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(54) **INTERMETALLIC COMPOUND SUPERCONDUCTING MATERIAL COMPRISING MAGNESIUM AND BERYLLIUM AND ALLOY SUPERCONDUCTING MATERIAL CONTAINING THE INTERMETALLIC COMPOUND AND METHOD FOR PREPARING THEM**

MAGNESIUM UND BERYLLIUM ENTHALTENDE SUPRALEITENDE INTERMETALLISCHE VERBINDUNG UND DIE INTERMETALLISCHE VERBINDUNG ENTHALTENDE SUPRALEITENDE LEGIERUNG UND VERFAHREN ZU IHRER HERSTELLUNG

COMPOSE INTERMETALLIQUE SUPRACONDUCTEUR RENFERMANT DU MAGNESIUM ET DU BERYLLIUM, ALLIAGE SUPRACONDUCTEUR RENFERMANT LEDIT COMPOSE INTERMETALLLIQUE ET PROCEDE POUR LEUR PREPARATION

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Description

Technical Field

[0001] This present invention relates to an intermetallic-compound superconductor and an alloy superconductor which can be utilized in superconducting electronics such as a large scale electric power transmission system, a superconductive power storage system, a high performance Josephson device and a high frequency electronic device, and which especially are high in superconducting transition temperature, are easy to manufacture, excel in malleability and ductility, and yet are altogether new. The invention also relates to a method of making such a novel superconductor.

Background Art

[0002] Superconductors are known to include a superconductor made of a simple metal, a superconductor made of a compound, and a superconductor made of composite oxides.

[0003] A simple metal superconductor may contain a simple metal such as Pb and Nb but is known to lack utility because it is low in superconducting transition temperature.

[0004] Known as intermetallic compound superconductors include those having a A15 type crystallographic structure of intermetallic compounds as represented by Nb_3Ge, Nb_3Ga, Nb_3Al and Nb_3Sn, and those having a chevrel type crystallographic structure of intermetallic compounds as represented by $PbMo_6S_8$. Intermetallic compound superconductors having an AlB_2 type crystallographic structure of intermetallic compounds as represented by NbB_2 are also known which, however, are also known to be extremely low in superconducting transition temperature (T_c = 0.62 K, see Journal of the Less-Common Metals, 67 (1979), 249 - 255). These intermetallic compound superconductors include one with Nb_3Ge which is relatively high in superconducting transition temperature (= about 23 K), but commonly have the disadvantage that they are weak in distortion and are fragile. Felner in "Absence of superconstructivity in BeB_2" (Los Alamos Nat. Lab., Preprint Archive,
Condensed Matter -2001) discloses a mixed (Mg, Be) B_2 system having the same Tc as pure Mg B_2.

[0005] Known as a composite oxide superconductor include La group oxide superconductors as represented by composition $La_{2-x}Ba_xCuO_4$, Y group oxide superconductors as represented by composition $Y_1Ba_2Cu_3O_{7-x}$, Bi group oxide superconductors as represented by composition $Bi_2Sr_2Ca_{n-1}Cu_nO_{2n+2}$, T1 group superconductors as represented by composition $Tl_2Ba_2Ca_{n-1}Cu_nO_{2n+2}$, and Hg group oxide superconductors as represented by $Hg_1Ba_1CaCu_1O_{6+x}$. These composite oxide superconductors are high in superconducting transition temperature and indeed include those which have their superconducting transition temperatures reaching as high as 150 K. The composite oxide superconductor has a perovskite structure made up of a lamination of an octahedral, pyramidal or planar superconducting layer of CuO_2, and a block layer (dissimilar in crystallographic structure to the superconducting layer) made of an atom or atoms such as La, Ca, Y, Bi or Hg and oxygen. As such the extreme complexity of the crystallographic structure of a composite oxide superconductor makes it difficult to conduct its production in a large volume and with good reproducibly. In addition, the superconductor being a composite oxide is naturally poor in both malleability and ductility, and is hard to use as a superconducting electric cable or wire.

[0006] A well known alloy superconductor is a Nb-Ti alloy, which is excellent in malleability and ductility and hence has been used to form superconducting electric cables or wires and superconducting magnets. However, an alloy conductor is as low in superconducting transition temperature as, e.g., about 9 K with the Nb-Ti alloy, and hence improvements in them are being sought.

