Transactions of the Materials Research Society of Japan 27 [1] 31-34 (2002)

Crystal Orientation of Deposited Films in Laser and Resistive Heating Methods under a High Magnetic Field

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Bismuth, a non-magnetic material with crystal magnetic anisotropy was vaporized in laser and resistive heating methods and deposited on a glass plate as a substrate under the high magnetic field of 12T. The glass plate was set at a position with the maximum intensity of the magnetic field set in parallel and perpendicular to the direction of the magnetic field. In the laser and resistive heating methods, the orientation of crystals in bismuth films was examined by use of an X-ray diffraction method and compared with the expected crystal orientation due to the anisotropic magnetization energy. In the two heating methods, the crystal orientation appeared in a different tendency.

Key words: high magnetic field, electromagnetic processing of materials, non-magnetic material, crystal orientation

1. INTRODUCTION

A rather large space of a high magnetic field has become available in a comparatively easy way even in academic laboratories due to the development of recent superconducting magnet technologies. Under the high magnetic field, its effect becomes tangible in not only ferromagnetic materials but also non-magnetic ones such as paramagnetic and diamagnetic, on which the magnetic field has been considered to reveal negligible effect.

The several attempts improving material properties have been done by use of the high magnetic field that can induce an effective magnetization force even in non-magnetic materials. It has two functions based on the magnetization force. One is known as the force in which a magnet pulls ferromagnetic and paramagnetic materials and repulses diamagnetic and the other is recognized as the force such as rotates a compass to the direction of the magnetic field. The former is mainly used for magnetic separations[1], magnetic levitations[2] and measurements of magnetic susceptibility of materials[1,3]. The latter is used for alignments of crystal orientations and texture structures on the basis of susceptibility differences associated with crystal magnetic anisotropy and a shape magnetic one. Especially, a significant fraction of materials have different magnetic susceptibility in each direction of their unit crystal cells so that they have the possibility to be oriented to a certain direction under the high magnetic filed, even if they are non-magnetic materials. Therefore, the possibility of a magnetic transportation and a magnetic rotation has been examined under several processes such solidification[4,5], electro-deposition[6], vapor-deposition[7,8,9] and solid phase reaction[10]. Now the application of the high magnetic field is expected as one of basic technologies in materials processing, and the materials science and technology relating to the high magnetic field is now going to open a gate.

In this paper, the crystalline orientation under the high magnetic field is studied in vapor-deposition processes, where two heatings using a CW-YAG laser and an electric current were adopted to vaporize bismuth under the imposition of the high magnetic field.

2. ESTIMATION OF CRYSTAL ORIENTATION UNDER A MAGNETIC FIELD

Bismuth, with a hexagonal structure and a crystal magnetic anisotropy was used as a target material. Magnetic susceptibilities of bismuth for *a,b*-axis and *c*-axis are $\chi_{a,b} = -1.24\times10^{-4}$ and $\chi_c = -1.76\times10^{-4}$, respectively[11,12]. In a magnetic field a magnetization energy U is given as[4],

$$U = -\frac{\chi}{2\mu_0(1+N\chi)^2}B^2 \qquad (1)$$

, where B is external magnetic field, N is the demagnetization factor due to a shape magnetic anisotropy, μ_0 is the magnetic permeability in vacuum and χ is the magnetic susceptibility. The relation of $U_{a,b} < U_c$ is derived by substituting the magnetic susceptibility for each crystal orientation of bismuth into Eq.(1). As the lower energy state is preferable, *a,b*-axis should be parallel to the direction of the magnetic field from the viewpoint of the magnetization energy, that is, a *c*-plane orientated film is stable when the substrate plane is set in perpendicular to the direction of the magnetic field and a *a,b*-plane orientated film when the substrate plane is in parallel to the direction of the magnetic field.

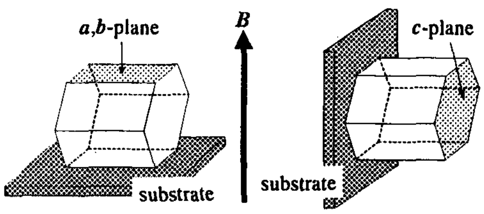

Fig.1 Preferable crystal orientations in a bismuth crystal under a magnetic field.

3. EXPERIMENTAL

Figures 2 and 3 show the schematic view of an experimental apparatus for the laser and resistive heating methods, respectively. The substrate and the crucible filled with bismuth of 5 nine purity were put in a vacuum chamber set in the bore of a superconducting magnet that generates 12T at the maximum. Experimental conditions for the both heating methods are listed in Tables 1 and 2, respectively. A glass plate(10mm×10mm) as the substrate was so cleaned in an ethanol bath with an ultrasonic cleaner as to eliminate organic materials on its surface and was set in parallel or perpendicular to the direction of the magnetic field at the position with the maximum magnetic flux density. The distance between the substrate and the target was fixed at 0.10m. After the degree of vacuum in the chamber reached at 5×10^{-3}Pa, a CW-YAG laser (wavelength: 1064nm) was irradiated from the upper part of the crucible in the laser heating and the temperature of the crucible was kept at 1073K in the resistive heating. The time for depositing was 30min. in both the vapor deposition methods.

