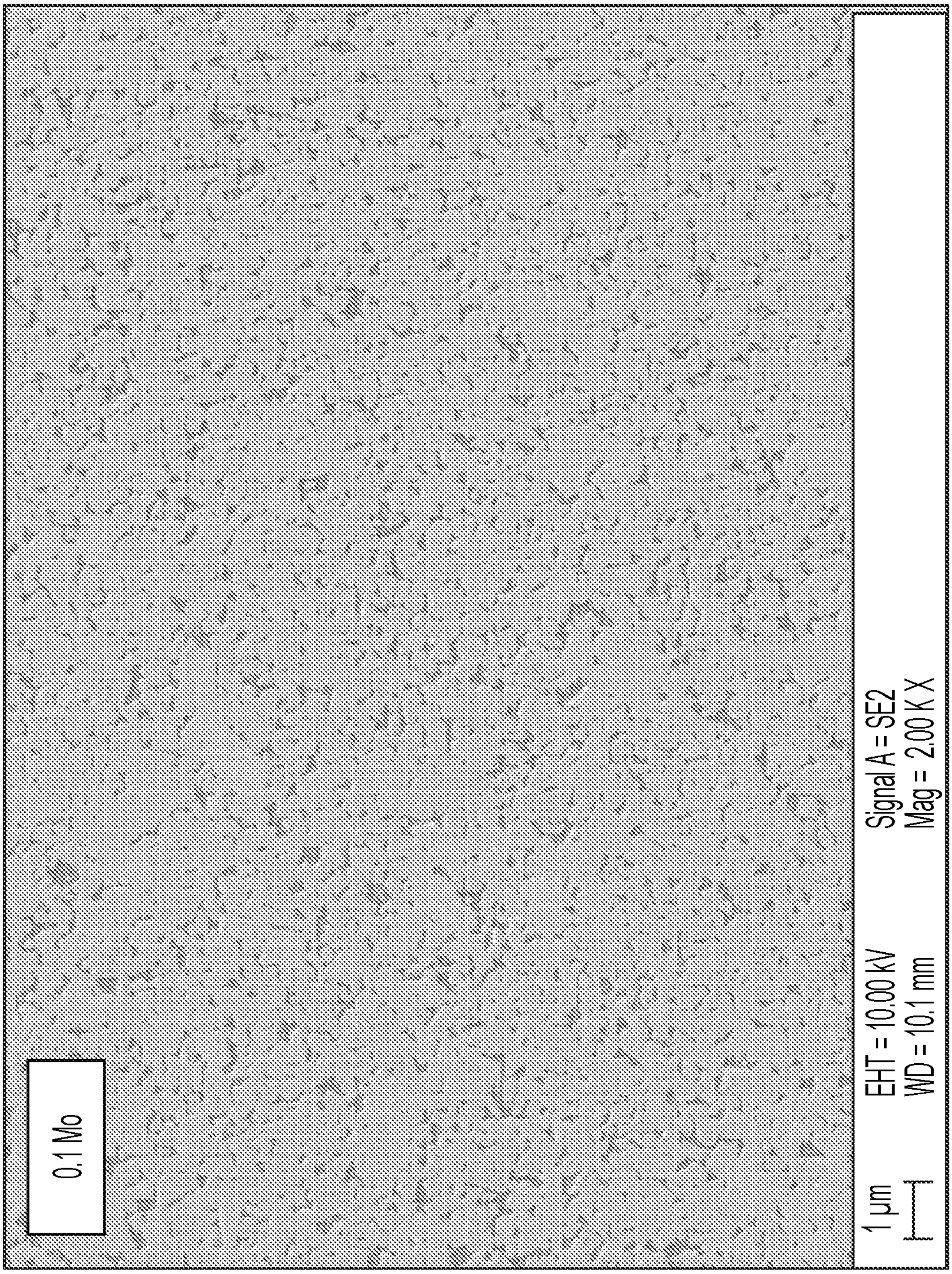


FIG. 9

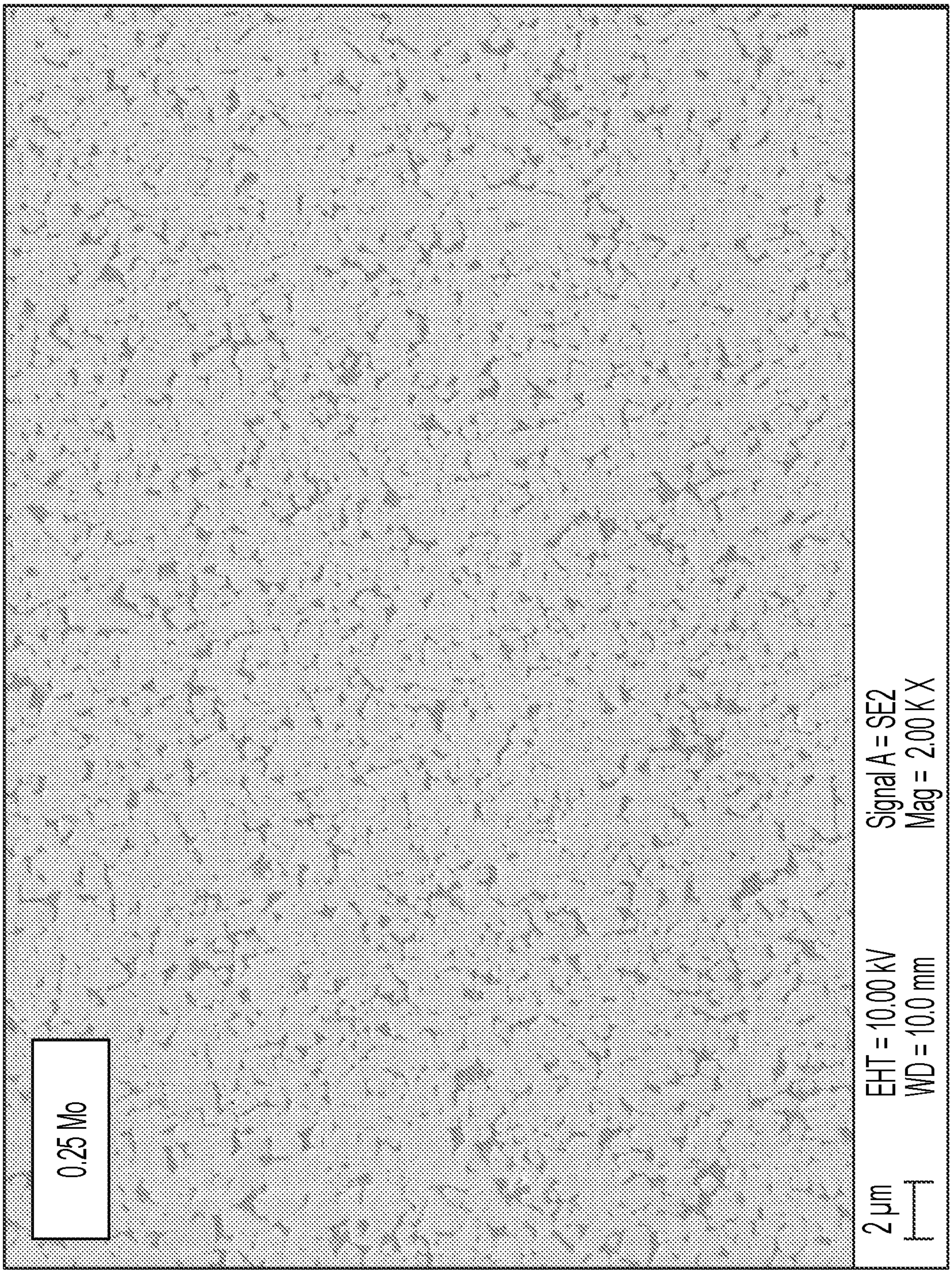


FIG. 10

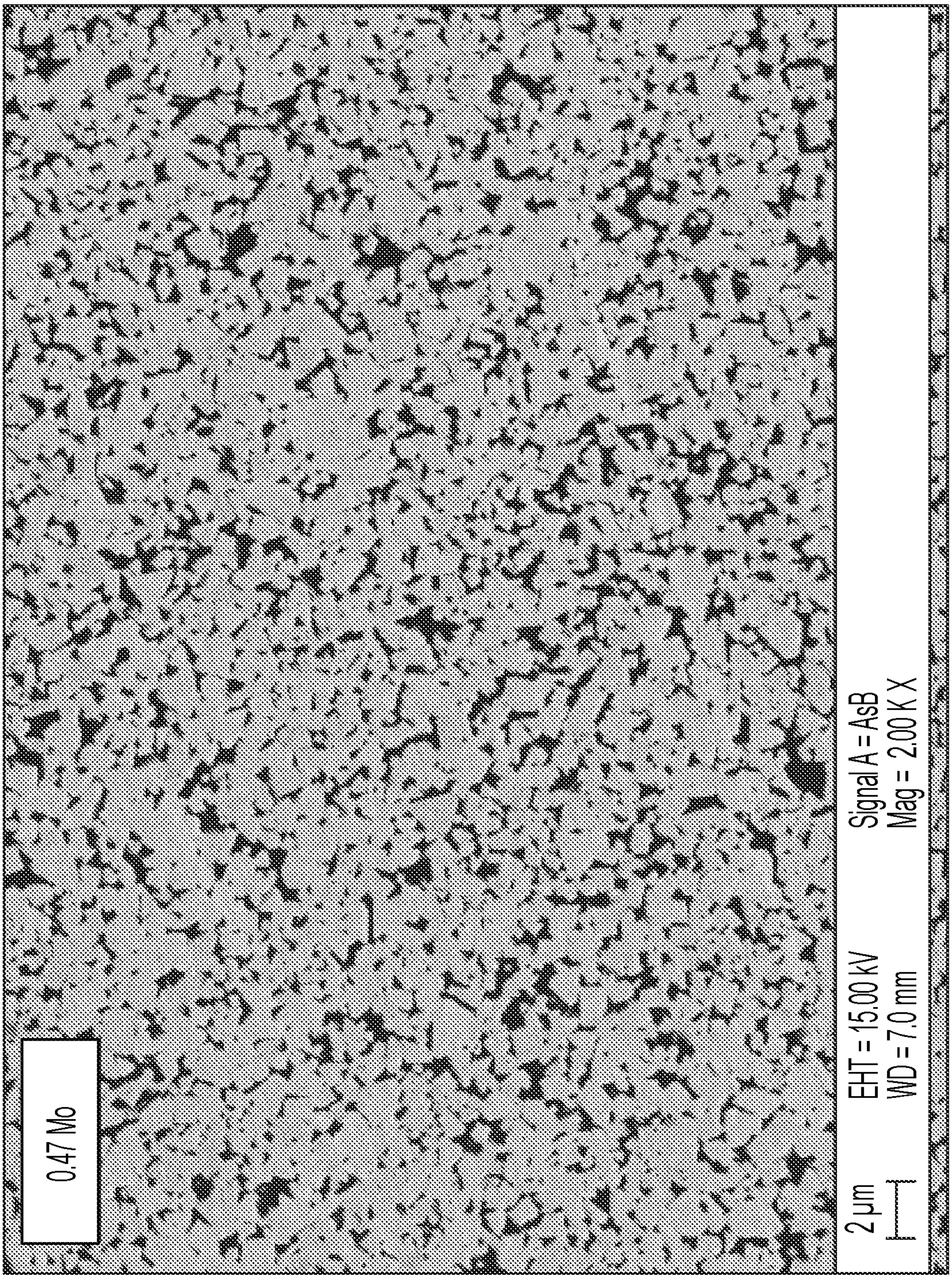


FIG. 11

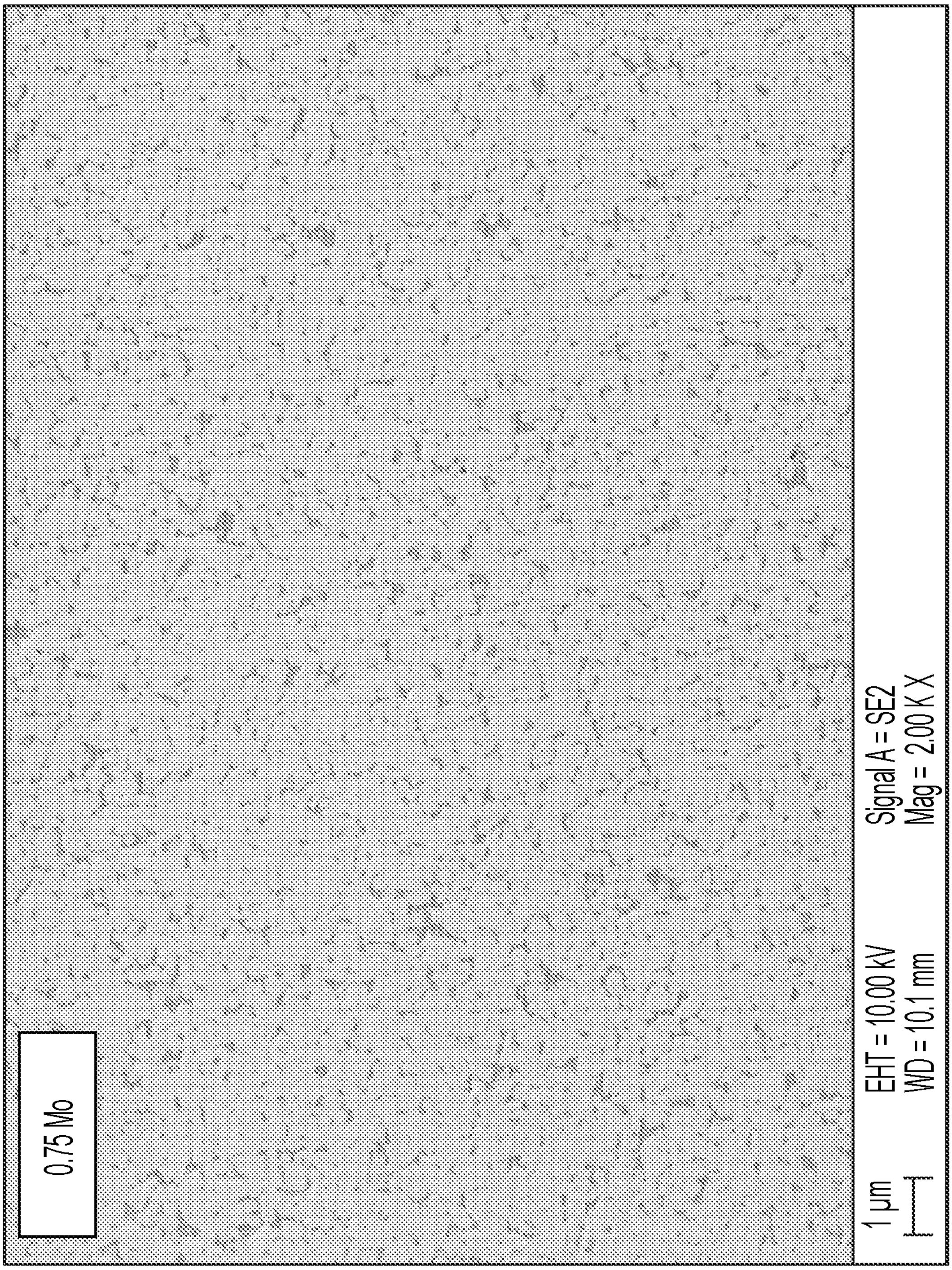


FIG. 12

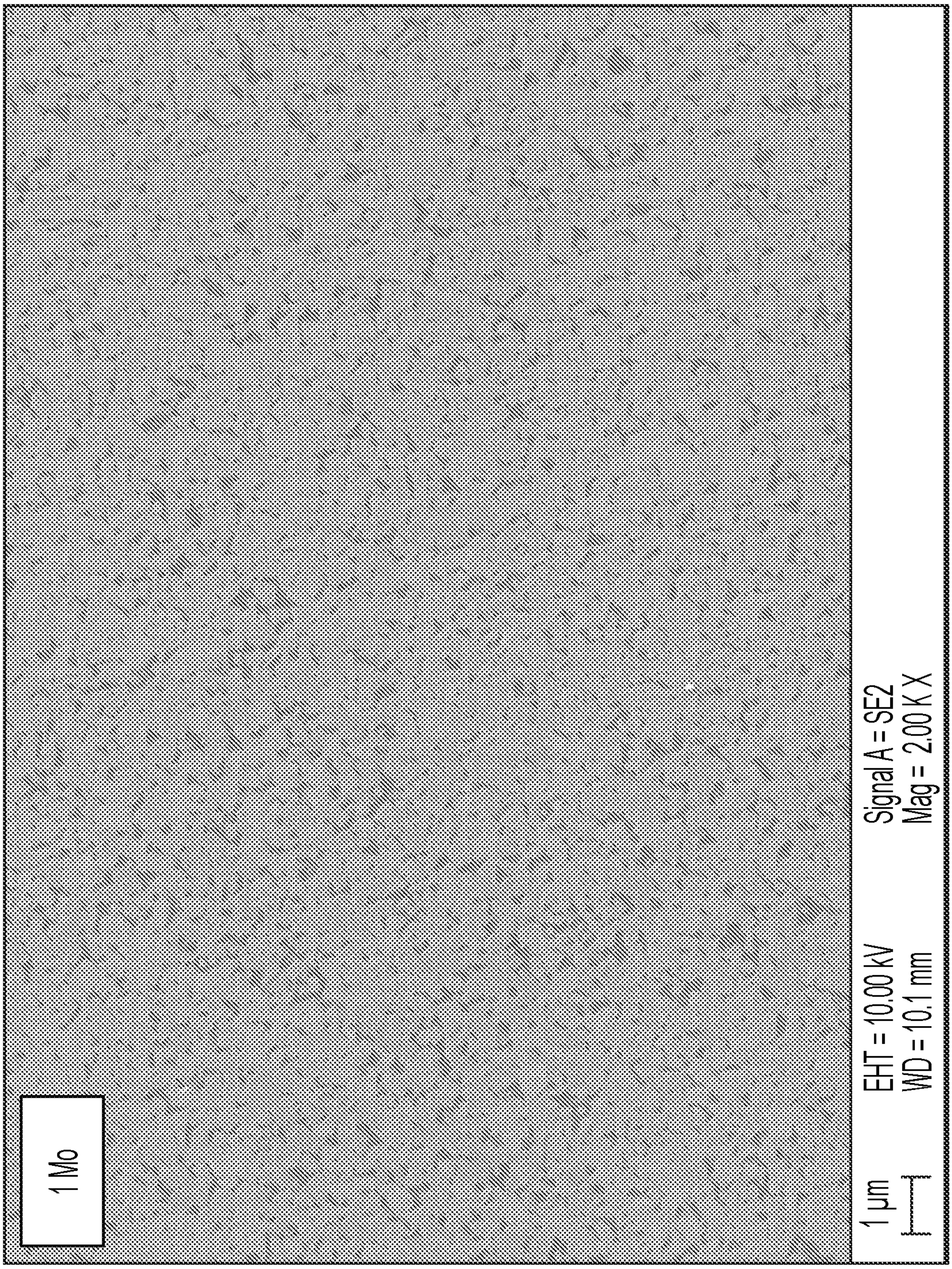


FIG. 13

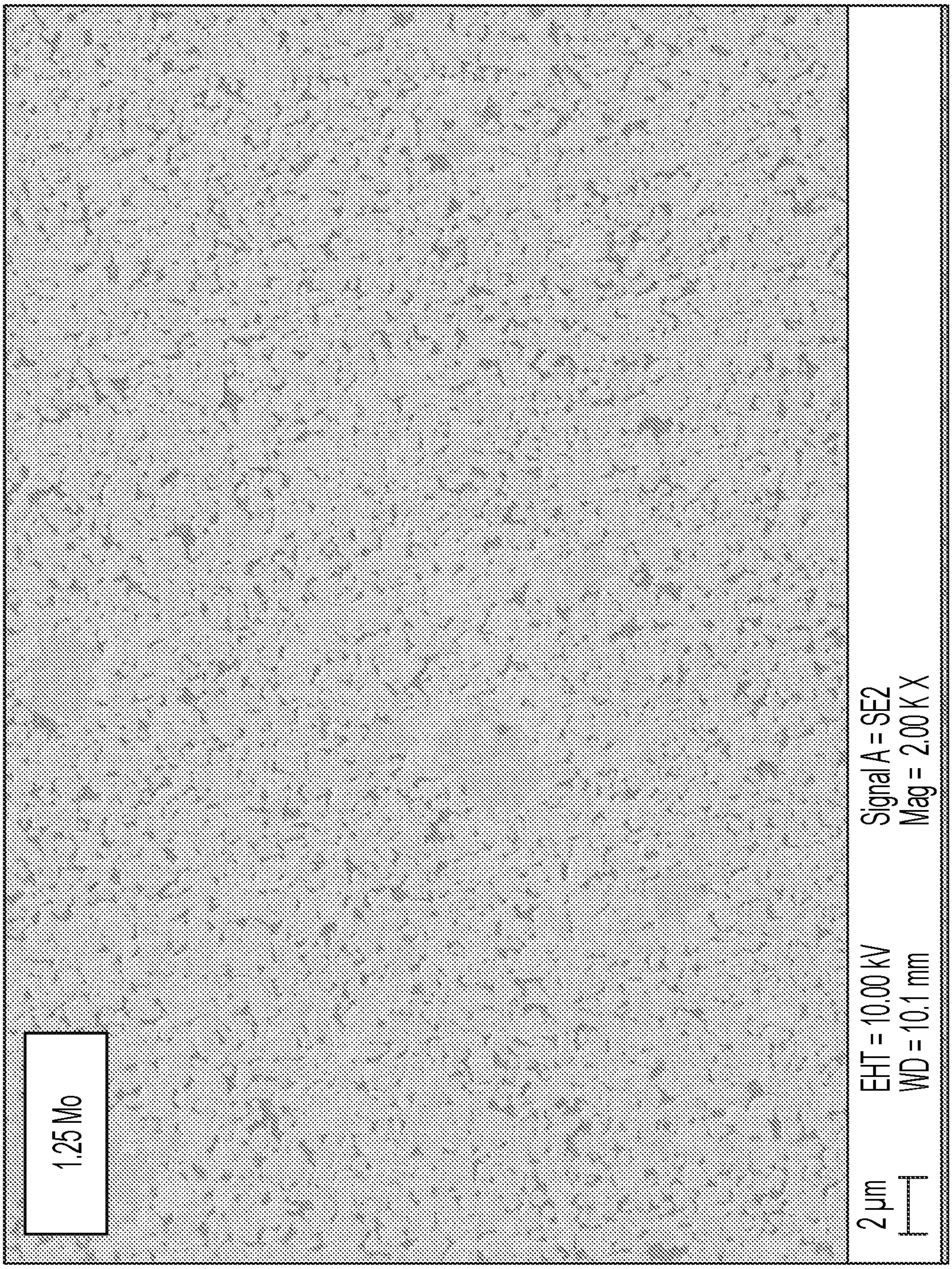