[0007] As to superconducting cables or wires, it should also be noted that it may happen that a portion of a superconducting cable incidentally becomes normally conductive. Once this takes place, it may bring about a phenomenon, known as the "quenching" phenomenon, that triggered by Joule heating of the portion rendered normally conductive to have a finite electrical resistance, the entire material in a moment becomes normally conductive. When the quenching phenomenon occurs, serious consequences are met such as the burning of the superconducting cable and the explosive vaporization of coolant, both due to the Joule heat.

[0008] An attempt that has so far been made to avoid the quenching phenomenon is to provide a current bypass for a superconducting cable by winding a metal wire low in electric resistivity (specific resistance) around the superconducting cable so that when a portion of the superconducting cables incidentally becomes normally conductive, the current is allowed to escape through the current bypass.

[0009] The metal wire low in electric resistivity must, however, be formed of a metal such as silver (Ag) that is expensive and must therefore make the superconducting cable costly.

[0010] It is accordingly an object of the present invention to provide an alloy superconductor that is high in superconducting transition temperature and also excels in malleability and ductility, and that can be used to form a superconducting cable without the need for a current bypassing metal wire. It is further an object of the present invention to provide methods of making superconductors reproducibly and at a relative low cost of manufacture.

Disclosure of the Invention

[0011] In order to attain the object first mentioned above there is provided in accordance with the present invention an alloy superconductor as defined in claim 1.

[0012] The said alloy superconductor preferably has a superconducting transition temperature (T_c) of 35 K.

[0013] The said alloy superconductor preferably has a specific resistance not greater than 6 x 10^{-5} ohm-cm at a temperature ranging from its superconducting transition temperature (T_c) of 35 K to a room temperature.

[0014] Also, the alloy superconductor made up as mentioned above has a superconducting transition temperature (T_c) of 35 K, and is higher in superconducting transition temperature than any alloy superconductor so far known and also excels in both malleability and ductility. Moreover, it is lower in specific resistance at a temperature ranging from the superconducting transition temperature to a room temperature than any alloy superconductor so far known.

[0015] Further, the alloy superconductor made up as mentioned above can be used as a superconductor high in superconducting transition temperature and also excellent in malleability and ductility for a superconducting electric wire or cable used .in a superconducting electric power transmission system, a superconducting electric power storage system or the like and also in a superconducting electronic component such as a high performance Josephson device and a high frequency or electronic device.

[0016] A method of manufacture of an alloy superconductor in accordance with the present invention comprises the steps of: mixing a Mg containing feedstock powder, a Be containing feedstock powder and a B containing feedstock powder together to form a mixture powder thereof so that the mixture powder contains Mg, Be and B at a compositional ratio of Mg : Be : B = 1 : x : y where $0 < x < 20$ and $0 < y < 20$, shaping the said mixture powder into the form of a pellet, and heating the said pellet in a pressurized inert gas to form the alloy superconductor.

[0017] An alternative method of manufacture of an alloy superconductor in accordance with the present invention may comprise the steps of: mixing a Mg containing powder, a Be containing feedstock powder and a B containing feedstock powder together to form a mixture powder thereof so that the mixture powder contains Mg, Be and B at a compositional ratio of Mg : Be : B = 1 : x : y where $0 < x < 20$ and $0 < y < 20$, shaping the said mixture powder into the form of a pellet, and pressing and heating or hot pressing the said pellet to form the alloy superconductor.

[0018] In the method of manufacture of an alloy superconductor mentioned above, the said pellet is advantageously heated in the said inert gas under a pressure of 1 to 200 MPa at a temperature of 600 to 1100°C for a period of several minutes or more.

[0019] In the method of manufacture of an alloy superconductor mentioned above, the said pellet is advantageously pressed and heated or hot pressed under a pressure of 0.1 to 6 GPa at a temperature of 700 to 1400°C for a period of several minutes or more.

[0020] The methods mentioned above of making an alloy superconductor permit an alloy superconductor containing an intermetallic compound in accordance with the present invention to be manufactured reproducibly and easily.