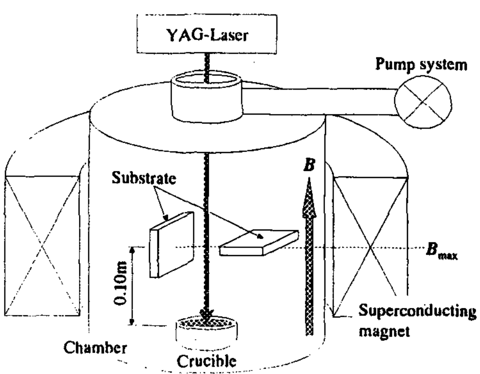

Fig.2 Schematic view of experimental apparatus for laser heating method.

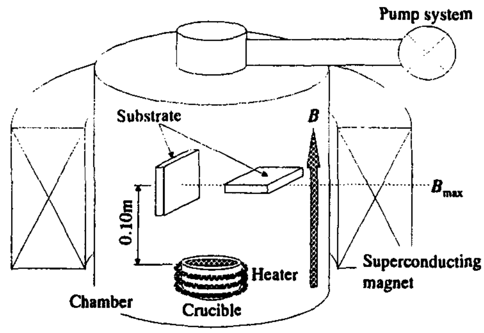

Fig.3 Schematic view of experimental apparatus for resistive heating method.

Table I Experimental conditions for laser heating method.

Pressure(Pa)	5×10^{-3}
Target to Substrate Distance(m)	0.1
Time of Deposition(min.)	30
Magnetic Flux Density(T)	0-12
Target	Bismuth
Substrate	Glass

Table II Experimental conditions for resistive heating method.

Pressure(Pa)	5×10^{-3}
Target to Substrate Distance(m)	0.1
Time of Deposition(min.)	30
Magnetic Flux Density(T)	0-12
Crucible Temperature(℃)	800
Target	Bismuth
Substrate	Glass

The orientation index[13] of samples was evaluated from the intensity of X-ray diffraction lines obtained in an X-ray diffraction analyzer (XRD) and the data of JCPDS.

4. RESULTS AND DISCUSSION

Figure 4 shows the relations between the magnetic field intensity and orientation indexes of (003) and (110) planes of bismuth films deposited on the substrate that was set in parallel to the direction of the magnetic filed in the laser heating. The orientation index of (003) plane that can be expected from the viewpoint of the magnetization energy increased with increasing of the magnetic field intensity and the orientation index of the energetically unfavorable plane (110) did not change with increase of magnetic field intensity. Figure 5 shows the relations between the magnetic field intensity and the orientation indexes of (003) and (110) planes of bismuth films deposited on the substrate that was set in perpendicular to the direction of the magnetic filed in the laser heating. The (003) plane orientation of *c*-plane is intensified though *a*,*b*-plane orientation should be preferable in the presence of the magnetic field and the orientation index of (110) plane does not change with increase of magnetic field intensity. That is, the orientation index of (003) plane increased with increasing of the magnetic field regardless of parallel and perpendicular directions of the magnetic field and that of (110) plane did not change with increase of the magnetic field intensity in the laser heating method. These results do not agree with the theoretical prediction based on susceptibility difference due to the crystal magnetic anisotropy.

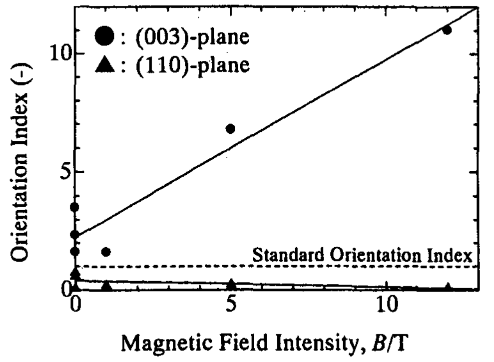

Fig.4 Relations between magnetic field intensity and orientation indexes of (003) and (110) planes of bismuth films under the magnetic field parallel to the substrate plane in laser heating method.

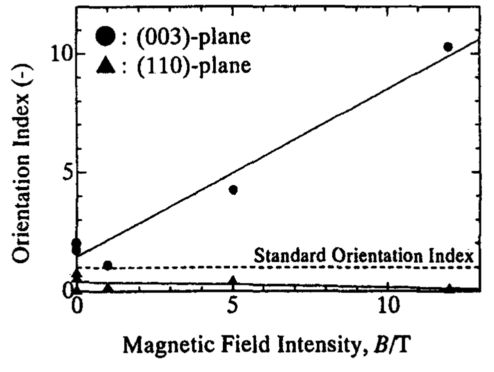

Fig.5 Relations between magnetic field intensity and orientation indexes of (003) and (110) planes of bismuth films under the magnetic fields perpendicular to the substrate plane in laser heating method.