FIG. 14

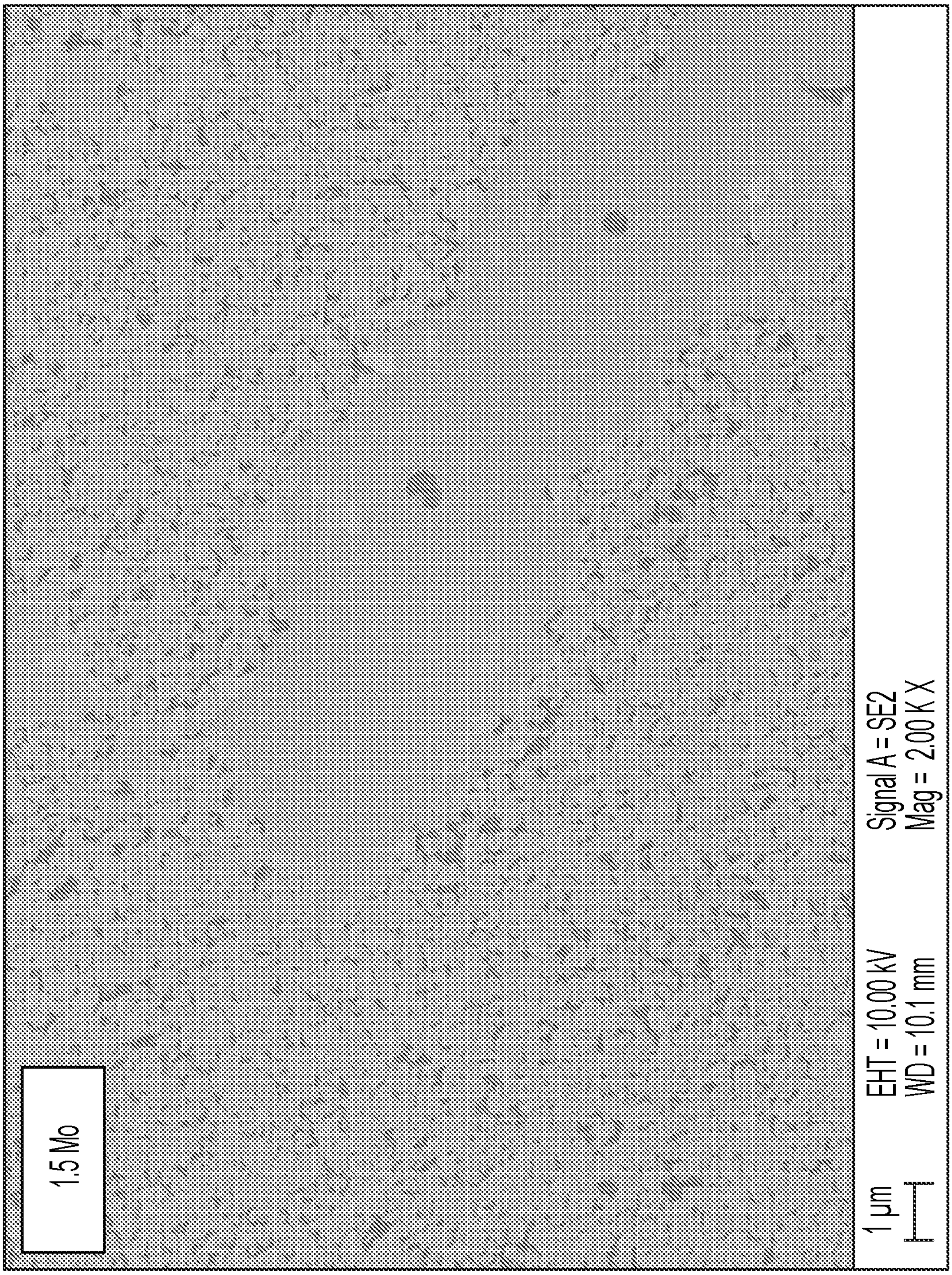


FIG. 15

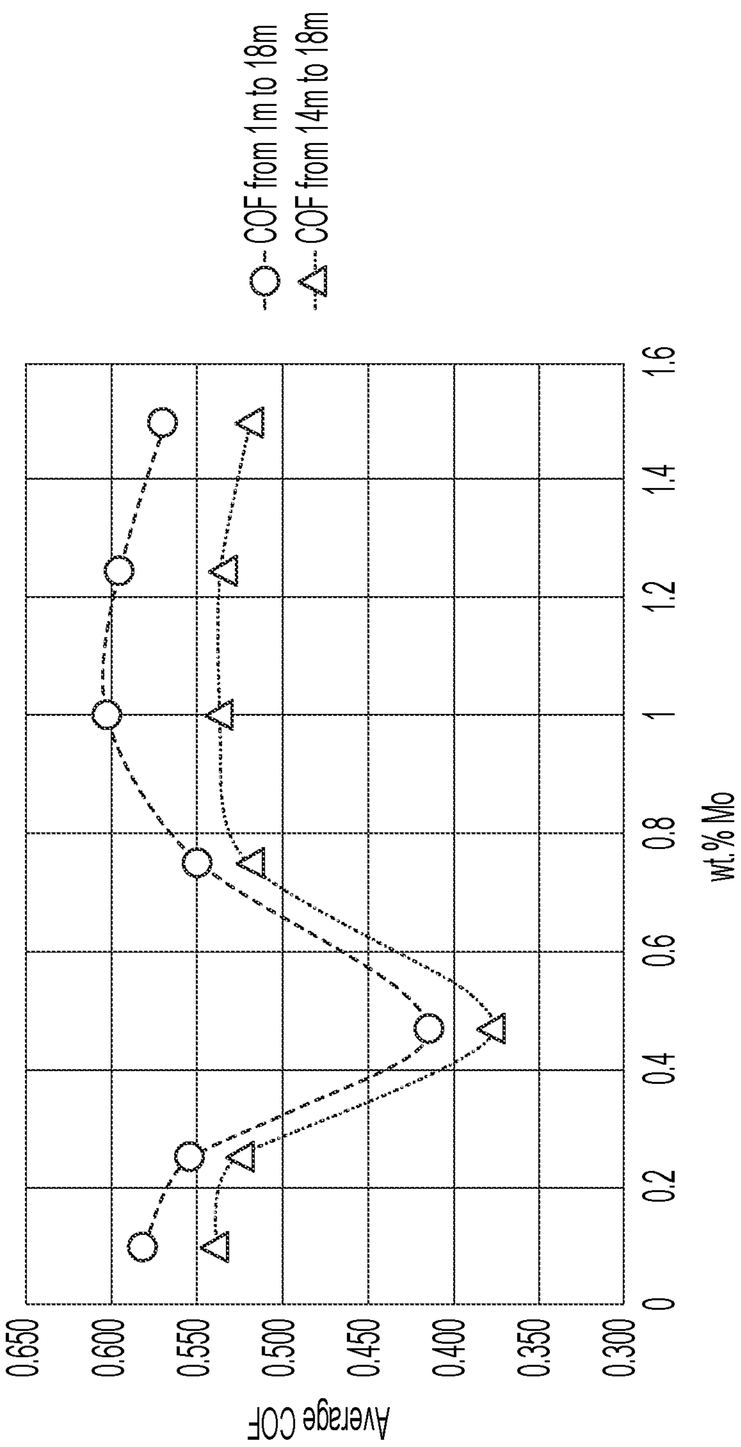

COF from 1m to 18m
COF from 14m to 18m
Average COF
0.650
0.600
0.550
0.500
0.450
0.400
0.350
0.300
wt.% Mo
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6