<u>Brief Description of the Drawings</u>

[0021] The present invention will better be understood from the following detailed description and the drawings attached hereto showing certain illustrative forms of embodiment of the present invention. In this connection, it should be noted that such forms of embodiment illustrated in the accompanying drawings hereof are intended in no way to limit the present invention but to facilitate an explanation and understanding thereof. In the drawings:

Fig. 1 is a diagram illustrating a result of powder X-ray diffraction measurements conducted of an alloy superconductor of a composition represented by composition formula: $Mg_1Be_xB_y$ (where $0 < x < 20$ and $0 < y < 20$) according to the present invention;

Fig. 2 is a diagram illustrating a result of measurements conducted to derive the temperature characteristics of the electrical resistivity of an alloy superconductor of a composition represented by composition formula: $Mg_1Be_xB_y$ (where $0 < x < 20$ and $0 < y < 20$) according to the present invention; and

Fig. 3 is a diagram illustrating a result of measurements conducted to derive the temperature characteristics of the magnetic susceptibility of an alloy superconductor of a composition represented by composition formula: $Mg_1Be_xB_y$ (where $0 < x < 20$ and $0 < y < 20$) according to the present invention.

<u>Best Modes for Carrying Out the Invention</u>

[0022] Hereinafter, the present invention will be described in detail with reference to suitable forms of implementation thereof illustrated in the drawing figures.

[0023] Fig. 1 is a diagram illustrating a result of powder X-ray diffraction measurements conducted of an alloy superconductor of a composition represented by composition formula: $Mg_1Be_xB_y$ (where $0 < x < 20$ and $0 < y < 20$) according to the present invention.

[0024] The X-ray diffraction measurements were conducted using a biaxial X-ray diffraction analyzer (made by company RIGAKU, model RINT2000).

[0025] From the powder X-ray diffraction measurement pattern shown in Fig. 1, it is seen that the alloy superconductor of the present invention has a crystallographic structure that is hexagonal and belongs to the space group p6/mmm. It is also seen that with its a-axis having a length of 3.084 angstroms and its c-axis having a length of 3.5508 angstroms, it is a hexagonal AlB_2 type crystallographic structure.

[0026] Also in identifying the chemical composition, use is made of EPMA (Electron Probe Micro Analysis) and ICP (Induced Coupled Plasma) methods.

[0027] Mention is next made of the superconducting characteristics of an alloy superconductor of an alloy superconductor of a composition represented by composition formula: $Mg_1Be_xB_y$ (where $0 < x < 20$ and $0 < y < 20$) according to the present invention.

[0028] Fig. 2 is a diagram illustrating a result of measurements conducted to derive the temperature characteristics of the specific resistance (electrical resistivity of an alloy superconductor of a composition represented by composition formula: $Mg_1Be_xB_y$ (where $0 < x < 20$ and $0 < y < 20$) according to the present invention. The electrical resistance was measured according to the 4-probe method.

[0029] From Fig. 2, it is seen that the electrical resistance decreases with the temperature decreased, and sharply becomes zero at a temperature of 35 K, which indicates that the intermetallic compound has a superconducting transition temperature of 35 K. It is also seen from Fig. 2 that its specific resistance for normal conduction is extremely as low as 6×10^{-5} ohm-cm over a temperature range from the superconducting transition temperature of 35 K to a room temperature.

[0030] Mention is next made of a result of measurements of the magnetic susceptibility of an alloy superconductor of a composition represented by composition formula: $Mg_1Be_xB_y$ (where $0 < x < 20$ and $0 < y < 20$) according to the present invention.

[0031] Fig. 3 is a diagram illustrating a result of measurements conducted to derive the temperature characteristics of the magnetic susceptibility of an alloy superconductor of a composition represented by composition formula: $Mg_1Be_xB_y$ (where $0 < x < 20$ and $0 < y < 20$) according to the present invention. The magnetic susceptibilities were measured using a DC susceptometer or DC susceptibility measurement apparatus (made by company Quantum Design, MPMS Series, Model MPMS-R2).

[0032] As is apparent from Fig. 3, exhibiting negative susceptibilities, namely diamagnetism, at temperatures lower than T_c = 35 K it is seen that the alloy superconductor of a composition represented by composition formula: $Mg_1Be_xB_y$ (where $0 < x < 20$ and $0 < y < 20$) according to the present invention is a superconductor having a superconducting transition temperature of T_c = 35 K.

[0033] If, in accordance with the method of manufacture according to the present invention, feedstock powders are mixed together to contain magnesium, beryllium and boron at a compositional ratio of Mg : Be : B = I : x : y where $0 < x < 20$ and $0 < y < 20$, then there comes out an alloy superconductor containing the intermetallic compound mentioned above. Here, the compositional ratio can be varied to meet with an application purpose. For example, making Mg larger in compositional proportion may produce a superconducting electric cable that especially excels in malleability and ductility.

