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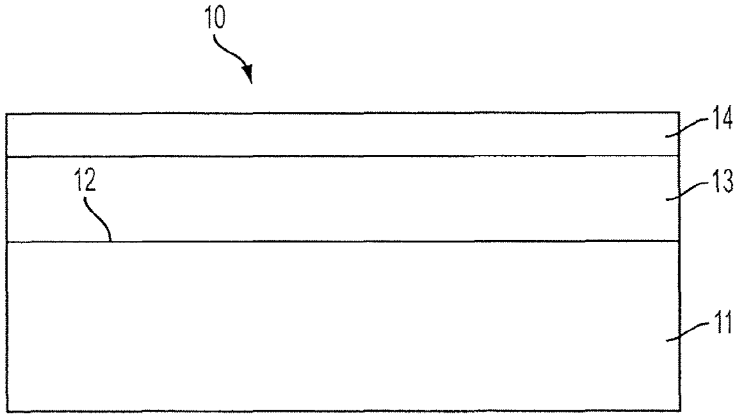

FIG. 1

(57) Abstract: A composite substrate for superconductors and methods for making the same are described. The composite substrate of the present invention includes at least a core layer having and a sheath layer having a cube texture on at least a portion its surface. In certain embodiments, the core layer can include a nickel-tungsten- molybdenum alloy having about 2-10 atomic percent tungsten and 2-15 atomic percent molybdenum. In some embodiments, the sheath layer can include nickel or a nickel-tungsten alloy having about 0 to 6 atomic percent tungsten. Generally, the core layer is stronger than the sheath layer and an interdiffusion zone can exist between the core layer and the sheath layer.

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COMPOSITE SUBSTRATES FOR HIGH TEMPERATURE SUPERCONDUCTORS HAVING IMPROVED PROPERTIES

INCORPORATION BY REFERENCE

[0001] All patents, patent applications and publications cited herein are hereby incorporated by reference in their entirety. The disclosures of these publications in their entireties are hereby incorporated by reference into this application in order to more fully describe the state of the art as known to those skilled therein as of the date of the invention described herein.

CROSS-REFERENCE TO RELATED APPLICATION

[0002] This patent application claims the benefit of the filing date of U.S. Patent Application No. 60/922,145, filed on April 6, 2007, the contents of which is incorporated by reference herein in its entirety.

FIELD OF THE INVENTION

[0003] The present invention relates to substrates for high temperature superconductors. More particularly, the present invention relates to composite substrates for high temperature superconductors having properties, such as improved mechanical properties.

BACKGROUND OF THE INVENTION

[0004] High Temperature Superconductors (HTS) have gained tremendous importance for their ability to provide improved current leads, improved transmission lines, improved magnetic windings, as well as uses in numerous other electrical conductor applications. One technique for fabricating a superconducting wire or tape is to deposit a superconducting film on a biaxially textured metallic substrate. The deposition of the superconducting layer on a biaxially textured metallic substrate can lead to the formation of textured superconducting layers that have improved superconducting properties. Although the currently utilized biaxially textured metallic substrates exhibit numerous advantageous properties, there is currently a need for continued improvements (such as improved mechanical and magnetic properties) of the biaxially textured substrates.

SUMMARY OF THE INVENTION

[0005] A composite substrate for superconductor articles is described. The composite substrate has a first layer that includes a metal or a metal alloy having a cube texture on at least a portion of its surface; and a second layer that includes a nickel-tungsten-molybdenum alloy containing about 2 to 10 atomic percent tungsten and 2 to 15 atomic percent molybdenum. The nickel-tungsten-molybdenum alloy has a higher yield strength than the metal or metal alloy of the first layer.

[0006] In certain embodiments, the composite substrate can further include a third layer where the second layer is between the first and third layers. The third layer can also include a metal or a metal alloy contained in the first layer and can also optionally have a cube texture on at least a portion of its surface.

[0007] In some embodiments, the composite substrate includes a first layer comprising nickel or a nickel-tungsten alloy having a cube texture on at least a surface of said first layer and having about 0 to 6 atomic percent tungsten; a second layer comprising a nickel-tungsten-molybdenum alloy having about 2-10 atomic percent tungsten and about 2-15 atomic percent tungsten; and an interdiffusion zone between the first layer and the second layer.

[0008] In other embodiments, the composite substrate may have a yield strength measured at 0.02% yield strain that is greater than 30% of the yield strength of a Ni – 5 at% W layer measured at 0.02% yield strain.

[0009] Methods for making the composite substrates of the invention are also described. The method includes feeding a first metal powder from a first compartment and a second metal powder from a second compartment to adjacent regions at a nip of at least two rollers; compacting the first metal powder and the second metal powder using at least two rollers to form a compacted green body having a first compacted region that includes the first metal powder and a second compacted region that includes the second metal powder; heating the compacted green body to form a composite substrate having a first layer and a second layer; and developing a cube texture on at least a surface of said first layer.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The above and other objects and advantages of the present invention will be apparent upon consideration of the following detailed description, taken in conjunction with the accompanying drawings, in which like reference characters refer to like parts throughout, and in which:

[0011] **FIG. 1** is a diagram of a high temperature superconductor (HTS) article having at least one biaxially-textured substrate **11** with biaxially-textured surface **12**, at least one epitaxial buffer layer with biaxially-textured surface, **13**, and a top layer of epitaxial, in-plane aligned superconducting layer of a rare earth-alkaline earth-transition metal oxide superconductor (RE-123) **14**;

[0012] **FIG. 2** shows a graph of different nickel alloy rolling assisted biaxially textured substrates (RABiTS) that tend to form particular textures in accordance with certain embodiments of the present invention;

[0013] **FIG. 3** shows a graph of lattice constant of various nickel alloys (as measured from their respective (200) reflections) as a function of their mechanical properties in accordance with certain embodiments of the present invention;

[0014] **FIGS. 4A** and **4B** show composite substrates **41** having a core **401** and at least one sheath **403** in accordance with certain embodiments of the present invention;

[0015] **FIG. 5** shows a method for making a composite substrate in accordance with certain embodiments of the present invention;

[0016] **FIGS. 6A** through **6C** show a roll compacting apparatus that can be utilized to make composite substrates in accordance with certain embodiments of the present invention;

[0017] **FIG. 7** shows a composite substrate **71** having Ni – 5 at% W alloys as sheath **703** and Ni – 5 at% W – 6 at% Mo as core **701** in accordance with certain embodiments of the present invention;

[0018] **FIG. 8** shows a diagram of a rectangular die mounted on a dual acting press that can be used to make the composite substrates in accordance with certain embodiments of the present invention;

[0019] **FIG. 9** shows an energy dispersive X-ray analysis (EDS) of composite substrate **71** of **FIG. 7** in accordance with certain embodiments of the present invention;

[0020] **FIGS. 10A** and **10B** show exemplary stress-strain curves of the composite substrate **71** of **FIG. 7**, a single layer Ni – 5 at% W, and a single layer Ni – 9 at% W substrates at room temperature and at about 77 K in accordance with certain embodiments of the present invention;

[0021] **FIGS. 11A** shows the permeability measurement of the composite substrate **71** of **FIG. 7** and Ni – 5 at% W in accordance with certain embodiments of the present invention;

[0022] **FIGS. 11B** and **11C** show the loss per cycle of the composite substrate **71** of **FIG. 7** and a single Ni – 5 at% W substrate in accordance with certain embodiments of the present invention;

[0023] **FIGS. 12A** and **12B** show the stress-strain curves of the composite substrate **71** of Example 2 and that of a single Ni – 5 at% W substrate at room temperature and at 77K in accordance with certain embodiments of the present invention; and

[0024] **FIGS. 13A** and **13B** show the loss per cycle of the composite substrate **71** of Example 2 and a single Ni – 5 at% W substrate in accordance with certain embodiments of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0025] As shown in **FIG. 1**, high temperature superconductor (HTS) articles such as **10**, particularly in the form of wires or tapes, can generally include substrate **11** with at least one textured surface **12**, at least one epitaxially deposited buffer layer **13**, and a top layer of epitaxially deposited or epitaxially grown in-plane aligned superconducting layer of a rare earth-alkaline earth-transition metal oxide superconductor (RE-123) **14**.

[0026] Layer **14** can be an in-plane aligned superconducting layer of RE-123 (e.g., YBCO). For example, YBCO can be biaxially textured wherein the c-axis of the orthorhombic crystal cell is parallel to the thickness direction of the HTS article and the ab-plane is perpendicular to the thickness direction of the HTS article. Or stated in a different way, the c-axis is perpendicular to the plane of the YBCO film and ab-plane is in the plane of YBCO film.

[0027] Buffer layer(s) **13** can be an epitaxial buffer layer and can be made of metal oxides, such as $LaAlO_3$, Y_2O_3, CeO_2, or yttria-stabilized zirconia (YSZ). Buffer layer(s) **13** can be a buffer to oxygen diffusion and reduce oxidation of the substrate **11**. Buffer layer(s) **13** can also serve as chemical barriers between substrate **11** and the layer **14**. Moreover, the buffer layer(s) **13** can have a coefficient of thermal expansion that is well matched with the superconductor material of layer **14**.

[0028] Substrate **11** can be fabricated over long lengths and large areas and can be made of a metal such as nickel (Ni) or Ni alloys and can provide flexibility for the article. For example, Ni alloys having about 4 to 5 atomic percent (at%) tungsten (W) are commonly utilized as substrate **11**. Substrate **11** can be formed using, for example, Rolling Assisted Biaxially Textured Substrates (RABiTS) process, which is described more fully in U.S. Patent No. 5,471,377 (hereinafter "the '377 patent"), the contents of which are incorporated by reference herein in its entirety. In short, RABiTS are produced by deforming a strip of metal or metal alloy between two or more rollers and allowing the strip to undergo plastic deformation leading to the development of a textured strip reduced in thickness. As described in the '377 patent, substrate **11** can develop different textures depending on the composition of the alloy, the processing history, and the like. Generally, cube or brass textures are most commonly observed.