FIG. 16

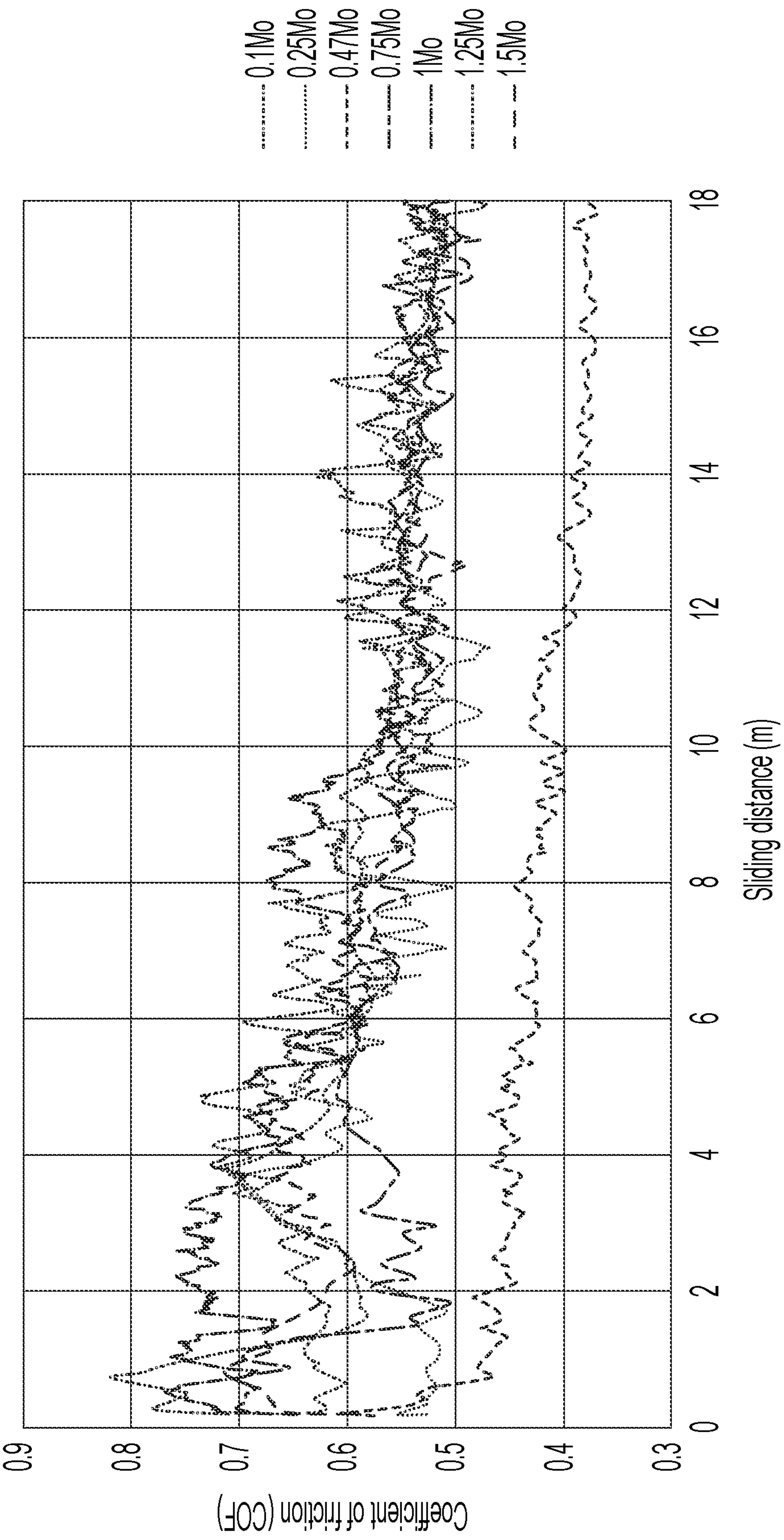
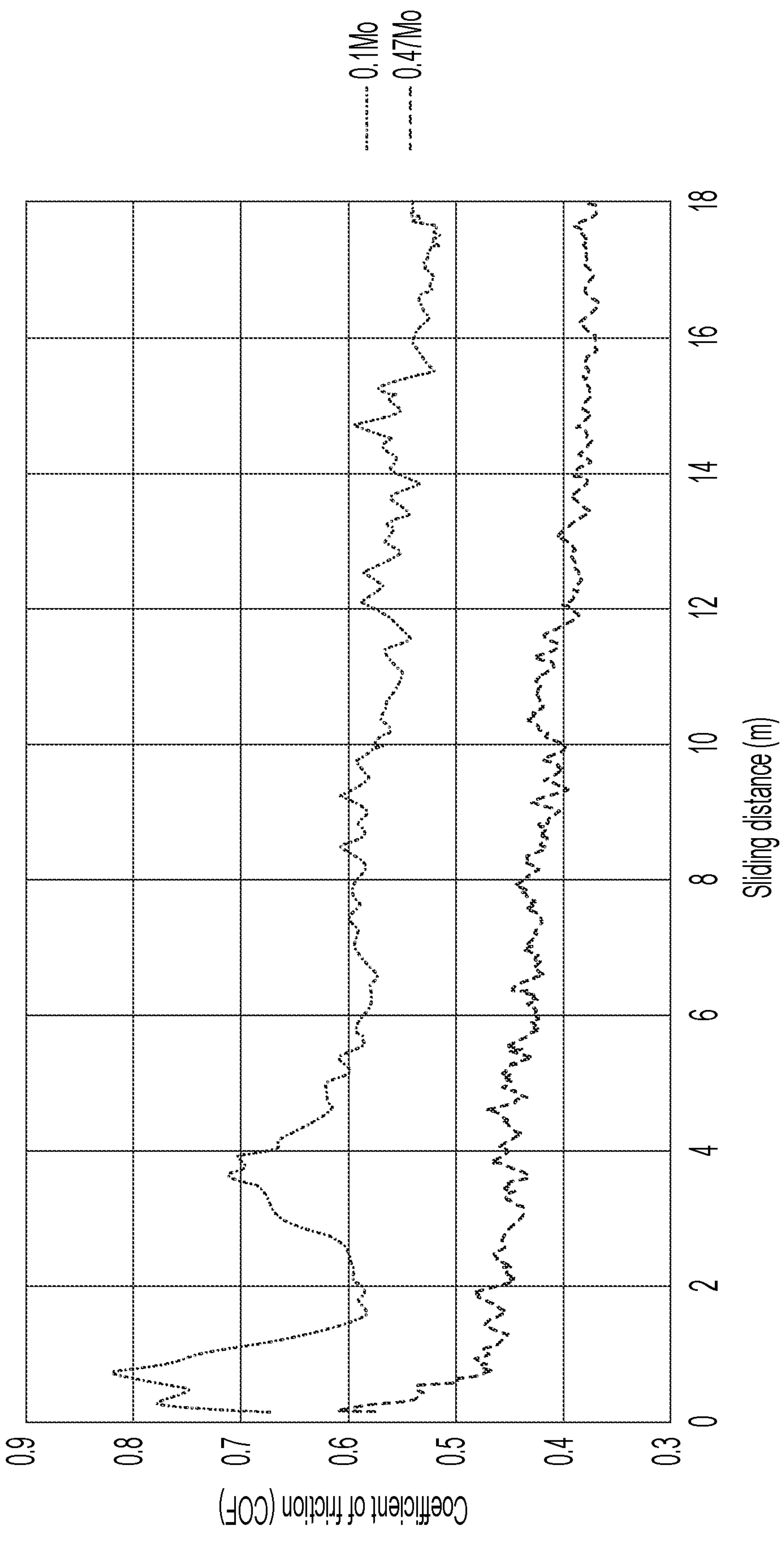

0.1Mo
0.25Mo
0.47Mo
0.75Mo
1Mo
1.25Mo
1.5Mo
Coefficient of friction (COF)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
Sliding distance (m)
0
2
4
6
8
10
12
14
16
18

FIG. 17



0.1Mo
0.47Mo
Coefficient of friction (COF)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0
2
4
6
8
10
12
14
16
18
Sliding distance (m)

FIG. 18

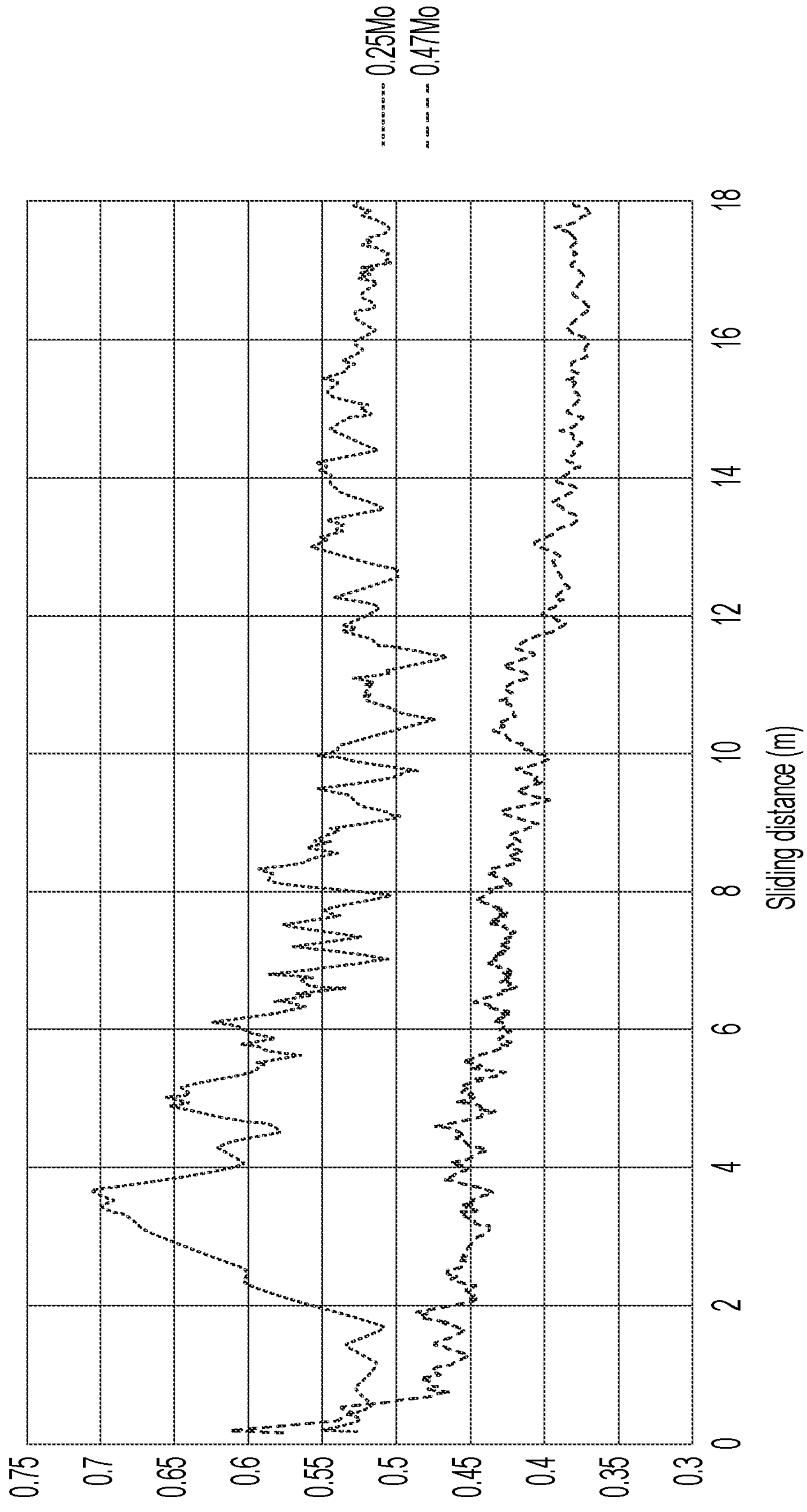

0.25Mo
0.47Mo
Coefficient of friction (COF)
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0
2
4
6
8
10
12
14
16
18
Sliding distance (m)

FIG. 19

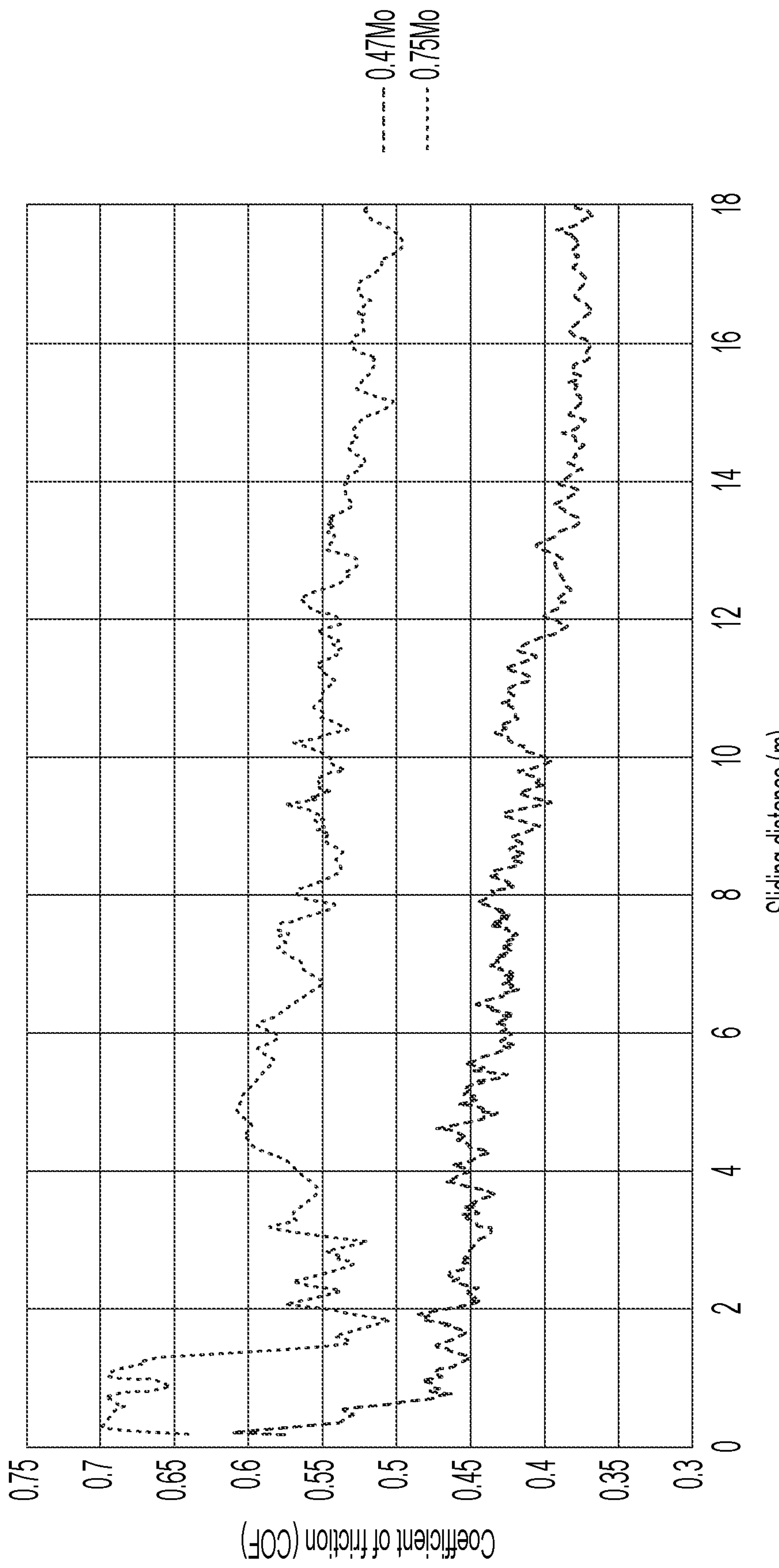

0.47Mo
0.75Mo
Coefficient of friction (COF)
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0
2
4
6
8
10
12
14
16
18
Sliding distance (m)