[0034] As regards feedstock powders, use may be made of Mg powder or MgO powder for Mg, Be powder for Be and B or BN powder for B.

[0035] In making an alloy superconductor, several methods are available.

[0036] In a first method, a Mg powder, a Be powder and a B powder are mixed together in the agitating apparatus to form a powder mixture, which is then shaped into a pellet form, which in turn is placed in a HIP (hot isostatic pressing) apparatus (made by, e.g., company Kobe Seiko, high temperature, high pressure atmosphere furnace) charged with an inert gas and is heated therein under an inert gas pressure of 1 to 200 MPa at a temperature of 600 to 1100°C for a period of several minutes or more. This method permits forming either superconductor with ease.

[0037] In a second method, a Mg powder, a Be powder and a B powder are mixed together in the agitating apparatus to form a powder mixture, which is then shaped into a pellet form, which in turn is placed in a cubic anvil pressing or like pressing apparatus and is heated therein under a pressure of 0.1 to 6 GPa at a temperature of 700 to 1400°C (hot pressed) for a period of several minutes or more. This method permits forming either superconductor with ease. High pressure is required to facilitate joining grain boundaries together while high temperature is needed to grow superconducting phase.

[0038] It should be noted here that an alloy superconductor according to the present invention is not limited in form to a polycrystalline sintered body as above but may in form be a polycrystalline bulk body, large single crystal, or a thin film.

[0039] Using a conventional bulk body fabricating apparatus such as a forging or a superhigh-pressure pressing and heating synthetic apparatus permits an intermetallic-compound or alloy superconductor in the form of a polycrystalline bulk body to be made that is light in weight, high in hardness and excels in corrosion resistance.

[0040] Also, a large single-crystal alloy superconductor is obtainable by using a known single-crystal growth process such as recrystallization, simple lifting, floating zone melting or fluxing, with the use of a suitable crucible in a controlled atmosphere.

[0041] Further, a thin-film alloy superconductor is obtainable by chemical gas-phase vapor deposition using a gas phase source containing magnesium, beryllium and boron at compositional ratio of Mg : Be : B = 1 : x : y Where $0 < x < 20$ and $0 < y < 20$, or by sputtering with the use of a target material as a sputtering source containing magnesium, beryllium and boron at the above compositional ratio. Also, for the substrate on which to form a thin-film alloy superconductor, use may be a metal substrate formed of, e.g., Cu, or a ceramic substrate, and may be a composite substrate having a ceramic deposited on a metal substrate. Such substrates may selectively be used to meet with a particular use or application.

[0042] A superconducting alloy that excels in malleability and ductility is obtainable by making larger the proportion of Mg that excels in malleability and ductility, or by compounding upon addition of another metal or metals that excels in malleability and ductility. Such a superconducting alloy can be worked by rolling or extrusion into an ultra-thin multi-core superconducting cable, a thin superconducting wire, or a superconducting alloy wire or cable.

Industrial Applicability

[0043] As can be appreciated from the foregoing description, the present invention provides an alloy superconductor which not only is high in superconducting transition temperature and excels in malleability and ductility, but also is low in specific resistance for normal conduction. Hence, it is not only useful for superconducting electronics such as a high performance Josephson device, a high frequency or electronic device, but also can highly advantageously be used to form superconducting electric cables to make them extremely less costly by eliminating the need to provide current bypassing metal wires therefor.

[0044] Further, using a method as described of making an alloy superconductor permits the alloy superconductor to be manufactured with an extremely high reproducibility, with ease, and at a reasonable cost.

Claims

1. An alloy superconductor **characterized in that** it contains an intermetallic compound made of Mg, Be, and B, and it is of a composition expressed by chemical composition formula: $Mg_1Be_xB_y$ where $0 < x < 20$ and $0<y<20$.

2. An alloy superconductor as set forth in claim 1, **characterized in that** it has superconducting transition temperature (T_c) of 35 K.

3. An alloy superconductor as set forth in claim 1 or 2, **characterized in that** it has a specific resistance not greater than 6×10^{-5} ohm-cm at a temperature ranging from its superconducting transition temperature (T_c) of 35 K to room temperature.