[0029] In a cube texture, the (100) atomic plane of the cube (the (100) plane) lies parallel to the plane of the substrate and a cube edge (the <001> direction) is generally parallel to the rolling direction. In short notation, such a cube texture is also commonly identified as (100)<001>. In a brass texture, the (110) plane lies parallel to the plane of the substrate and the <112> direction is generally parallel to the rolling direction. Generally, a biaxial texture resembles grains of single crystals that are in slightly different orientations with each other.

[0030] Ni – 5 at% W substrates, in particular, exhibit excellent cube texture and a 0.02% yield stress of about 180 MPa at room temperatures and about 250 MPa at about 77K (operating temperature). However, higher strength can increase process stability and allow reduction in thickness. Substrates having excellent texture, higher mechanical strengths, and/or exhibiting ferromagnetic loss reduction are described. The improved substrates can be easily manufactured at long lengths desired for current carrying applications.

[0031] **FIG. 2** shows a graph of different nickel alloys RABiTS that tend to form particular textures. Certain metals and metal alloys, such as Ni270 (pure Ni), Ni – 5at% W, Ni – 14at% Cr, Ni – 10at% Cr – 2 at% W, Ni – 5 at% W – 1 at% V, tend to form a cube texture during RABiTS processing. Other alloys, such as Ni – 7 at% W and Ni – 9.3at% W, tend to form brass texture when processed. Yet other alloys, such as Ni – 7 at% Cr – 4 at% W and Ni – 5 at% W – 1 at% Si, tend to form mixed texture with about 70-80% cube texture. Although not wishing to be bound by theory, some generalized trends can be observed from **FIG. 2**. As shown, alloys having larger lattice constants may tend to form brass textures while alloys having smaller lattice constants may tend to form the desired cube texture.

[0032] However, as shown in **FIG. 3**, alloys having larger lattice constant also may tend to have stronger mechanical properties. For example, Ni – 9 at% W alloy exhibits about 290 MPa yield stress at 0.02% strain (room temperature) while Ni – 5 at% W alloy exhibits only about 190 MPa yield stress at 0.02% strain (room temperature). As a trade-off between the two desired properties is required, development of suitable alloys having the desired texture with superior mechanical properties remains a difficult problem.

[0033] A composite substrate is described with reference to **FIGS. 4A** and **4B**. A composite substrate **41** includes core **401** and a sheath **403**. Core **401** is formed with an alloy having mechanical properties that are superior to the sheath **403**. The composite substrate **41** may be in the form of a bilayer (sheath – core), as illustrated in **FIG. 4B** or a trilayer (sheath – core – sheath) structure, as illustrated in **FIG. 4A**. In certain embodiments, sheath(s) **403** form(s) cube texture on at least a portion of the surface upon rolling. In some embodiments, the composite substrate **41** has a yield stress that is about 30%-200%, e.g., at least 30%, 40%, 50%, 75%, 100%, 150%, or even 200%, greater than the yield stress of a Ni – 5 at% W alloy having a cube texture. Other suitable composite substrate **41** structures will be readily apparent to one of ordinary skill in the art.

[0034] In some other embodiments, composite substrate **41** may exhibit a magnetic permeability that is about 2-10 times, e.g., at least 2, 3, 4, 5, 6, 7, 8, 9, or even 10 times, smaller than the permeability of a Ni – 5 at% W alloy having a cube texture. In certain embodiments, composite substrate **41** of the present invention may have permeability values that are significantly lower than that of a Ni – 5 at% W alloy having a cube texture while the loss per cycle remain similar or lower.

[0035] Core **401** can make up about 50%-90%, e.g., at least 50%, 60%, 70%, 80%, or 90%, of the total thickness of the composite substrate **41**. For example, when the composite substrate **41** is in a trilayer structure, core **401** may include about 60% of the total thickness and each sheath **403** may independently include about 10%-30%, e.g., about 10%, 15%, 20%, 25%, and 30%, of the total thickness of the structure. As another example, when the composite substrate **41** is in a bilayer structure, core **401** may include about 70%-90%, e.g., about 70%, 80%, or 90%, of the total thickness and the sheath **403** may include about 10%-30%, e.g., about 30%, 20%, or 10%, of the total thickness of the structure.

[0036] In certain embodiments, metal alloys of core **401** and sheath **403** may include metal constituents that are desirably resistant to oxidation during processing and/or operation and lead to reduced magnetic properties. Additional consideration may include availability/cost of metal powders, purity of metal powders, size of metal powders, polydispersity of metal powders, and the like when a powder metallurgical approach to processing is used.

[0037] Core **401** may include alloys that have superior mechanical properties as compared to sheath **403**. For example, core **401** may include alloys having a yield stress of about 250 MPa-500 MPa, e.g., at least 250, 275, 300, 325, 350, 375, 400, 450, or 500 MPa, at about 0.02% strain (either room temperature and/or operating temperatures). In certain embodiments, core **401** may include constituents that lead to high degree of twinning during processing. Suitable alloys include nickel-tungsten alloys, nickel-tungsten-transition metal alloys, and commercial nickel alloys such as, for example, Haynes C276 or C22, and the like. Exemplary transition metals that can be utilized in nickel-tungsten-transition metal alloys include Ti, Y, Hf, V, Zr, Ta, Cr, Nb, Mo, Co, Cu, and Pd. In some embodiments, core **401** may be capable of being rolled to high reductions (well over 90% reduction in thickness). Some exemplary alloys may include nickel-tungsten alloys having about 7-12 at% tungsten, nickel-tungsten-molybdenum alloys having about 2-10 at% tungsten and about 2-15 at% molybdenum, nickel-tungsten-chromium alloys having about 5-12 at% tungsten and about 4-15 at% chromium. For example, suitable alloys may be

Ni – 9.5 at% W,
Ni – 10 at% W,
Ni – 5 at% W – 6 at% Mo,
Ni – 6 at% W – 6 at% Cr,
and the like.

[0038] Core **401** may include additional constituents, such as metal powders. For example, when core **401** is a Ni(W,Mo) alloy, core **401** may contain powders of W and/or Mo. Without wishing to be bound by theory, the metal powders may provide additional strength and stiffness to core **401**, beyond the solid solution strengthening obtained by the alloys described above. In certain embodiments, the metal powders may form an interface that adheres well with the surrounding alloy. For example, in a Ni(W,Mo) alloy core, core **401** can contain particles of Ni W and/or Mo dispersed throughout a Ni(W,Mo) alloy, where the particles form a compositionally gradual interface transitioning from the alloy to the W or Mo particles that adheres well to the surrounding alloy.

[0039] Sheath **403** is an alloy capable of forming a cube texture upon rolling of the composite substrate **41**. That is, after rolling and a final anneal of the rolled substrate, the surface of the sheath has a sharp cube texture, with an in-plane texture $\delta\phi$ FWHM value of less than 10°, preferably less than 8°, and a cube texture percentage of more than 90%. In certain embodiments, sheath **403** may include constituents that enhance the stacking fault energy of the sheath alloy. For example, certain amounts of Cr, W, and/or V can be added to Ni or Al can be added to Cu to reduce the stacking fault energy that still allows the formation of a cube texture without transitioning into a brass texture. Suitable metals or metal alloys may include nickel, nickel-tungsten alloys, pure Ni such as Ni270, nickel-chromium alloys, nickel-chromium-tungsten alloys, nickel-tungsten-vanadium alloys, nickel-vanadium alloys, nickel-copper alloys, nickel-copper-aluminum alloys, copper-aluminum alloys, and the like. Some exemplary alloys may include nickel-tungsten alloys having 0-6 at% tungsten, nickel-chromium alloys having about 0-15 at% chromium, nickel-chromium-tungsten alloys having about 0-15 at% chromium and 0-6 at% tungsten, nickel-tungsten-vanadium alloys having about 0-6 at% tungsten and about 0-10 at% vanadium, copper-aluminum alloys having less than about 1 at% aluminum, and the like. For example, suitable metals or metal alloys may include

Ni,
Ni – 1 at% W,
Ni – 2 at% W,
Ni – 3 at% W,
Ni – 4 at% W,
Ni – 5 at% W,
Ni – 6 at% W,
Ni – 14 at% Cr,
Ni – 10 at% Cr – 2 at% W,
Ni – 5 at% W – 1 at% V,
Cu – 50 at% Ni – 1.5 at% Al,
and the like.

[0040] In certain embodiments, an interdiffusion zone may exist between core **401** and sheath **403** where certain atomic constituents from core **401** and sheath **403** may have diffused into sheath **403** and core **401**, respectively. For example, if core **401** includes a metal alloy having three constituents (metals A, B, and C) and sheath **403** includes a metal alloy having two constituents (metals A and B), the third constituent (metal C) in core **401** may diffuse a distance into sheath **403** thereby forming an interdiffusion zone. In some embodiments, the thickness of sheath **403** is sufficient to provide a texture for subsequent deposition of a superconducting material on the sheath **403** without being affected by the crystal structure or texture of the interdiffusion zone. While not wishing to be bound by theory, such an interdiffusion zone may be beneficial in promoting adhesion between core **401** and sheath **403** and increasing the mechanical properties of composite substrate **41**.

[0041] Composite substrates **41** can be made in using a variety of different methods. For example, composite substrates **41** can be made using a batch process or a continuous process.