FIG. 20

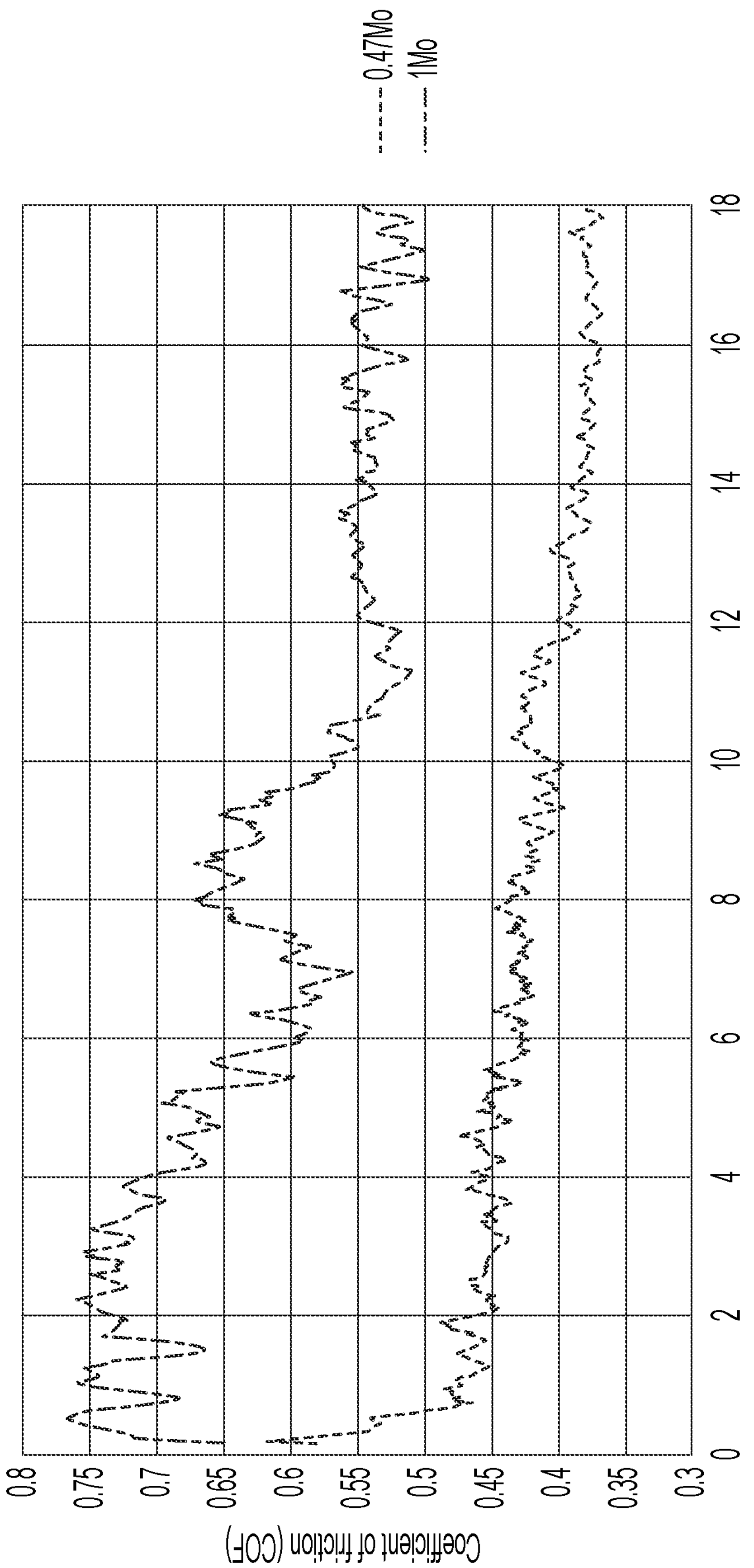

0.47Mo
1Mo
Coefficient of friction (COF)
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0
2
4
6
8
10
12
14
16
18
Sliding distance (m)

FIG. 21

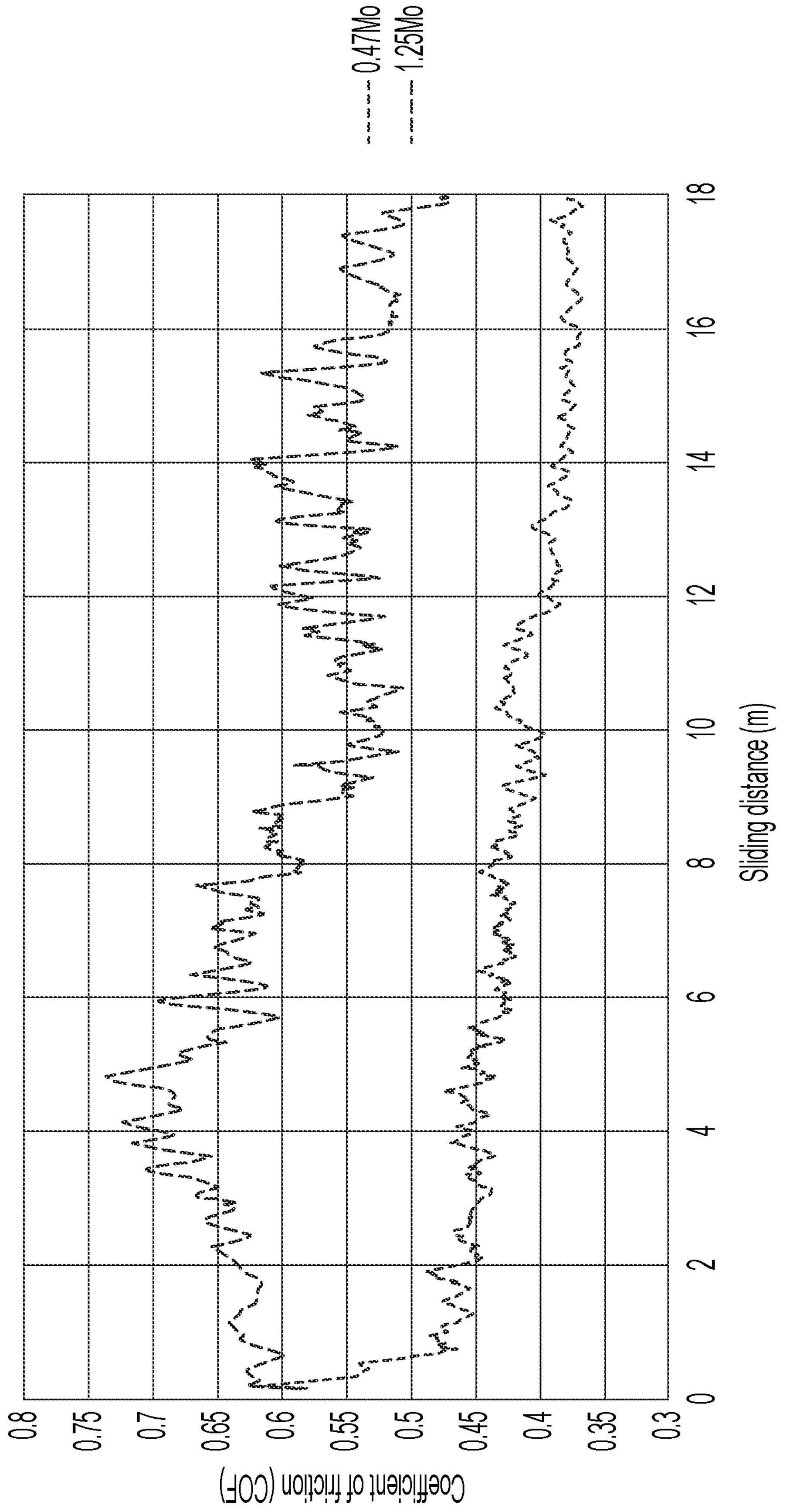

0.47Mo
1.25Mo
Coefficient of friction (COF)
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0
2
4
6
8
10
12
14
16
18
Sliding distance (m)