4. A method of making an alloy superconductor, **characterized in that** it comprises the steps of mixing a Mg containing feedstock powder, a Be containing feedstock powder and a B containing feedstock powder together to form a mixture powder thereof so that the mixture powder contains Mg, Be and B at a compositional ratio of Mg : Be : B = 1 : x : y where $0 < x < 20$ and $0 < y < 20$, shaping said mixture powder into the form of a pellet, and heating said pellet with applying pressure to form the alloy superconductor.

5. A method of making an alloy superconductor as set forth in claim 4, **characterized in that** said pellet is heated in an inert gas under pressure of 1 to 200 MPa at temperature of 600 to 1100 °C for a period of several minutes or more.

6. A method of making an alloy superconductor as set forth in claim 4, **characterized in that** said pellet is pressed and heated under pressure of 0.1 to 6 GPa at temperature of 700 to 1400 °C for a period of several minutes or more.

Patentansprüche

1. Supraleitende Legierung, **dadurch gekennzeichnet, daß** sie eine intermetallische Verbindung, hergestellt aus Mg, Be und B, beinhaltet und aus einer Zusammensetzung besteht, durch die chemische Formel $Mg_1Be_xB_y$ ausgedrückt, wobei $0 < x < 20$ und $0 < y < 20$.

2. Supraleitende Legierung nach Anspruch 1, **dadurch gekennzeichnet, daß** sie eine supraleitende Sprungtemperatur (T_c) von 35 K besitzt.

3. Supraleitende Legierung nach Anspruch 1 oder 2, **dadurch gekennzeichnet, daß** sie einen spezifischen Widerstand nicht größer als 6×10^{-5} Ohm-cm bei einer Temperatur, welche zwischen seiner supraleitenden Sprungtemperatur (T_c) von 35 K und der Raumtemperatur liegt, besitzt.

4. Verfahren zum Herstellen einer supraleitenden Legierung, **dadurch gekennzeichnet, daß** es die Schritte des Zusammenmischens eines Mgenthaltenden Feedstock-Pulvers, eines Be-enthaltenden Feedstock-Pulvers und eines B-enthaltenden Feedstock-Pulvers, um daraus ein Pulvergemisch zu erzeugen, so daß das Pulvergemisch Mg, Be und B in einem Verhältnis der Zusammensetzung von Mg : Be : B = 1 : x : y enthält, wobei $0 < x < 20$ und $0 < y < 20$, des Formens des Pulvergemisches in Form eines Pellets, und des Erhitzens des Pellets unter der Anwendung von Druck, um den Legierungs-Supraleiter zu bilden, umfaßt.

5. Verfahren zum Herstellen einer supraleitenden Legierung nach Anspruch 4, **dadurch gekennzeichnet, daß** das Pellet in einem Inertgas unter einem Druck von 1 bis 200 MPa bei einer Temperatur von 600 bis 1100 °C für einen Zeitraum von einigen Minuten oder mehr erhitzt wird.

6. Verfahren zum Herstellen einer supraleitenden Legierung nach Anspruch 4, **dadurch gekennzeichnet, daß** das Pellet unter einem Druck von 0,1 bis 6 GPa bei einer Temperatur von 700 bis 1400 °C für einen Zeitraum von einigen Minuten oder mehr gepreßt und erhitzt wird.

Revendications

1. Supraconducteur en alliage, **caractérisé en ce qu'**il contient un composé intermétallique constitué de Mg, Be, et B, et **en ce qu'**il a une composition exprimée par la formule de composition chimique: $Mg_1Be_xB_y$, où $0 < x < 20$ et $0 < y < 20$.

2. Supraconducteur en alliage selon la revendication 1, **caractérisé en ce qu'**il a une température de transition de supraconduction (T_c) de 35 K.

3. Supraconducteur en alliage selon la revendication 1 ou 2, **caractérisé en ce qu'**il a une résistance spécifique n'excédant pas 6×10^{-5} ohm-cm, à une température allant de sa température de transition de supraconduction (T_c) de 35 K à la température ambiante.

4. Procédé de fabrication d'un supraconducteur en alliage, **caractérisé en ce qu'**il comprend les étapes de mélange d'une poudre de charge contenant du Mg, une poudre de charge contenant du Be et une poudre de charge contenant du B pour former une poudre de mélange, de telle sorte que la poudre de mélange contient du Mg, du Be et du B selon un rapport de composition de Mg : Be : B = 1 : x : y où $0 < x < 20$ et $0 < y < 20$, donnant à la poudre de mélange la forme d'une pastille, et chauffant ladite pastille en appliquant une pression pour former le supraconducteur en alliage.