[0042] Composite substrates **41** can be made using co-extrusion, in which a tube or other hollow structure (made of the metal or metal alloy for sheath **403**) is filled with a core material, and extruded to form a composite strip or bar, as described in V. Subramanya Sarma, B. de Boer, J. Eickemeyer, B. Holzapfel, "On the development of high strength and bi-axially textured Ni-3%W/Ni-10%Cr-1.5% Al composite subtrate for coated conductor application," Scripta Materialia, Vol. 48(8), (2003), pp. 1167-1171 and V. Subramanya Sarma, J. Eickemeyer, A. Singh, L. Schultz, B. Holzapfel, "Development of high strength and strongly cube textured Ni-4.5% W/Ni-15% Cr composite substrate for coated conductor application," Acta Materialia, Vol. 51(16), (2003), pp. 4919-4927, both of which are incorporated by reference herein in its entirety. The composite strip is further rolled to consolidate and densify the core material and to develop a cube texture on the surface of the sheath layer. After rolling, a composite foil results.

[0043] Composite substrates can also be made using a cladding process, in which two or three strips, one being the core material, and one or two being the sheath material, are bonded in a rolling operation, as described in Y. Zhao, H.L. Suo, M. Liu, D. He, Y.X. Zhang, R. Fan, L. Ma, M.L. Zhou, "Fabrication of reinforced and biaxially textured NiW alloy substrates by spark plasma sintering technique," IEEE Trans. On Appl. Supercond., Vol. 17, (2007) p. 3424, which is incorporated by reference herein in its entirety. This cladding process is a common commercial process for making composite foils. The constituent starting strips are made the usual way, using casting, hot rolling and cold rolling to strip, or other commercial processes to make metal strip. Clad products can also be made in batch or longer length using explosive welding or friction welding.

[0044] In certain embodiments, powder metallurgy processing methods can be utilized to fabricate composite substrate **41** of the present invention. An exemplary powder metallurgy processing method is described with reference to **FIG. 5**. In step **501** of **FIG. 5**, suitable elemental metal powders are mixed at appropriate atomic or weight proportions to obtain the desired metal alloy composition after powder consolidation and heat treatment. In certain embodiments, each constituent metal powders may each have about 95%-100%, e.g., at least 95%, 97%, 98%, 99%, 99.5%, 99.9%, 99.95%, purity. In some other embodiments, each constituent metal powders may have particle diameters of about 0.1-10 micrometers, e.g., up to 10, 5, 2, 1, 0.1 micrometers. In yet some other embodiments, metal powders may have a range of particle sizes to promote more efficient compacting during step **503**. Moreover, each metal powder may have a range of particle sizes to obtain metal particles dispersed throughout core **401**. Powders may be mixed using any appropriate methods such as stirring, shaking, blending, and the like.

[0045] As shown in step **503** of **FIG. 5**, the mixed powders may be compacted to form a green body having a desired composite substrate structure in any suitable method. For example, the mixed powders may be compacted using a compression molding machine, a press machine, using two or more rollers, and the like. For example, compaction can be carried out from about 10 to 50 tons per square inch at room temperature or higher.

[0046] An exemplary batch process is shown in step **505** of **FIG. 5**, where the compacted green body may be sintered to further promote bonding of the powders and form the alloy. For example, the compacted green body may be sintered at about 1000 °C to about 1400 °C at about 10 to 300 millitorr pressure for about 0.1 to 10 hours.

[0047] At step **507** of **FIG. 5**, the pre-sintered structure may be homogenized at elevated temperature(s) for a desired amount of time to aid in formation of alloy and/or to improve alloy homogeneity and density in each layer of the composite structure. For example, pre-sintered nickel alloy composite structure may be homogenized at temperatures of about 1000-1400°C for about 5-200 hrs. In certain embodiments, the oxygen partial pressure can be lowered to prevent oxidation of the alloying elements. For example, oxygen partial pressure can range from about 10^{-6} to about 10^{-12} atmospheres.

[0048] In certain embodiments, the homogenization can be carried out to obtain metal particles dispersed through the alloy. For example, in a Ni(W,Mo) alloy core, core **401** can be made using powders that include Ni, W, and Wo metal particles, where a certain percentage of smaller W and/or Mo particles (e.g., average diameter of 5 microns) and a certain percentage of larger W and/or Mo particles (e.g., average diameter of 100 microns) were compacted and optionally sintered. The homogenization can then be carried so that smaller W and/or Mo particles react with Ni to form a dense Ni(W,Mo) alloy, while the larger particles remain partially uncoverted and embedded in the Ni(W,Mo) alloy solution, leading to a compositionally gradual interface that adheres well to the surrounding alloy.

[0049] At step **509** of **FIG. 5**, the homogenized composite structure can be processed to develop a desired texture on at least the surface of the sheath layer(s). For example, the homogenized composite structure can be processed using two or more rollers for compaction, as discussed below.

[0050] It should be noted that additional steps may be carried out in addition to the steps described in **FIG. 5**. Furthermore, some of the steps described in **FIG. 5** may be omitted as desired and/or suitable. Such modifications will be readily apparent to one of ordinary skill in the art and are within the scope of the invention.

[0051] In certain embodiments, steps **503** through **509** can be carried out using a roll compacting (or powder rolling) process as described in the *Metals Handbook, Ninth Edition,* Volume 7, "Powder Metallurgy," pages 401-405 and Jones, W.D., "Fundamental Priciples of Powder Metallurgy," London, 1960, p. 924, the contents of which are incorporated herein in their entireties. **FIG. 6A** shows an exemplary roll compacting apparatus that can be utilized in the present invention. As shown, powders mixed in step **501** can be fed from a specialized hopper (*see, e.g.,* **FIGS. 6B and 6C** which show specialized hoppers to form a trilayer composite substrate) to a set of compacting rolls to produce a continuous green (unsintered) strip or sheet (step **503**). (See MacKay, M.L., "Innovation in P/M: An Engine Bearing Material, Met. Prog. Vol. 111 (6), 1977, pp. 32-35, contents of which are incorporated by reference herein in its entirety.)

[0052] The compacted green strip or sheets may be sintered and/or homogenized in, for example, a sintering furnace and/or a Bell furnace shown in **FIG. 6A** (steps

505 and/or **507**). Typically, for Ni alloys, sintering can be carried out in a furnace at the outlet of a powder compaction mill at about 800-1100 °C for about 5 and 20 minutes. Homogenization, carried out for formation of the solid solution Ni alloy (for example, a solid solution Ni-5W), can be carried out at about 1000-1400 °C for about 5 to 100 hrs or longer. To avoid oxidation, homogenization can be carried out under reducing conditions, such as pure hydrogen, or hydrogen mixed with argon or nitrogen.

[0053] In certain embodiments, the sintered and/or homogenized strip or sheet can be re-rolled to develop a desired texture at least on the surface of sheath layers.

[0054] In yet other embodiments utilizing a rolling mill to compact the powders, pre-alloyed powders can be used. Such pre-alloyed powders can be made with an atomization process such as water or gas atomization, or rotating electrode process, or rotating crucible atomization, or other processes used by those skilled in the art. Size of such pre-alloyed powders can range from about 20 microns to about several hundreds of microns.

EXAMPLE 1

[0055] Composite substrate **71** having core **701** and sheath **703** (see **FIG. 7**) was made as described below. Ni – 5 at% W alloys were utilized for sheath **703** and Ni – 5 at% W – 6 at% Mo were utilized as core **701**. Elemental Ni, W, and Mo metal powders corresponding to the compositions for core **701** and sheath **703** were weighed and mixed in a V blender for a sufficient time to insure uniform mixing. The metal powders were below 10 microns and had an average particle size of 2 microns.

[0056] Mixed powders for composite substrate **71** were loaded into a 1.5 inches by 6.3 inches rectangular die mounted on a dual acting press as shown in **FIG. 8**. Mixed powders for core **701** corresponding to about 80% of the total thickness of the composite substrate **71** and mixed powders for sheath **703** corresponding to about 20% of the total thickness of the composite substrate **71** were loaded into the rectangular die.

[0057] The powder mixtures were then compressed at 30 tons per square inch. The compacted green body was ejected and sent for sintering. The green body had a density of about 6.58 g/cc.

[0058] The sintering/homogenizing was carried out in two steps. The first step was carried out at 150 °C at a pressure of 200 millitorr in flowing argon containing 5% hydrogen gas for 5 hours. This step removed any organics that may be present in the compacted green body. In the second step, the compacted green body was heated to 1150 °C at 60 °C per hour and held for 50 hours. This step was also carried out at a pressure of 200 millitorr in flowing argon containing 5% hydrogen gas. After sintering, a solid bar with a density of from 80 to 90% of the density of wrought material of the same composition was obtained.

[0059] Next, the sintered/homogenized bilayer was rolled to 1.27mm on a two high rolling mill. The 1.27 mm thick strip was then transferred to a four high rolling mill and rolled to a foil with a thickness of about 70 microns to form composite substrate **71**.

[0060] The foils were cut into samples which were annealed at 1150 °C in flowing argon containing 5% hydrogen gas, at atmospheric pressure, for up to about 30 minutes to develop the desired cube texture. The surface of the sheath layer showed a sharp cube texture with a FWHM of about 7°.

[0061] The final thickness of the composite substrate **71** was about 70 μm. **FIG. 9** shows an energy dispersive X-ray analysis (EDS) showing about 7 μm unconverted Ni – 4 at% W sheath layer and about 7 μm interdiffusion zone. Core **701** was about 55 μm thick and contained grains of about 50 microns and heavily twinned crystals.

[0062] **FIGS. 10A** and **10B** show exemplary stress-strain curves of the obtained bilayer composite substrate **71** (curves **1001**), a single layer Ni – 5 at% W (curves **1003**), and a single layer Ni – 9 at% W (curves **1005**)substrates at room temperature (**FIG. 10A**) and at about 77 K (**FIG. 10B**). As shown, the composite substrate **71** has significantly improved mechanical properties at both temperatures. For example, the room temperature 0.02% yield strength is about 375 MPa, which is about double that of Ni – 5 at% W (about 190 MPa). At about 77K, the 0.02% yield strength is about 480 MPa, which is also about double that of Ni – 5 at% W (about 250 MPa)

[0063] **FIG. 11A** shows the permeability measurement of the composite substrate **71** and Ni – 5 at% W. As shown, the permeability of the composite substrate **71** was decreased by a factor of about 7. **FIGS. 11B** and **11C** show the loss per cycle of the composite substrate **71** and Ni – 5 at% W, which shows that the total loss per cycle remained similar for both substrates although B_{coer} increased for the composite substrate **71**. The measurements were conducted at about 77 K.