FIG. 22

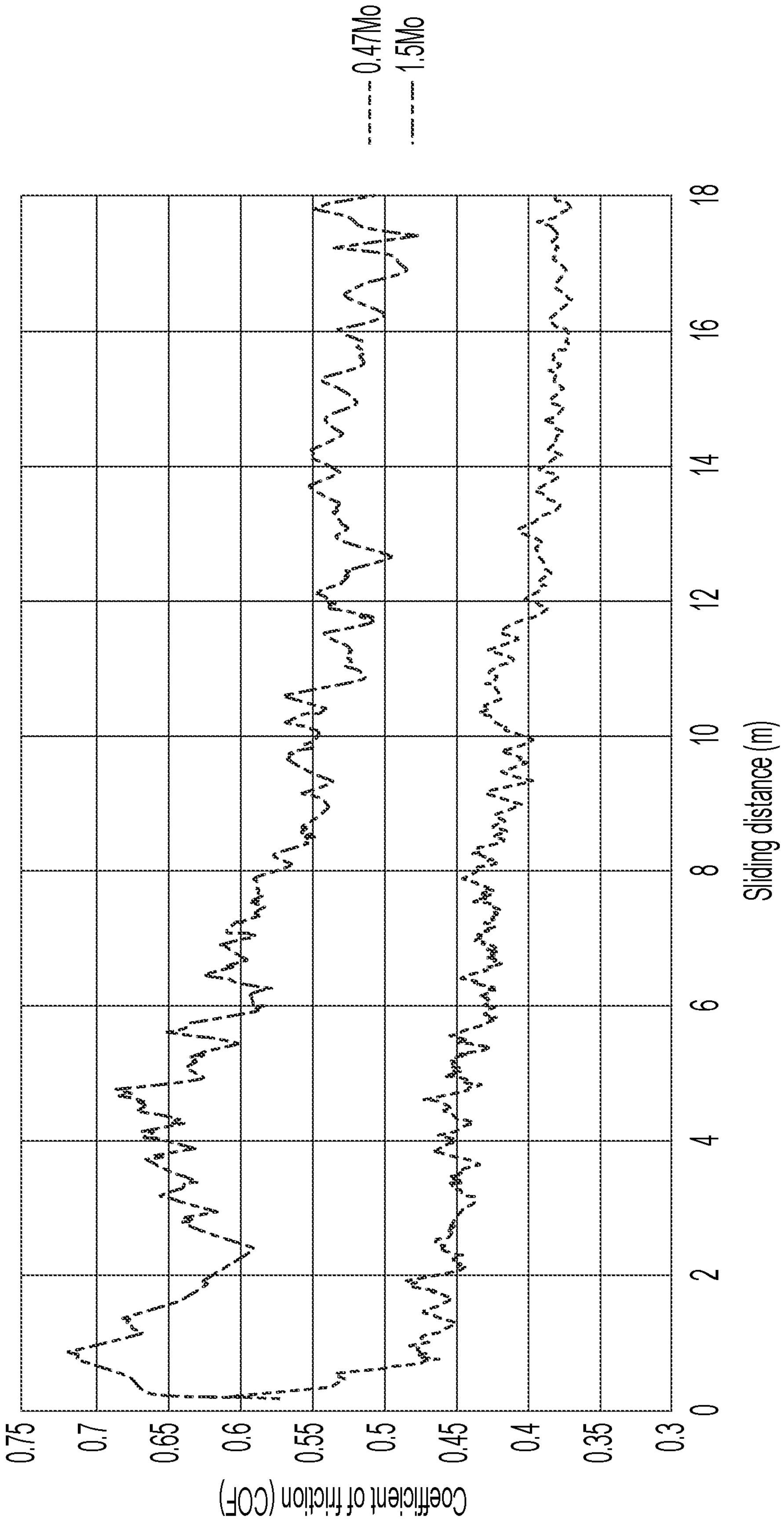

0.47Mo
1.5Mo
Coefficient of friction (COF)
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0
2
4
6
8
10
12
14
16
18
Sliding distance (m)