5. Procédé de fabrication d'un supraconducteur en alliage selon la revendication 4, **caractérisé en ce que** ladite pastille est chauffée dans un gaz inerte sous pression de 1 à 200 MPa, à une température de 600 à 1 100°C pendant plusieurs minutes ou plus.

6. Procédé de fabrication d'un supraconducteur en alliage selon la revendication 4, **caractérisé en ce qu'**on appuie sur ladite pastille et **en ce qu'**elle est chauffée sous une pression de 0,1 à 6 GP à une température de 700 à 1 400°C pendant plusieurs minutes ou plus.

FIG. 1

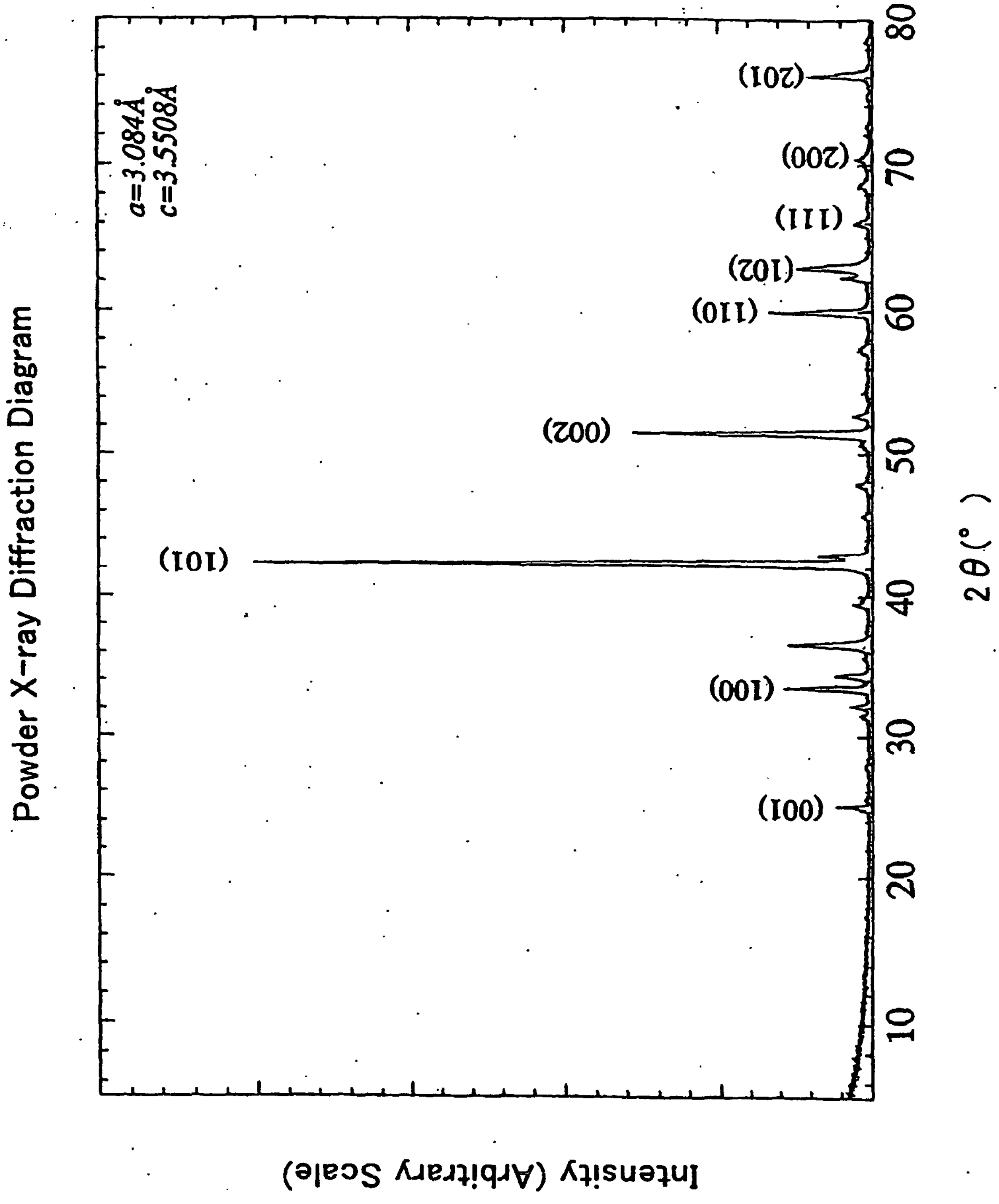

Powder X-ray Diffraction Diagram
a=3.084Å
c=3.5508Å
(100)
(001)
(101)
(002)
(110)
(102)
(111)
(200)
(201)
10
20
30
40
50
60
70
80
2θ(°)
Intensity (Arbitrary Scale)