EXAMPLE 2

[0064] Composite substrate **71** was made as described in Example 1, except Ni – 4 at% W alloys were utilized for sheath **703** and Ni – 9.3 at% W were utilized as core **701**. **FIGS. 12A** and **12B** show the stress-strain curves of the composite substrate **71** of Example 2 (curves **1201, 1203, 1205,** and **1207**) and that of a single Ni – 5 at% W substrate (curve **1209**) at room temperature (**FIG. 12A**) and at 77K (**FIG. 12B**). As before, strength improved, but only at best about 30% more than that of the single – 5 at% W. **FIG. 13A** also shows the loss per cycle of the composite substrate **71** of Example 2. As before, B_{coer} increased while loss per cycle remain similar to that of the single Ni – 5 at% W substrate (see **FIG. 13B**).

EXAMPLE 3

[0065] Other composite substrates having a bilayer or trilayer configuration were also made as described in Example 1. For the trilayer configuration, mixed powders for sheath **703** corresponding to about 20% of the total thickness of the composite substrate **71**, mixed powders for core **701** corresponding to about 60% of the total thickness of the composite substrate **71**, and mixed powders for sheath **703** corresponding to about 20% of the total thickness of the composite substrate **71** were loaded into the rectangular die and pressed to form the compacted green body. Various composite substrates were produced as shown in **Table 1** below.

Table 1: Composite Substrates

Sample	Compression (tons per square inch)	Bi/trilayer	Core composition (at%)	Thickness (inches)
1	30	Trilayer	Ni-6W-6Cr	0.25
2	45	Trilayer	Ni-6W-6Cr	0.25
3	30	Bilayer	Ni-9.5W	0.15
4	45	Bilayer	Ni-9.5W	0.15
5	30	Trilayer	Ni-5W-6Mo	0.25
6	45	Trilayer	Ni-5W-6Mo	0.25
7	30	Bilayer	Ni-5W-6Mo	0.15
8	45	Bilayer	Ni-5W-6Mo	0.15

[0066] Upon review of the description and embodiments of the present invention, those skilled in the art will understand that modifications and equivalent substitutions may be performed in carrying out the invention without departing from the essence of the invention. Thus, the invention is not meant to be limiting by the embodiments described explicitly above, and is limited only by the claims which follow.

CLAIMS:

1. A composite substrate comprising:

a first layer comprising a metal or a metal alloy having a cube texture on at least a portion of a surface of said first layer; and

a second layer comprising a nickel-tungsten-molybdenum alloy comprising about 2 to 10 atomic percent tungsten and 2 to 15 atomic percent molybdenum; wherein

said nickel-tungsten-molybdenum alloy has a higher yield strength than said metal or metal alloy.

2. The composite substrate of claim 1, wherein said nickel-tungsten-molybdenum alloy comprises about 5 atomic percent tungsten and about 6 atomic percent molybdenum.

3. The composite substrate of claim 1, wherein said first layer comprises nickel or a nickel-tungsten alloy comprising about 0 to 6 atomic percent tungsten.

4. The composite substrate of claim 3, wherein said first layer comprises a nickel-tungsten alloy comprising about 4 to 5 atomic percent tungsten.

5. The composite substrate of claim 1, wherein said first layer comprises nickel or a nickel-molybdenum alloy comprising about 0 to 7 atomic percent molybdenum.

6. The composite substrate of claim 1, wherein said first layer comprises nickel or a nickel-tungsten-molybdenum alloy comprising about 0 to 6 atomic percent tungsten and about 0 to 7 atomic percent molybdenum.

7. The composite substrate of claim 1, wherein at least about 90% of the surface of said first layer comprises a cube texture.

8. The composite substrate of claim 1, wherein

said first layer is about 5-50% of the total thickness of said composite substrate; and

said second layer is about 50-95% of the total thickness of said composite substrate.

9. The composite substrate of claim 1, wherein said second layer further comprises tungsten and/or molybdenum metal particles.

10. The composite substrate of claim 1, further comprising a third layer between said first layer and said third layer, said third layer comprising a metal or a metal alloy.

11. The composite substrate of claim 10, wherein said third layer comprises nickel or a nickel-tungsten alloy comprising about 0 to 6 atomic percent tungsten.

12. The composite substrate of claim 11, wherein said third layer comprises a nickel-tungsten alloy comprising about 4 to 5 atomic percent tungsten.

13. The composite substrate of claim 12, wherein said nickel-tungsten-molybdenum alloy comprises about 5 atomic percent tungsten and about 6 atomic percent molybdenum.

14. The composite substrate of claim 13, wherein said first layer comprises nickel or a nickel-tungsten alloy comprising about 0 to 6 atomic percent tungsten.

15. The composite substrate of claim 10, wherein at least about 90% of the surface of said first layer comprises a cube texture.

16. A method for making a composite substrate, said method comprising:

providing a first metal powder and a second metal powder;

compacting said first metal powder and said second metal powder to form a compacted green body having a first compacted region comprising the first metal powder and a second compacted region comprising the second metal powder;

heating said compacted green body to form a composite substrate having a first layer and a second layer; and

developing a cube texture on at least a surface of said first layer.

17. The method of claim 16, further comprising:

mixing a first composition which comprises metal powders corresponding to said first metal powder; and

mixing a second composition which comprises metal powders corresponding to said second metal powder;

said mixing said first composition and said second composition being carried out prior to said providing.

18. The method of claim 16, wherein said second layer comprises a nickel-tungsten-molybdenum alloy containing about 2 to 10 atomic percent tungsten and about 2 to 15 atomic percent molybdenum.

19. The method of claim 18, wherein said first layer comprises a nickel-tungsten alloy containing about 0 to 6 atomic percent tungsten.

20. The method of claim 16, said providing further including providing a third metal powder; wherein

said composite substrate further comprises a third layer, said second layer being between said first layer and said third layer.

21. The method of claim 20, further comprising mixing a third composition which comprises metal powders corresponding to said third metal powder prior to said providing.

22. The method of claim 21, wherein said third composition is substantially the same as said second composition.

23. The method of claim 16, wherein said first metal powder and said second metal powder comprises elemental metal powders or pre-alloyed metal alloy powders.

24. The method of claim 16, wherein said heating includes densifying said compacted green body, sintering said compacted green body, homogenizing at least a part of each of said first layer and said second layer, or combinations thereof.

25. The method of claim 24, wherein in said homogenizing, at least some of said first metal powder first metal powder and the second metal powder form an alloy and at least some of said first metal powder and/or second metal powder form particles dispersed in the alloy.

26. The method of claim 16, wherein said second metal powder is selected to obtain a composite substrate having a yield stress that is at least 230 MPa at room temperature.

27. The method of claim 16, wherein said second metal powder is selected to obtain a composite substrate having a yield stress that is at least 30% higher than the yield stress of nickel-tungsten alloy having about 5 atomic percent tungsten.

28. The method of claim 16, wherein said providing includes feeding a first metal powder from a first compartment and a second metal powder from a second compartment to adjacent regions at a nip of at least two rollers.

29. The method of claim 28, wherein said compacting is carried out using said at least two rollers.

30. A composite substrate comprising:

a first layer comprising nickel or a nickel-tungsten alloy having a cube texture on at least a surface of said first layer and having about 0 to 6 atomic percent tungsten;

a second layer comprising a nickel-tungsten-molybdenum alloy having about 2-10 atomic percent tungsten and about 2-15 atomic percent tungsten; and

an interdiffusion zone between said first layer and said second layer.

31. The composite substrate of claim 30, wherein

said nickel-tungsten alloy comprises about 4 to 5 atomic percent tungsten; and

said nickel-tungsten-molybdenum alloy comprises about 5 atomic percent tungsten and 6 atomic percent molybdenum.

32. The composite substrate of claim 30, further comprising:

a third layer comprising a nickel or a nickel-tungsten alloy having about 0 to 6 atomic percent tungsten; and

a second interdiffusion zone between said second layer and said third layer.

33. The composite substrate of claim 32, wherein

said nickel-tungsten alloy comprises about 4 to 5 atomic percent tungsten; and

said nickel-tungsten-molybdenum alloy comprises about 5 atomic percent tungsten and 6 atomic percent molybdenum.