Figure 6 shows the relations between the magnetic field intensity and the orientation indexes of (003), (110) and (202) planes of bismuth films deposited on the substrate that was set in parallel to the magnetic filed in the resistive heating. The orientation index of (003) plane of *c*-plane is increased and (202) plane that is detected strongly in the absence of magnetic field, is suppressed with increasing of the magnetic field intensity. On the other hand, Fig.7 shows the relations between the magnetic field intensity and the orientation indexes of (003), (110) and (202) planes in films deposited on the substrate that was set in perpendicular to the magnetic filed in the resistive heating. Though the orientation of (110) plane excepted from the magnetization energy is not clearly seen in the imposition of magnetic filed, the orientation index of (202) plane, which corresponds to a plane locating between *c*- and *a*,*b*-planes, increased with increasing of the magnetic field intensity, and that of (003) plane decreased. The reason why the intensity of (202) plane increases with increasing of the magnetic field is considered that the intensity of the magnetic field was not large enough to rotate crystals to the preferable direction of (110) plane. In the case of the resistive heating, the tendency of experimental results agrees with the theoretical prediction in both the parallel and perpendicular directions.

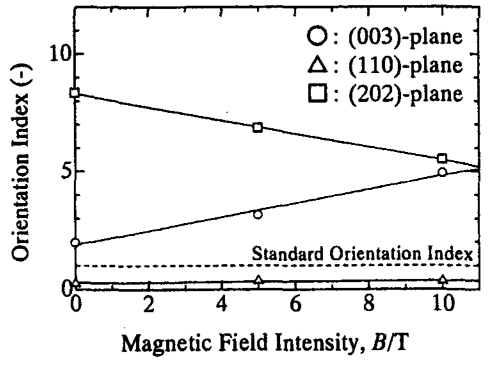

Fig.6 Relations between magnetic field intensity and orientation indexes of (003), (110) and (202) planes of bismuth films under the magnetic fields parallel to the substrate plane in resistive heating method.

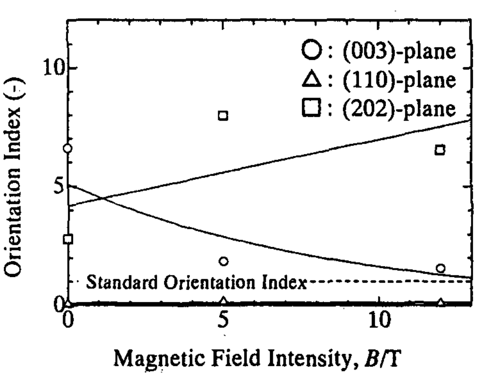

Fig.7 Relations between magnetic field intensity and orientation indexes of (003), (110) and (202) planes of bismuth films under the magnetic fields perpendicular to the substrate plane in resistive heating method.

5. SUMMARY

Bismuth was vaporized in the laser and resistive heatings and deposited under the high magnetic field. The following results have been obtained.

1) In the case of the laser heating, *c*-plane orientation increased with increasing of the magnetic field regardless of magnetic filed directions.
2) In the case of the resistive heating, the crystal orientation of a thin film appeared as expected from the magnetization energy in both the parallel and perpendicular directions of the magnetic field.

REFERNCES

[1] N.Waki, K.Sassa and S.Asai, *Tetsu-to-Hagane*, **86**, 363-369 (2000).
[2] E.Beaugnon and R.Tournier, *Nature*, **349**, 470 (1991).
[3] F.Gaucherand and E.Beaugnon, *Physica B*, **294-295**, 96-101 (2001).
[4] H.Morikawa, K.Saasa and S.Asai, *Mater. Trans., JIM*, **8**, 814-818 (1998).
[5] H.Yasuda, K.Tokieda and I.Ohnaka, *Mater. Trans., JIM*, **41**, 1005-1021 (2000).
[6] T.Taniguchi, K.Sassa and S.Asai, *Mater. Trans., JIM*, **41**, 981-984 (2000).
[7] S.Mitani, H.L.Bai, Z.J.Wang, H.Fujimori and M.Motokawa, *The 3rd International Symposium on Electromagnetic Processing of Materials, Nagoya, Japan, ISIJ*, 630-634 (2000).
[8] M.Tahashi, K.Sassa, I.Hirabayashi and S.Asai, *Mater. Trans., JIM*, **41**, 985-990 (2000).
[9] S.Awaji, K.Watanabe, Y.Ma and M.Motokawa, *Physica B*, **294-295**, 482-485 (2001).
[10] M.Ito, K.Sassa, M.Doyama, S.Yamada and S.Asai, *TANSO*, **191**, 37-41 (2000).
[11] Landolt-Börnstein, "Eigenschaften der Materie in ihren Aggregatzständen (9teil, Magetic Properties I)", Springer, (1962), pp.1-12.
[12] Landolt-Börnstein, "Eigenschaften der Materie in ihren Aggregatzständen (10teil, Magnetic Properties II)", Springer, (1967), pp.2-65.
[13] K.S.Willson and J.A.Rogers, *Tech. Proc. American Electroders Society*, **51**, 92-95 (1964).

(Received December 21, 2001; Accepted January 30, 2002)