FIG. 23

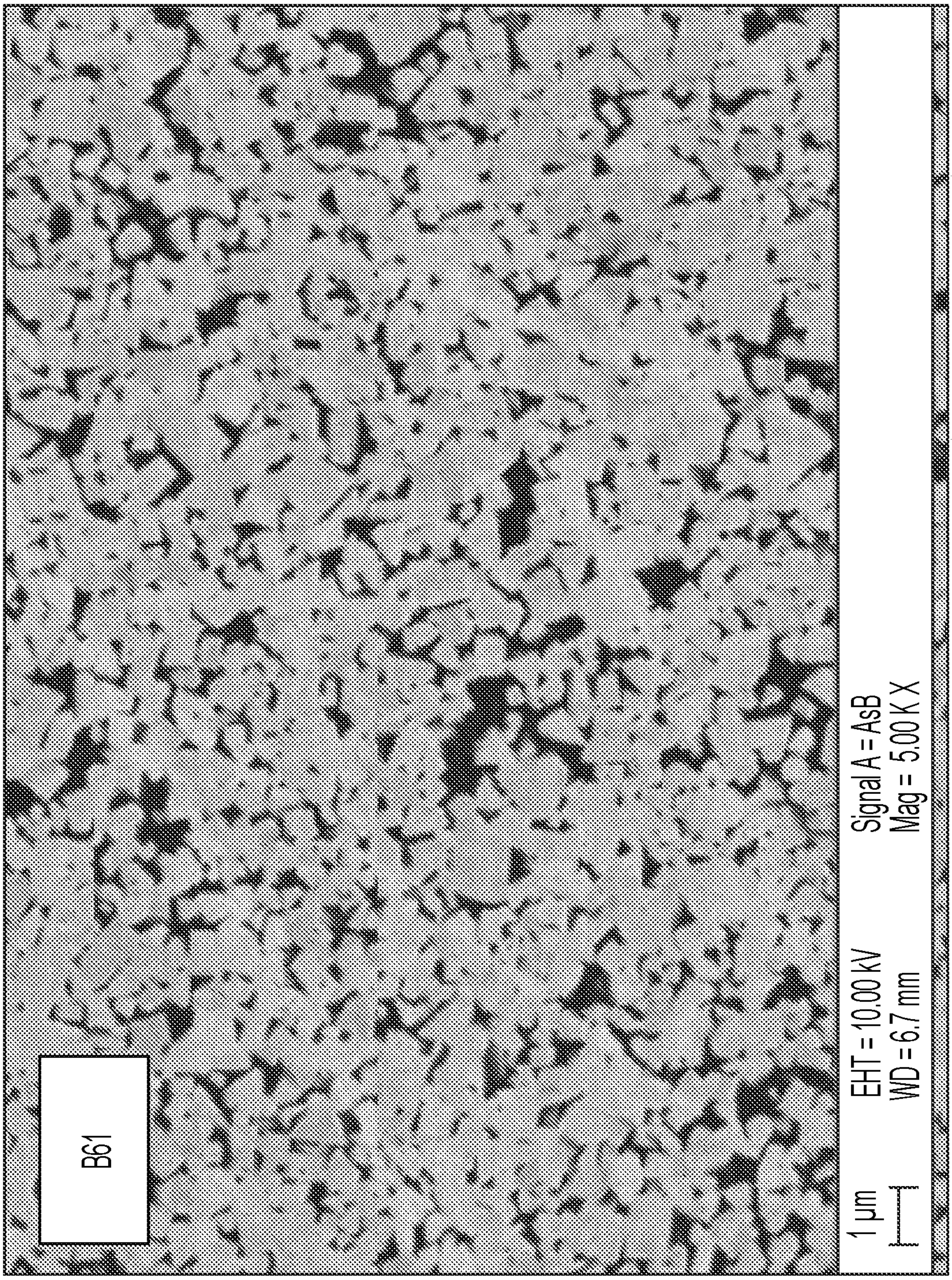


FIG. 24

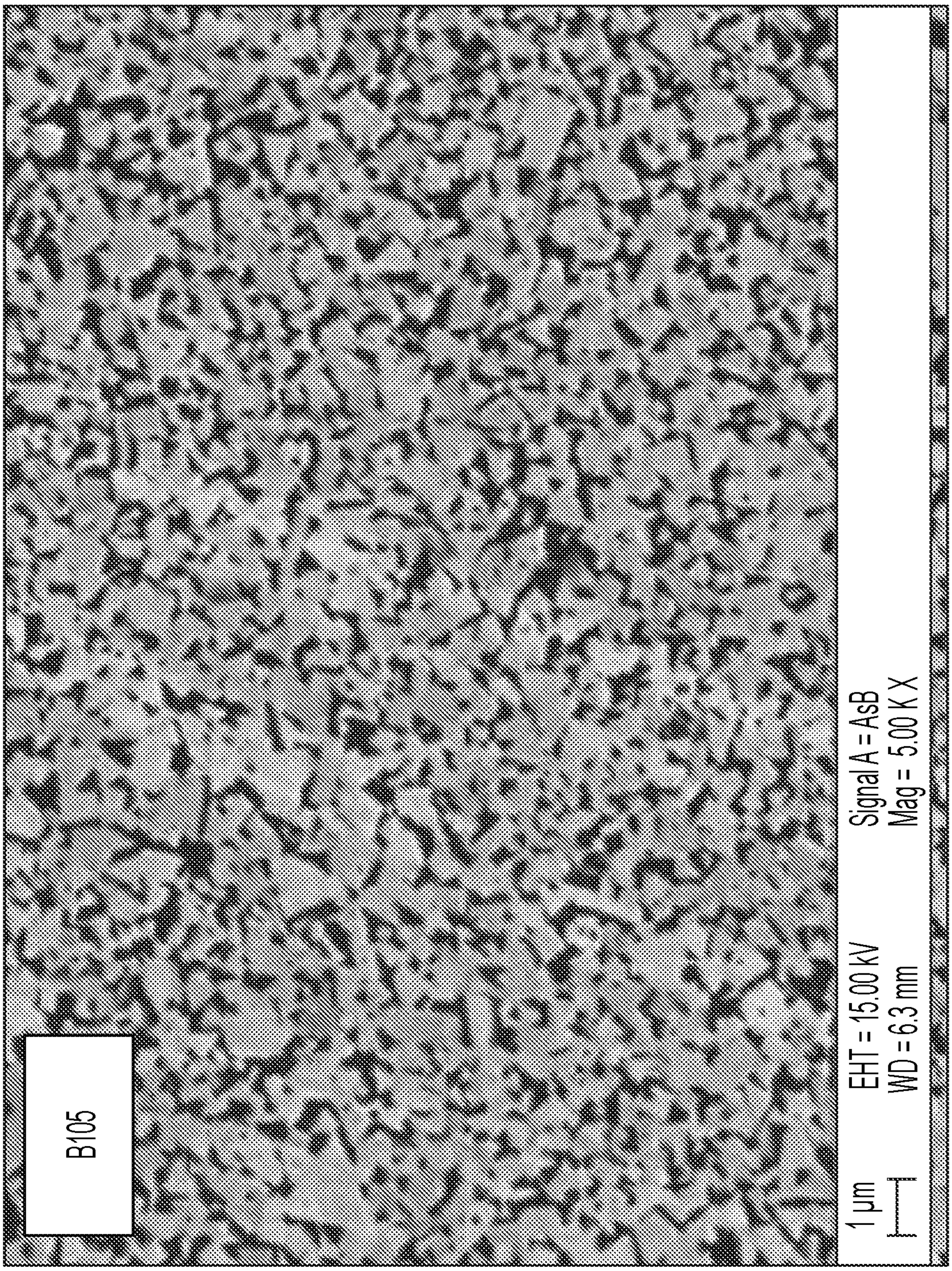


FIG. 25

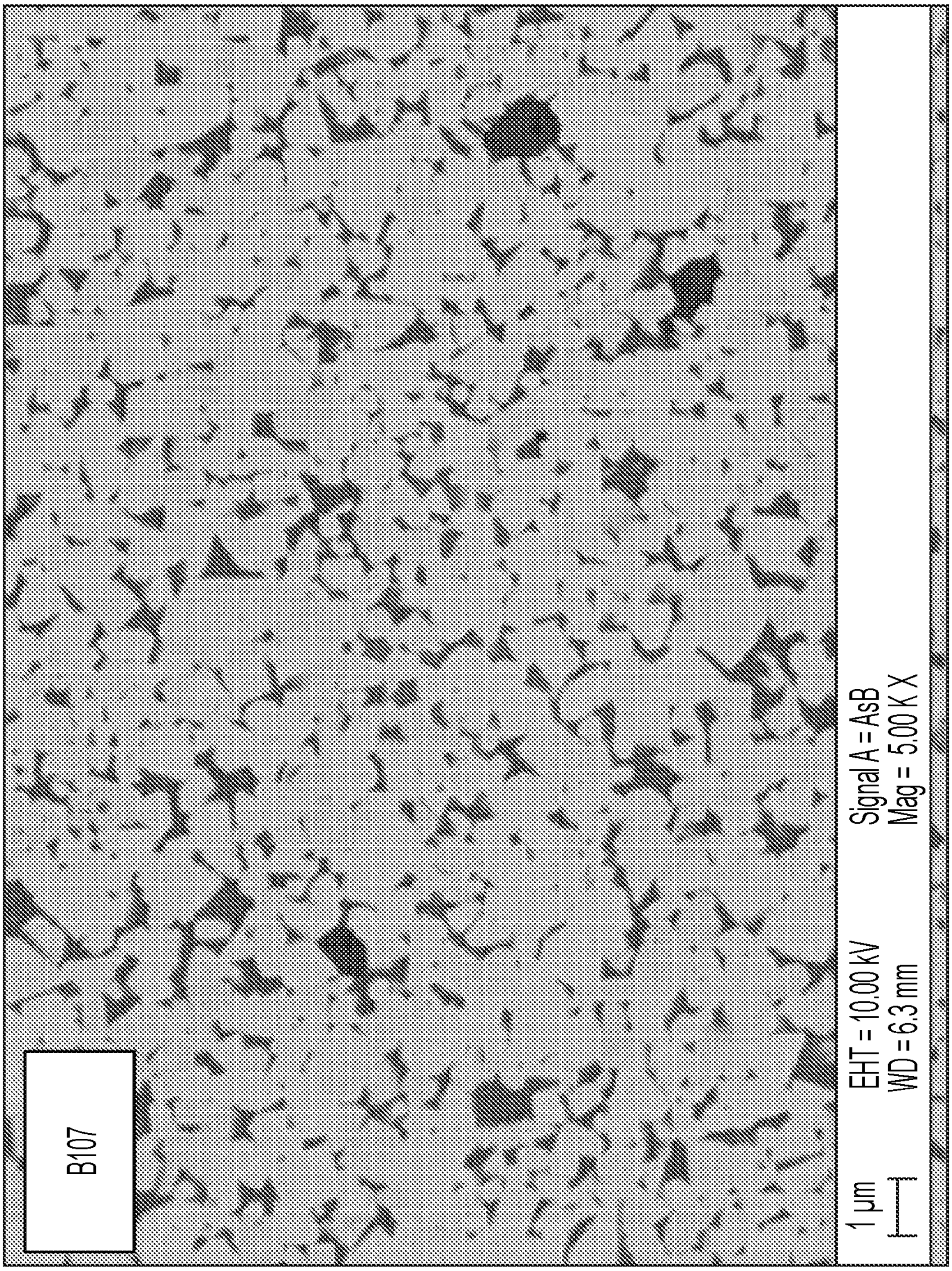


FIG. 26

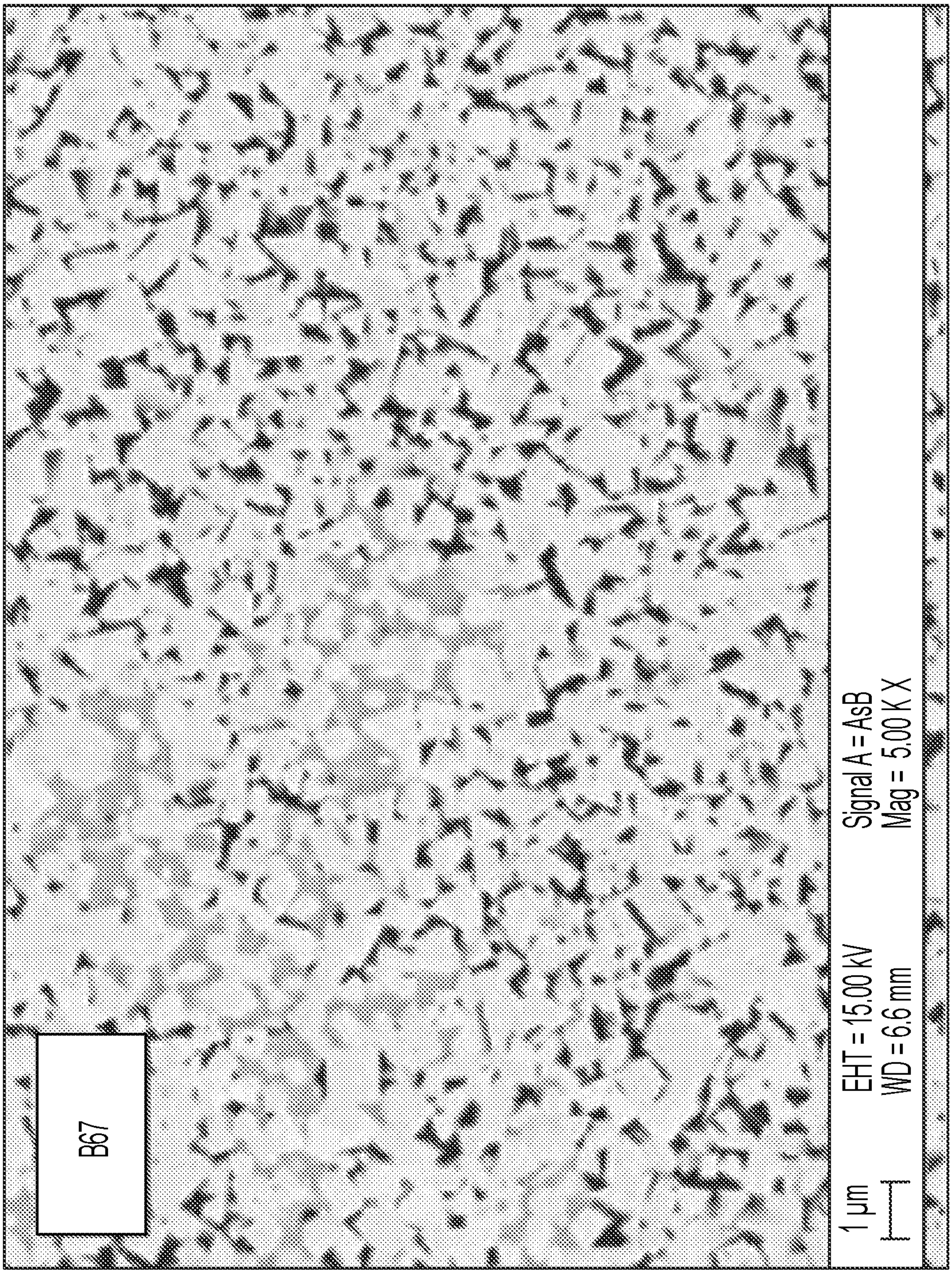


FIG. 27

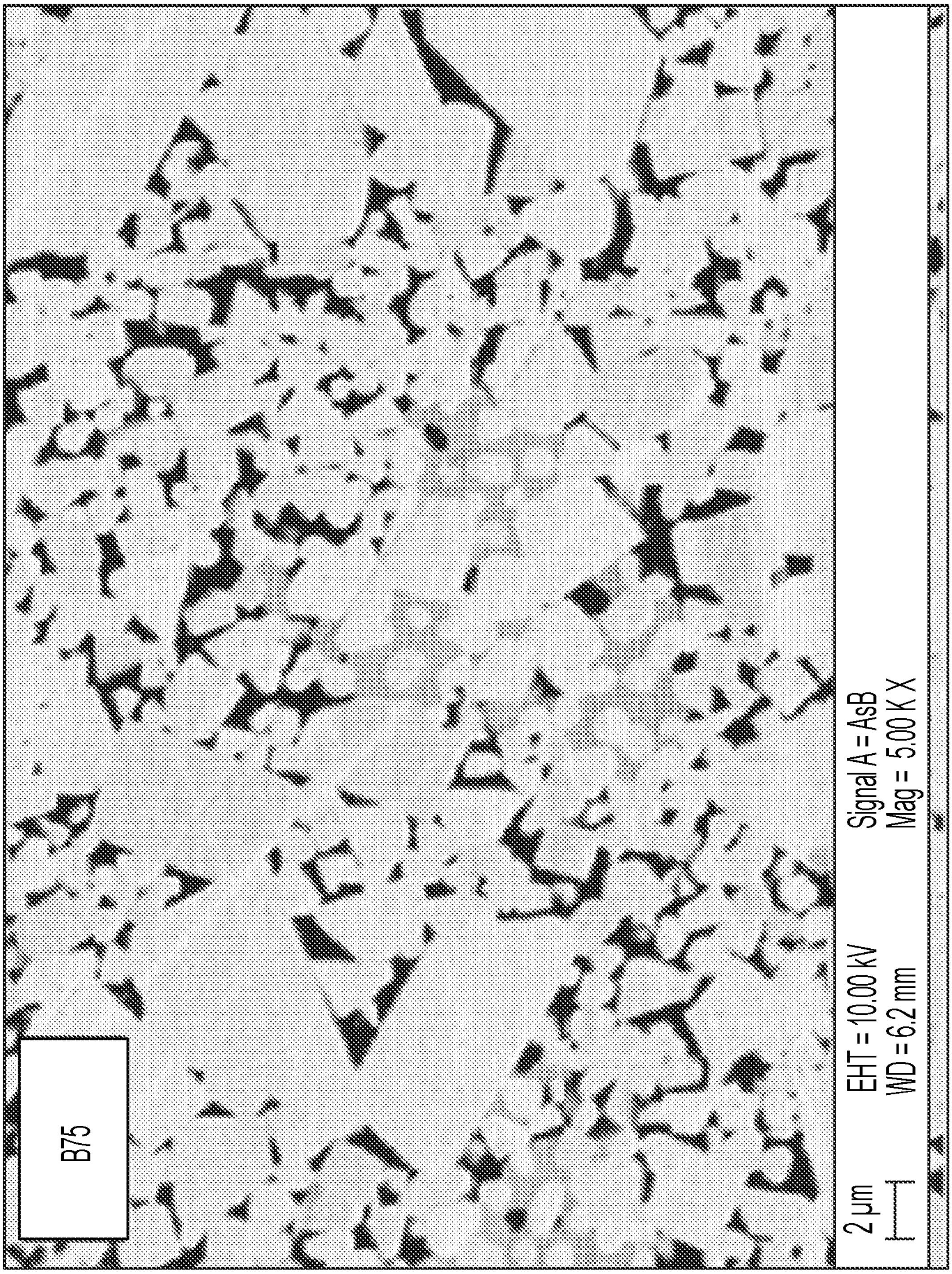


FIG. 28

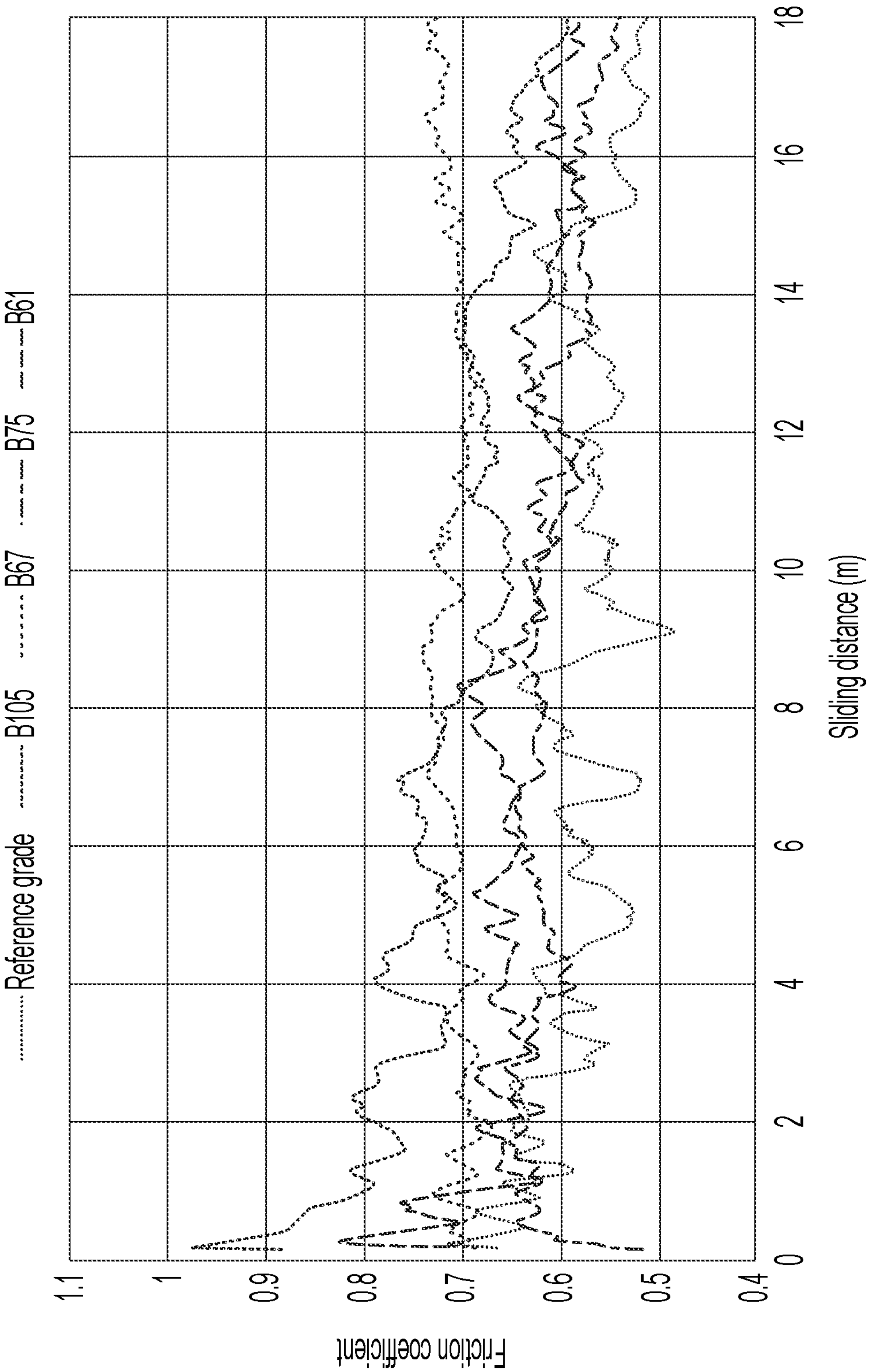

Reference grade
B105
B67
B75
B61
Friction coefficient
Sliding distance (m)
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0
2
4
6
8
10
12
14
16
18

FIG. 29

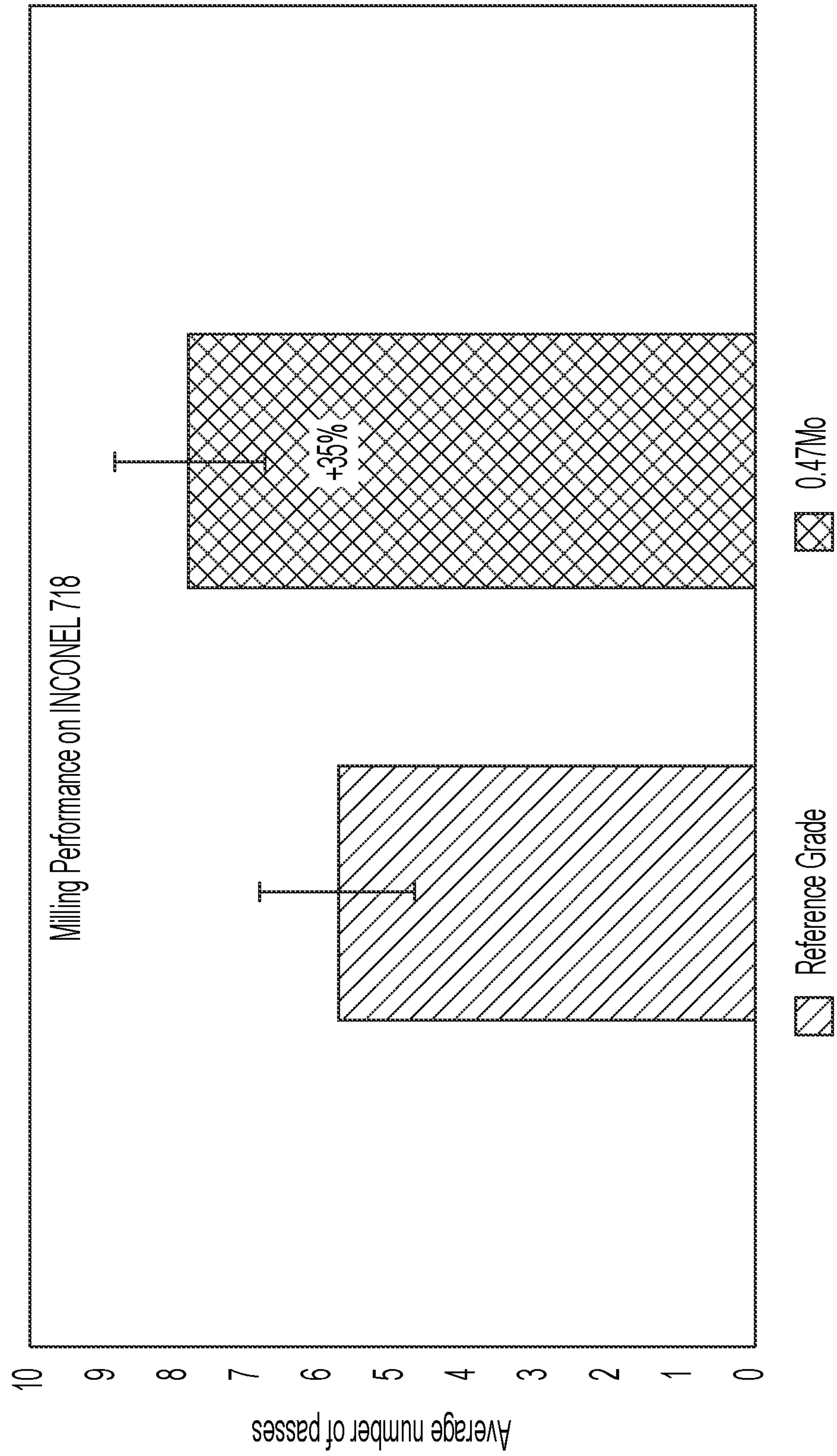

Milling Performance on INCONEL 718
+35%
Average number of passes
0
1
2
3
4
5
6
7
8
9
10
Reference Grade
0.47Mo

FIG. 30

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2022/078252

A. CLASSIFICATION OF SUBJECT MATTER
INV. C22C29/06 C22C29/08
ADD. B22F3/10 B22F5/00

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 B22F

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	MORTON C W ET AL: "The temperature ranges for maximum effectiveness of grain growth inhibitors in WC-Co alloys", INTERNATIONAL JOURNAL OF REFRACTORY METALS AND HARD MATERIALS, ELSEVIER, AMSTERDAM, NL, vol. 23, no. 4-6, 1 July 2005 (2005-07-01), pages 287-293, XP027651158, ISSN: 0263-4368 [retrieved on 2005-07-01]	1-10,16, 18-20
A	figures 1,5,6	11-15,17

-/--

[x] Further documents are listed in the continuation of Box C.

[x] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"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	Date of mailing of the international search report
18 January 2023	30/01/2023

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Momeni, Mohammad