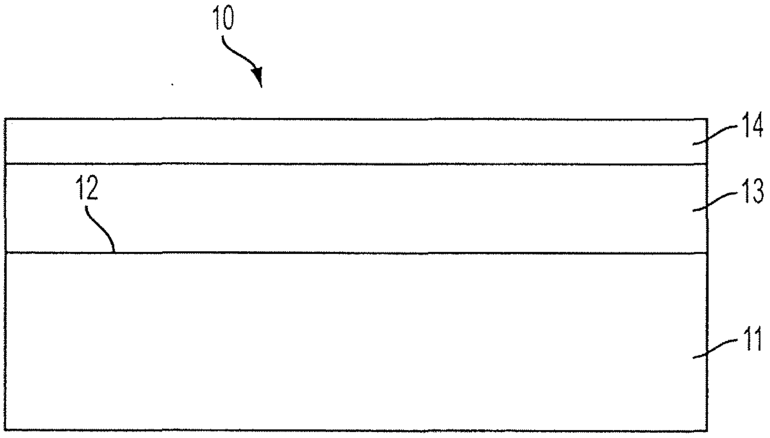

FIG. 1

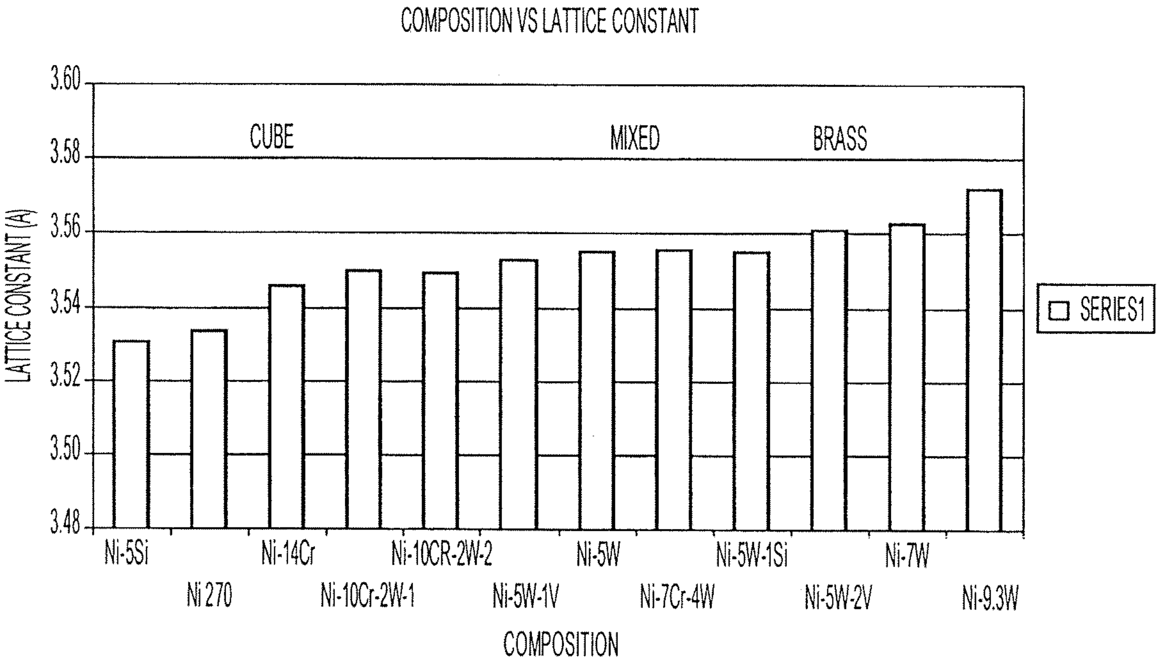
COMPOSITION VS LATTICE CONSTANT
3.60
3.58
3.56
3.54
3.52
3.50
3.48
LATTICE CONSTANT (A)
CUBE
MIXED
BRASS
SERIES1
Ni-5Si
Ni 270
Ni-14Cr
Ni-10Cr-2W-1
Ni-10CR-2W-2
Ni-5W-1V
Ni-5W
Ni-7Cr-4W
Ni-5W-1Si
Ni-5W-2V
Ni-7W
Ni-9.3W
COMPOSITION

FIG. 2

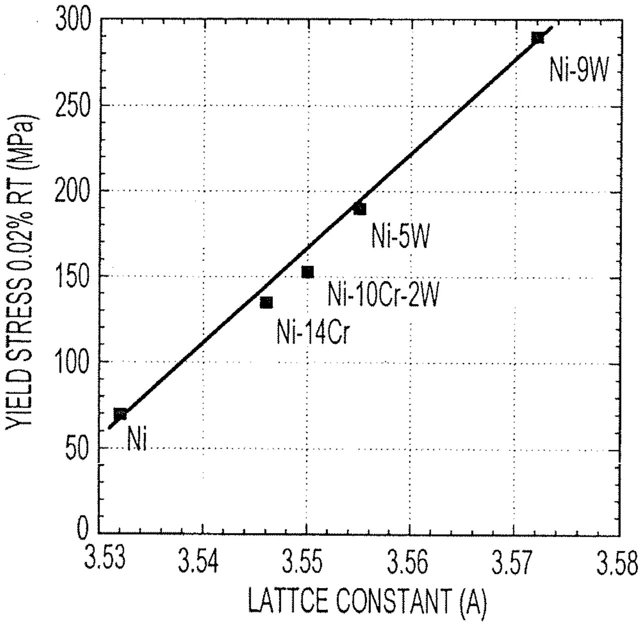
YIELD STRESS 0.02% RT (MPa)
300
250
200
150
100
50
0
3.53
3.54
3.55
3.56
3.57
3.58
LATTCE CONSTANT (A)
Ni-9W
Ni-5W
Ni-10Cr-2W
Ni-14Cr
Ni

FIG. 3

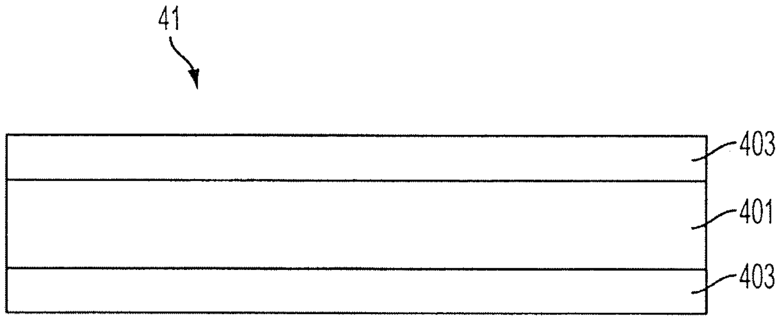

FIG. 4A

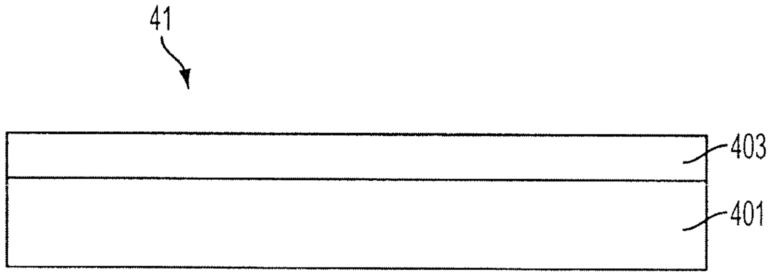

FIG. 4B

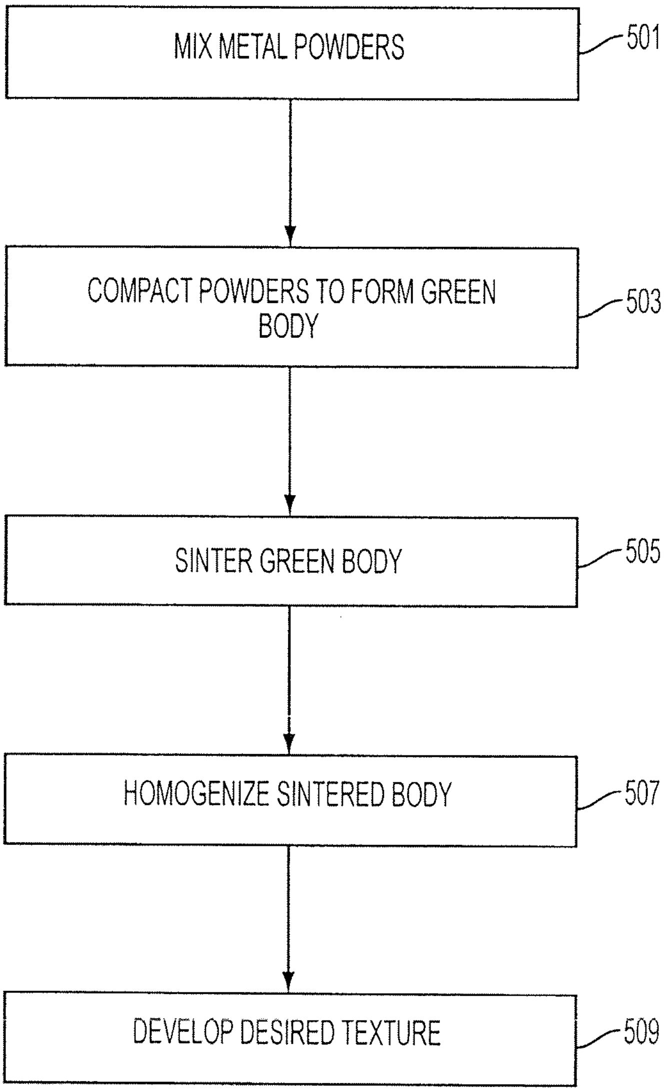
MIX METAL POWDERS
501
COMPACT POWDERS TO FORM GREEN BODY
503
SINTER GREEN BODY
505
HOMOGENIZE SINTERED BODY
507
DEVELOP DESIRED TEXTURE
509

FIG. 5

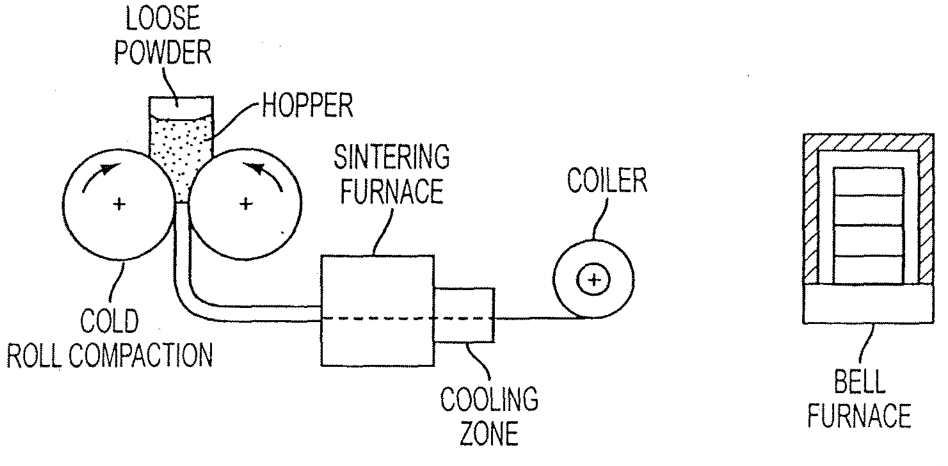
LOOSE
POWDER
HOPPER
SINTERING
FURNACE
COILER
COLD
ROLL COMPACTION
COOLING
ZONE
BELL
FURNACE