FIG. 2

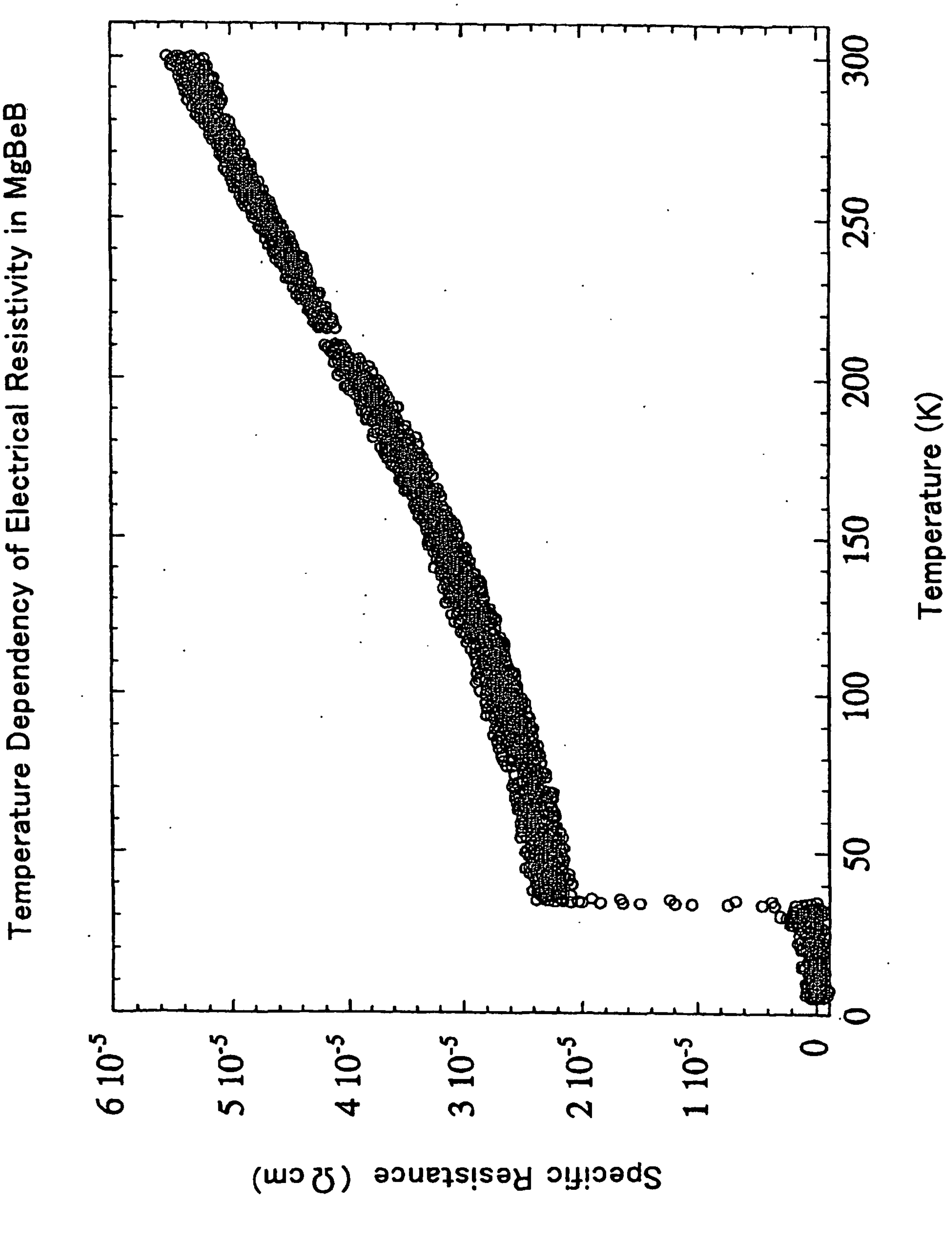
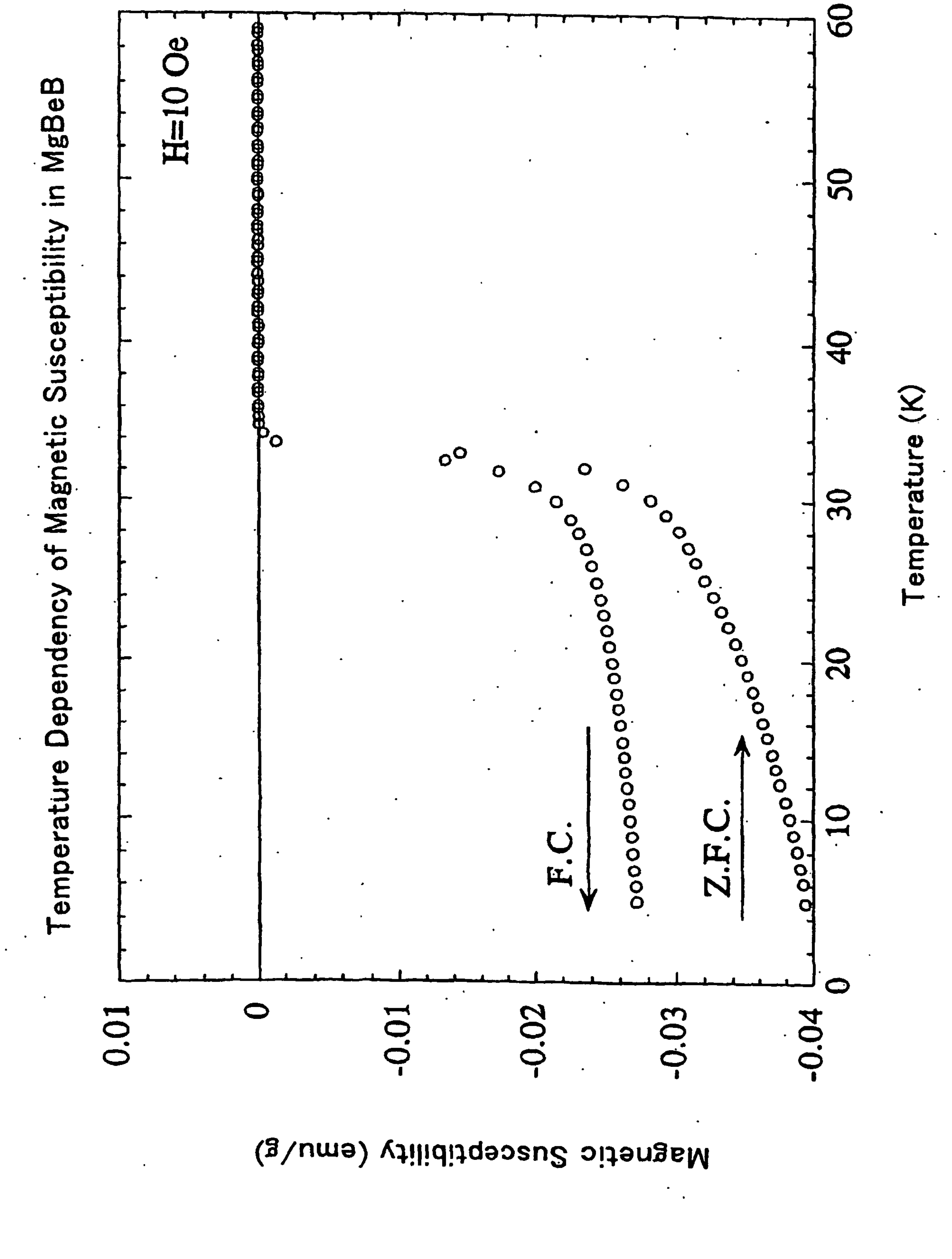

Temperature Dependency of Electrical Resistivity in MgBeB
Specific Resistance (Ω cm)
Temperature (K)
0
50
100
150
200
250
300
1 10-5
2 10-5
3 10-5
4 10-5
5 10-5
6 10-5

FIG. 3


Temperature Dependency of Magnetic Susceptibility in MgBeB
H=10 Oe
F.C.
Z.F.C.
Temperature (K)
0
10
20
30
40
50
60
Magnetic Susceptibility (emu/g)
0.01
0
-0.01
-0.02
-0.03
-0.04