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WEIDOW J ET AL: "Characterisation of WC-Co with cubic carbide additions", INTERNATIONAL JOURNAL OF REFRACTORY METALS AND HARD MATERIALS, ELSEVIER, AMSTERDAM, NL, vol. 27, no. 2, 1 March 2009 (2009-03-01), pages 244-248, XP025937880, ISSN: 0263-4368, DOI: 10.1016/J.IJRMHM.2008.11.007 [retrieved on 2008-11-30] tables 1,2	1-20

X	US 6 911 063 B2 (GENIUS METAL INC [US]) 28 June 2005 (2005-06-28)	1-7,9, 10,16, 18-20
A	tables 13,14	8,11-15, 17

X	GUO SHENGDA ET AL: "The optimization of mechanical property and corrosion resistance of WC-6Co cemented carbide by Mo2C content", CERAMICS INTERNATIONAL, ELSEVIER, AMSTERDAM, NL, vol. 46, no. 11, 8 April 2020 (2020-04-08) , pages 17243-17251, XP086164771, ISSN: 0272-8842, DOI: 10.1016/J.CERAMINT.2020.04.011 [retrieved on 2020-04-08]	1-10,16, 18-20
A	figures 6a,6b; table 1	11-15,17

X	CN 109 652 698 A (LIU BINGFEI) 19 April 2019 (2019-04-19)	1-10,16, 18-20
A	claim 1	11-15,17

X	EP 1 054 071 A2 (SANDVIK AB [SE]) 22 November 2000 (2000-11-22)	1-10,16, 18-20
A	paragraphs [0028], [0030]	11-15,17

X	EP 0 913 489 A1 (SUMITOMO ELECTRIC INDUSTRIES [JP]) 6 May 1999 (1999-05-06) tables 1,2	1-20

X	US 3 816 081 A (HALE T) 11 June 1974 (1974-06-11)	1-10,16, 18-20
A	Example 2	11-15,17

X	WO 98/03690 A1 (SANDVIK AB [SE]; OESTLUND AAKE [SE] ET AL.) 29 January 1998 (1998-01-29)	1-10,16, 18-20
A	Example 1	11-15,17
	-----	
10 X	GB 705 844 A (SANDVIKENS JERNVERKS AB) 17 March 1954 (1954-03-17)	1-10,16, 18-20
A	Example 2	11-15,17

1	-/--	

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 101 892 409 A (ZHUZHOU HUARUI HARD ALLOY TOOLS CO LTD) 24 November 2010 (2010-11-24)	1-6, 8-10,16, 18-20
A	claim 1	7,11-15, 17