FIG. 6A

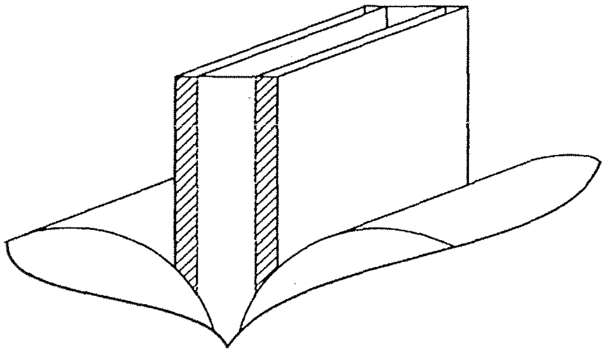

FIG. 6B

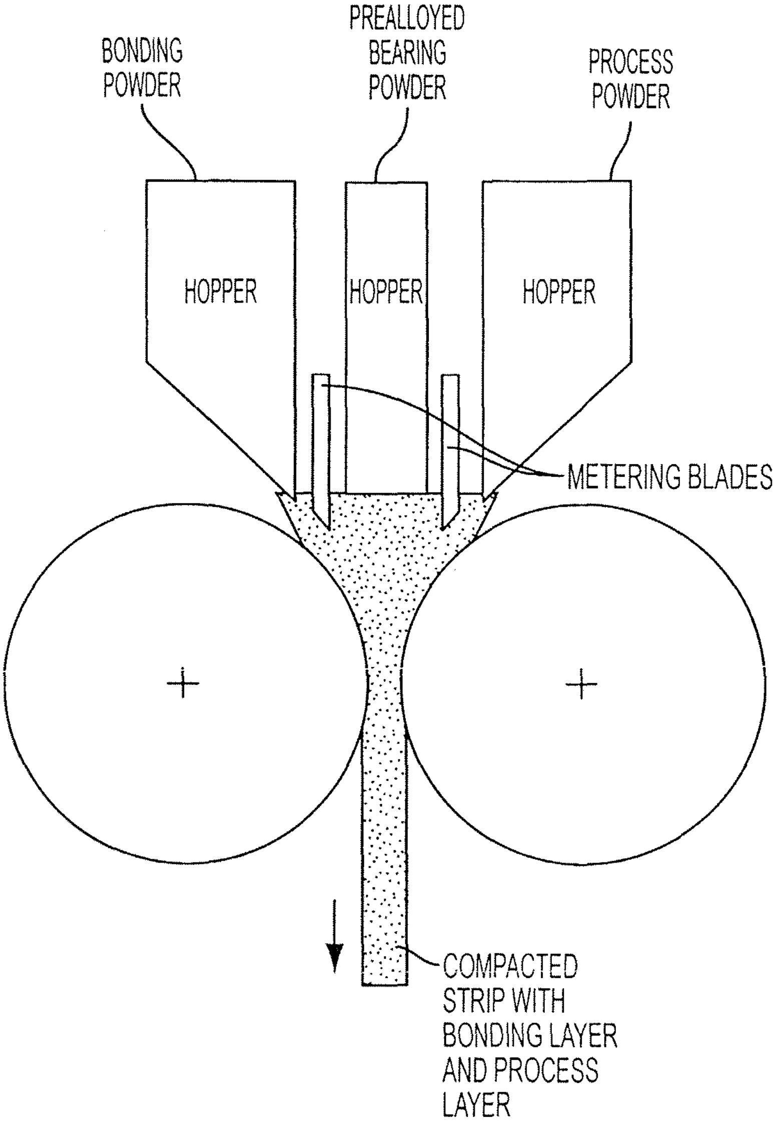
BONDING POWDER
PREALLOYED BEARING POWDER
PROCESS POWDER
HOPPER
HOPPER
HOPPER
METERING BLADES
COMPACTED STRIP WITH BONDING LAYER AND PROCESS LAYER

FIG. 6C

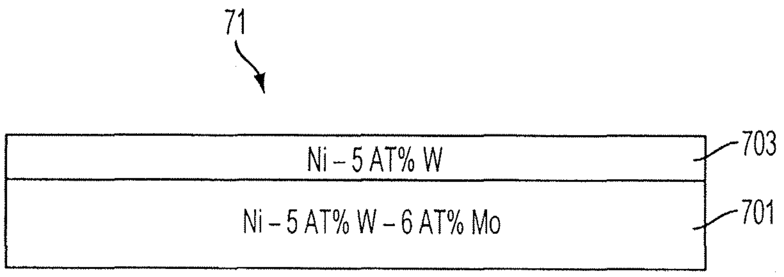

FIG. 7

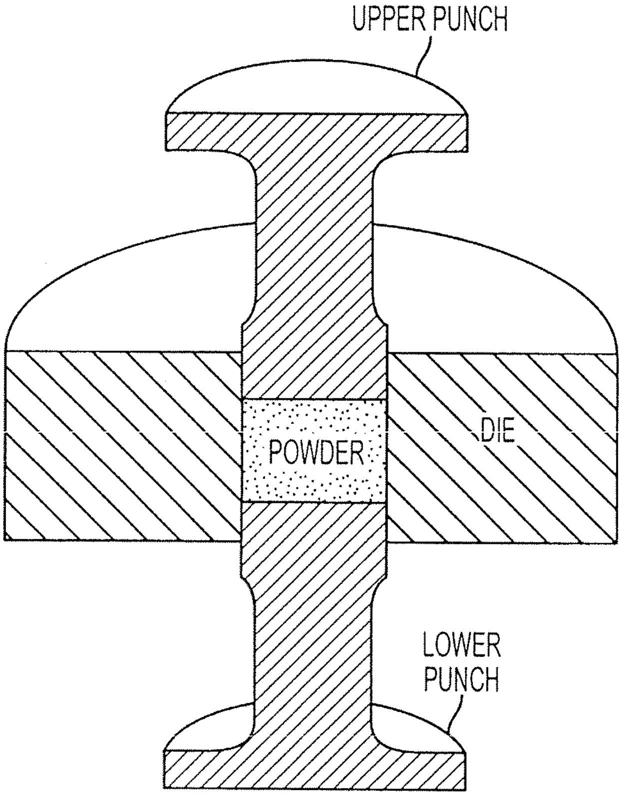

FIG. 8

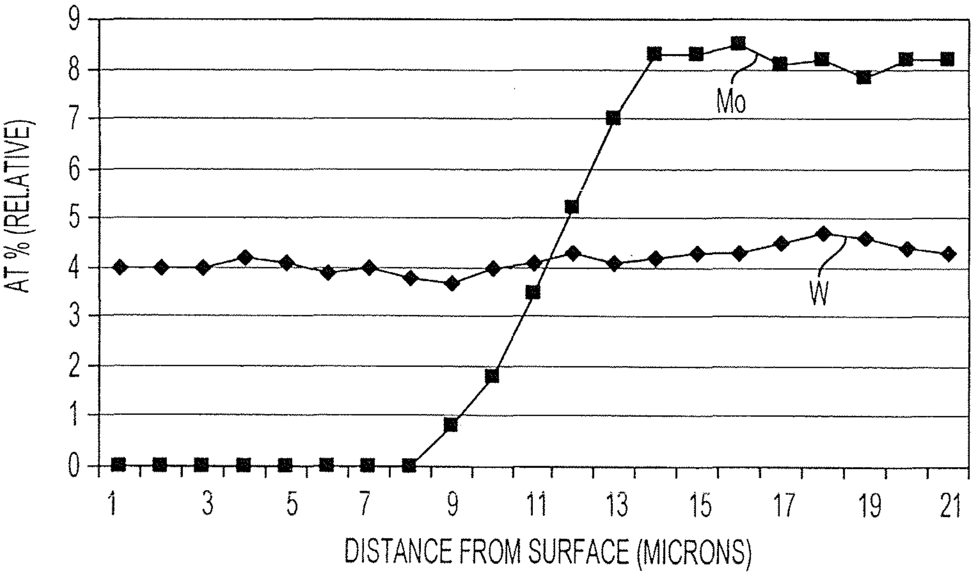
9
8
7
6
5
4
3
2
1
0
AT % (RELATIVE)
1
3
5
7
9
11
13
15
17
19
21
DISTANCE FROM SURFACE (MICRONS)
Mo
W