X	CN 101 121 983 A (ZHUZHOU CEMENTED CARBIDE GROUP [CN]) 13 February 2008 (2008-02-13)	1-6, 8-10,16, 18-20
A	Examples 2-5	7,11-15, 17
X	EP 2 499 268 A1 (ELEMENT SIX GMBH [DE]) 19 September 2012 (2012-09-19)	11-15, 17-20
A	paragraphs [0030], [0031], [0032], [0034]	1-10,16
X	EP 2 011 890 A1 (SANDVIK INTELLECTUAL PROPERTY [SE]) 7 January 2009 (2009-01-07)	11-15, 17-20
A	paragraph [0032]	1-10,16

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2022/078252

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
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			IL	160248	A	28-04-2011
			JP	2006513119	A	20-04-2006
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			TW	I279445	B	21-04-2007
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			JP	2000336437	A	05-12-2000
			US	6228139	B1	08-05-2001
EP 0913489	A1	06-05-1999	CN	1211284	A	17-03-1999
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US 3816081	A	11-06-1974	AT	345003	B	25-08-1978
			AU	6435174	A	10-07-1975
			BE	810171	A	16-05-1974
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			GB	1450654	A	22-09-1976
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			ZA	74169	B	27-11-1974
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			DE	69706864	T2	28-03-2002
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CN 101121983	A	13-02-2008	NONE			

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2022/078252

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			CN	103233155	A	07-08-2013
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			JP	5117931	B2	16-01-2013
			JP	2009013495	A	22-01-2009
			KR	20080106080	A	04-12-2008
			US	2008314200	A1	25-12-2008
			US	2011183832	A1	28-07-2011