FIG. 9

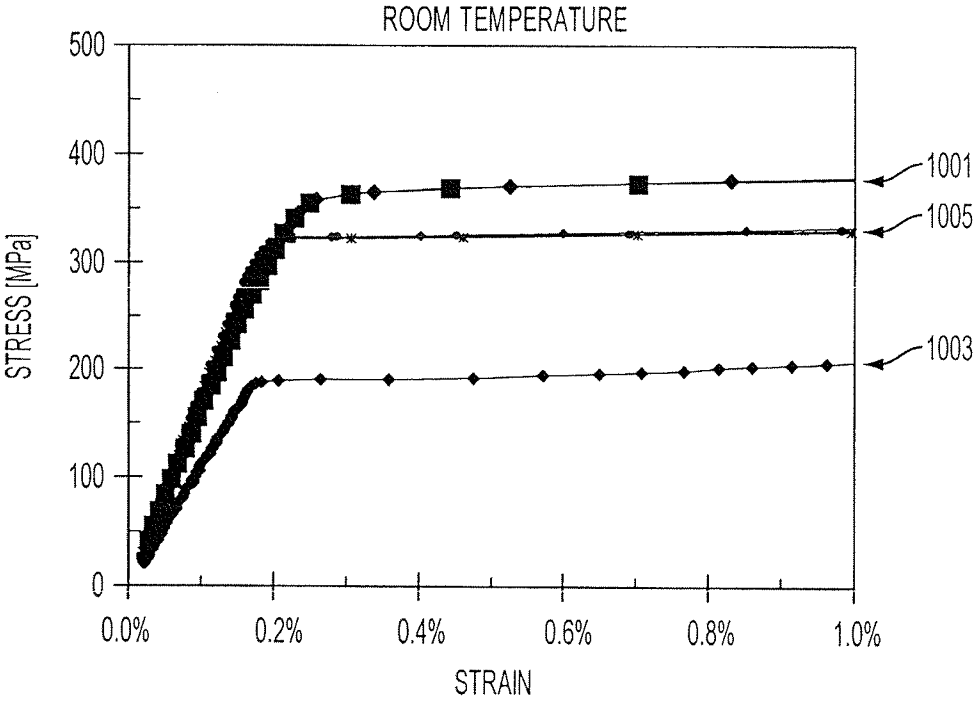
ROOM TEMPERATURE
STRESS [MPa]
500
400
300
200
100
0
0.0%
0.2%
0.4%
0.6%
0.8%
1.0%
STRAIN
1001
1005
1003

FIG. 10A

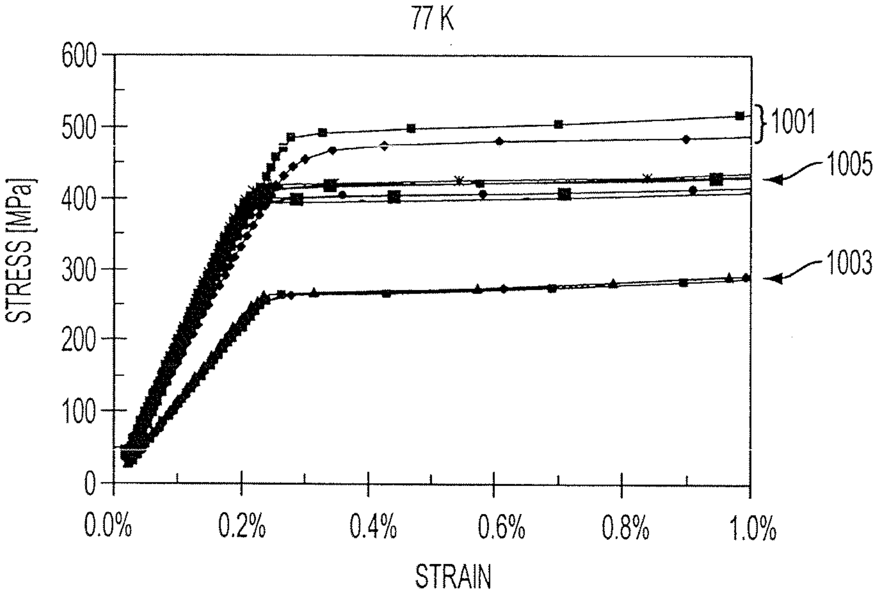
77 K
600
500
400
300
200
100
0
STRESS [MPa]
0.0%
0.2%
0.4%
0.6%
0.8%
1.0%
STRAIN
1001
1005
1003

FIG. 10B

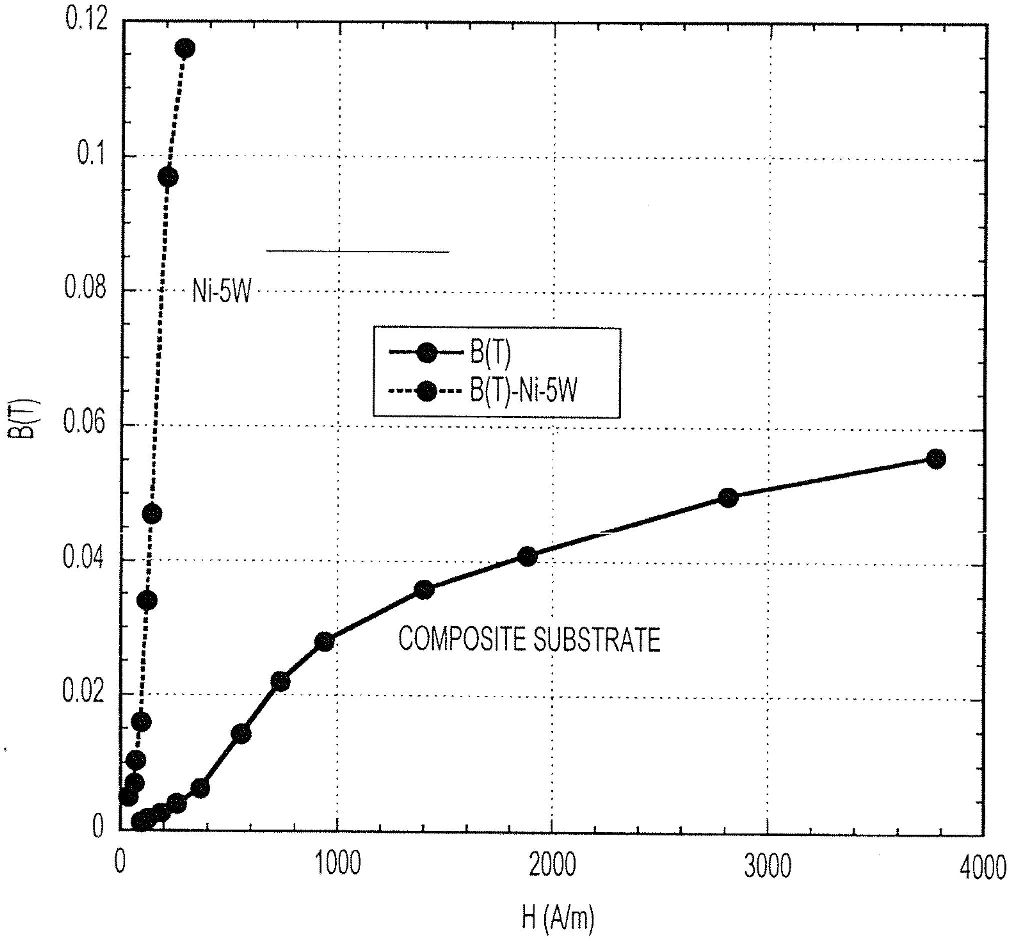
0.12
0.1
0.08
0.06
0.04
0.02
0
B(T)
0
1000
2000
3000
4000
H (A/m)
Ni-5W
B(T)
B(T)-Ni-5W
COMPOSITE SUBSTRATE

FIG. 11A

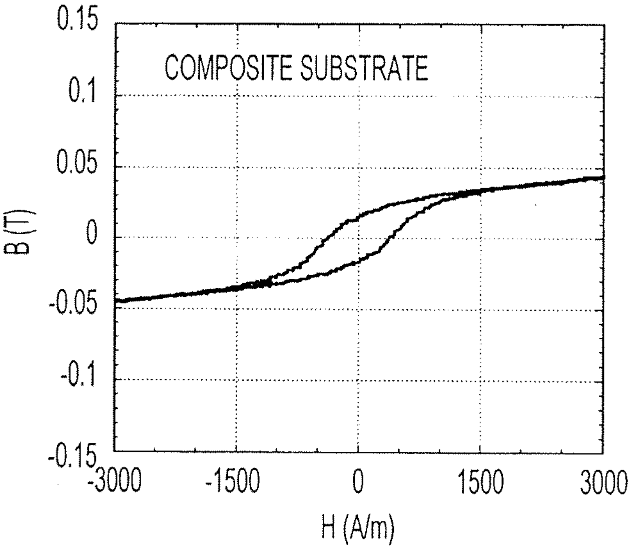

FIG. 11B

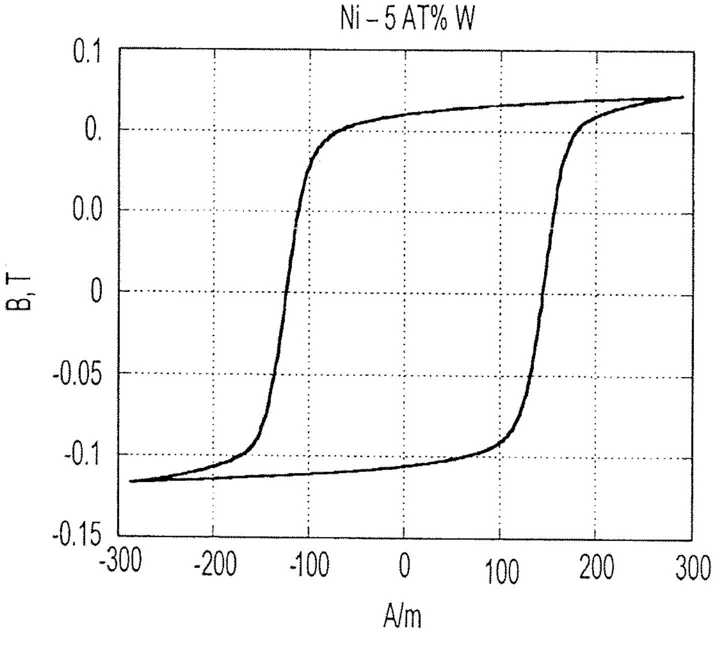

FIG. 11C

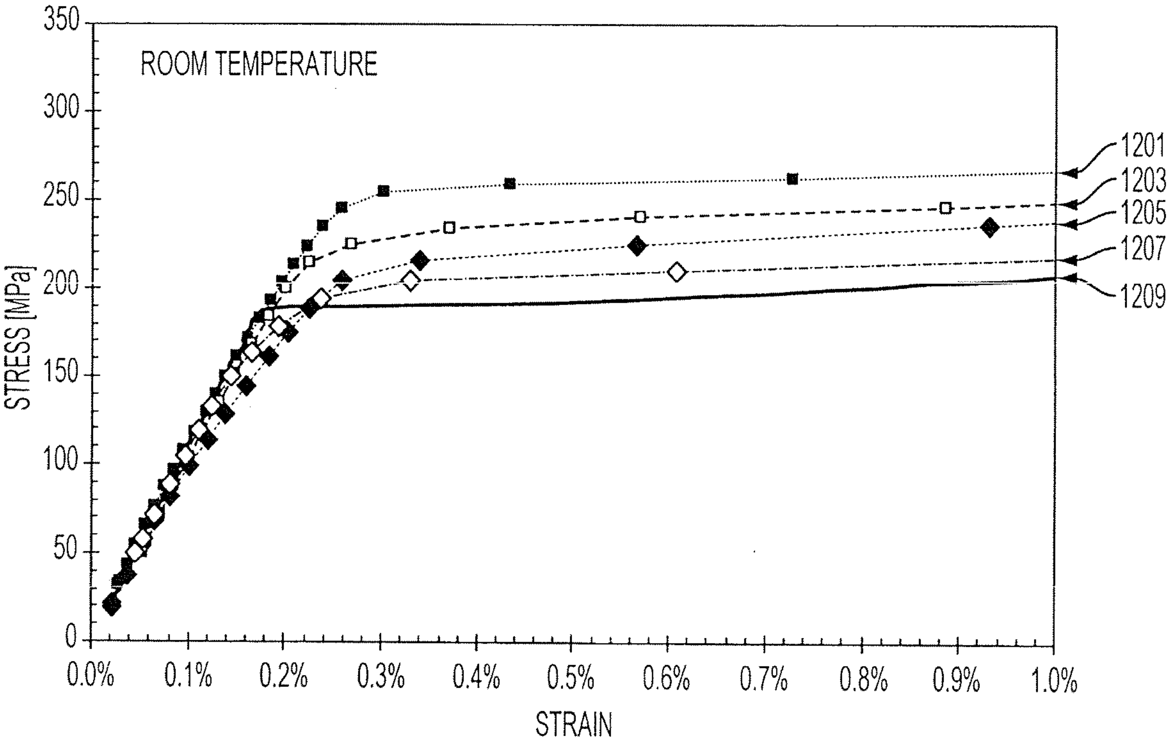
ROOM TEMPERATURE
STRESS [MPa]
STRAIN
350
300
250
200
150
100
50
0
0.0%
0.1%
0.2%
0.3%
0.4%
0.5%
0.6%
0.7%
0.8%
0.9%
1.0%
1201
1203
1205
1207
1209

FIG. 12A

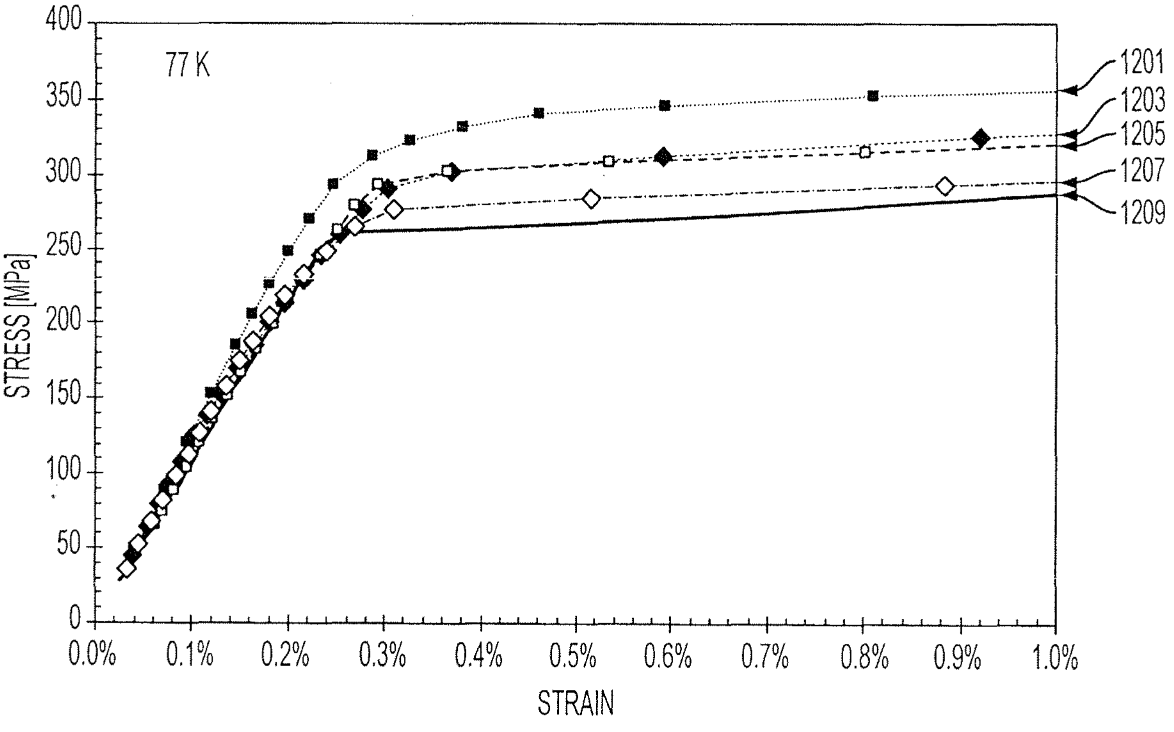
77 K
STRESS [MPa]
STRAIN
400
350
300
250
200
150
100
50
0
0.0%
0.1%
0.2%
0.3%
0.4%
0.5%
0.6%
0.7%
0.8%
0.9%
1.0%
1201
1203
1205
1207
1209

FIG. 12B

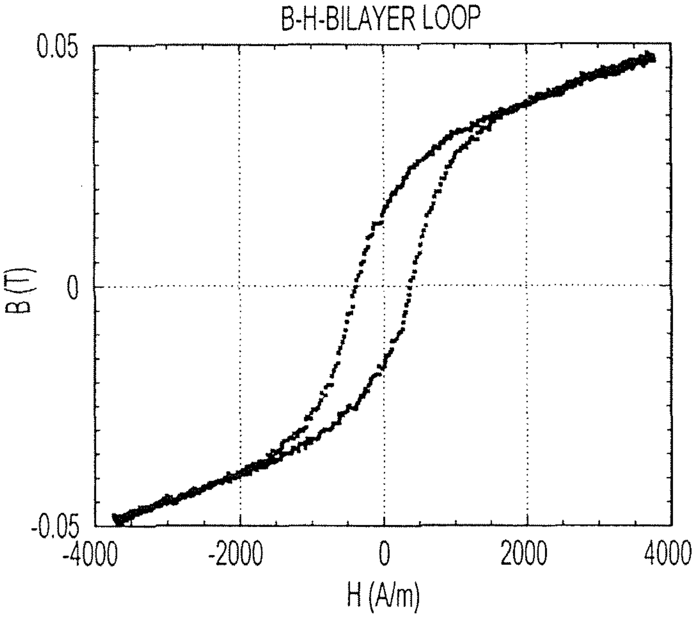

FIG. 13A

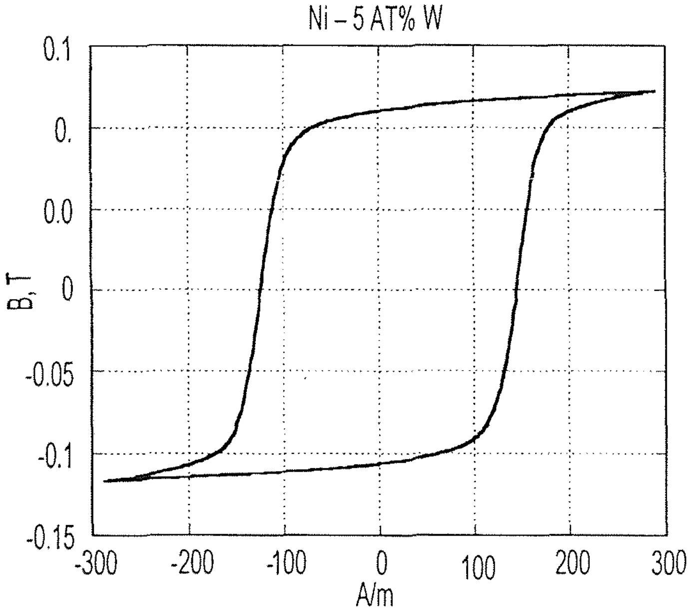

FIG. 13B

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2008/059133

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L39/24

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)
H01L

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 practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	BHATTACHARJEE ET AL: "Recrystallization textures of powder metallurgically prepared pure Ni, Ni-W and Ni-Mo alloy tapes for use as substrates for coated superconductors" PHYSICA C, NORTH-HOLLAND PUBLISHING, AMSTERDAM, NL, vol. 449, no. 2, 15 November 2006 (2006-11-15), pages 116-121, XP005671992 ISSN: 0921-4534 page 1999 -----	16,17,19
A	US 2002/076567 A1 (HONJO TETSUJI [JP] ET AL) 20 June 2002 (2002-06-20) -----	1-30
A	US 2005/031890 A1 (DE BOER BERND [DE] ET AL) 10 February 2005 (2005-02-10) -----	1-30

☐ Further documents are listed in the continuation of Box C.

☒ 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 document 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 5 September 2008	Date of mailing of the international search report 15/09/2008
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Koskinen, Timo

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2008/059133

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2002076567 A1	20-06-2002	JP 2002203439 A	19-07-2002
US 2005031890 A1	10-02-2005	AT 353375 T	15-02-2007
		CN 1404531 A	19-03-2003
		WO 0246108 A2	13-06-2002
		EP 1341941 A2	10-09-2003
		ES 2280419 T3	16-09-2007
		JP 2004515650 T	27-05-2004