Progress in Superconductivity Vol.1, No1 pp 51-55 15 August 1999

Evolution of Cube Texture in the Nickel-Silver-Stainless steel Multi-layer Sheet

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Received July 23, 1999

Abstract

A Ni/Ag/Stainless steel 310S(SS310S) multi-layer sheet has been fabricated by a combination of vacuum brazing, cold rolling and texture annealing processes. After heat -treating the thin Ni/Ag/SS310S multi-layer sheet at 900℃ for 2h, development of (100)<001>cube texture on Ni surface was revealed by (111) pole figure. Quantitative chemical analysis was made by EPMA for the cross-section of the Ni/Ag/SS310S multi-layer sheet. EPMA results showed that Ag diffusion into the Ni layer, which may suppress the cube texture development, was negligible. A small amount of Cr atoms were detected in the Ni layer. It showed that Ag can be used as a chemical barrier of alloying element atoms in Ni layer for the Ni/Ag/SS310S multi-layer sheet and a strong cube texture was developed for the Ni layer in the Ni/Ag/SS310S multi-layer sheet.

Keywords: nickel, silver, stainless steel, cube texture, chemical barrier

I. Introduction

Among the high-T_c oxide superconductors(T_c> 77K), $YBa_2Cu_3O_{7-\delta}$ (YBCO) has the advantage of magnetic field resistance in critical current density(J_c) at 77K, in addition to high T_c and J_c. Therefore, there has been many approaches for fabricating high J_c YBCO film on polycrystalline substrates in order to use it as a current carrying conductor. However, the weak superconducting coupling of high-angle grain boundaries act as a bottle neck in achieving a high J_c YBCO polycrystalline conductor.

In order to overcome the weak coupling, Iijima et al.[1] deposited biaxially aligned YSZ buffer layer films on Ni-based alloy (HASTELLOY C-276) using the ion beam assisted deposition(IBAD). A high J_c YBCO tape conductor with the J_c of 10^6 A/㎠ was obtained by the subsequent deposition of biaxially aligned YBCO films on the biaxially aligned YSZ buffer layer.

Goyal et al.[2] succeeded in fabricating high Jc superconducting tapes by epitaxial deposition of ceramic buffer layers and YBCO thick films on a cube textured Ni substrate. The fabrication technique of cube textured Ni metal is so simple to scale up industrially. However, pure nickel has some disadvantages for practical applications because of its relatively weak mechanical properties and strong ferromagnetism that cause magnetic hysteresis loss in ac applications. Therefore improvement of these properties of nickel is needed without sacrificing sharp cube texture which is most important to obtain high Jc YBCO film conductor.

The joining of dissimilar material with nickel metal may be one of the ways to modify the properties of the Ni metal substrate, RABiTS(rolling-assisted- biaxially-textured-substrate). The prerequisite in selecting a joining material is that the nickel metal should have a sharp cube texture when it is processed by severe cold rolling and long heat treatment after joining. It has been known that the development of cube texture of nickel sheet is suppressed

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by the incorporation of impurity atoms in the metal[3]. Therefore, in order to meet this requirement, the joined material should be chemically inert to nickel while the joined interface should be mechanically strong enough not to be split during severe mechanical deformation and high temperature annealing processes. Good adhesion between joined metals usually indicates the presence of a chemical reaction. Therefore, it is a subtle problem to compromise these two properties.

Very recently, Lee et al.[4] showed that sharp (100)<001> cube texture was developed for the Ni layer in the Ag/Ni bi-layer prepared by a combination of powder metallurgy, diffusion bonding, cold rolling and texture annealing processes. Thereby, they suggested that Ag can be used as a chemical barrier for Ni and the joining of dissimilar materials leads to the modification of the properties of each of the joined materials.

The Ag has been selected because Ni, Cr and Fe, which are major alloying elements of commercial stainless steel, has a very low solubility in Ag[5] and Ag has lower melting point than Ni and SS310S stainless steel (hereafter, SS310S). SS310S was selected because it is non-magnetic, mechanically strong, relatively cheap, oxidation resistive and so on.

Brazing, which was used here to construct a Ni/Ag/SS310S multi-layer structure, takes place below the melting point of the parts or base metals to be joined by virtue of having a third metal which becomes molten placed between the parts that are to be joined. Since this "filler" metal becomes molten during the joining process it can form an excellent mechanical fit, even on an atomic level, with the base metals[6]. Ag takes a role of as a filler metal as well as a base metal of a Ni/Ag/SS310S multi-layer structure.

In this work, we report the successful role of Ag as a chemical barrier and the development of cube texture in a Ni/Ag/SS310S multi-layer that was prepared using the combination of vacuum brazing, cold rolling and texture annealing processes.

II. Experimental

Starting materials were high purity 1 mm-thick silver sheet(3N), 1 mm-thick nickel plate(4N) and 1.5 mm thick commercial 310S stainless steel. Brazing of Ni and SS310S sheets were performed by placing the Ag sheet between Ni and SS310S sheets and then heating above the melting point of Ag. The brazed 3.5 mm thick Ni/Ag/SS310S specimen was cold rolled to 90㎛. In order to obtain a cube texture, the Ni/Ag/SS310S multi-layer sheet was heated at a rate of 500℃/h and held at 900℃ for 2h. All the heat treatments were done in a vacuum at a pressure of ~ $5.0x 10^{-6}$ Pa.

The texture was measured by the Schultz reflection method. The α angle (rotation angle around an axis perpendicular to the goniometer axis) of the cube texture was measured between 20° and 90° . The microstructures were observed by an optical microscope(OM). The sectional chemical composition change along Ag/Ni interface measured by electron probe microanalyser(EPMA)

III. Results and Discussion

Fig.1 shows the cross-sectional OM microstructure of the Ni/Ag/SS310S multi-layer sheet which was cold rolled with a reduction amount of ~ % and heat treated at 900℃ for 2h. It is seen that an interface between the silver and nickel layers is clearly distinguished as well as the interface between Ag and SS310S.

Fig. 2 gives a (111) pole figure of the Ni surface of

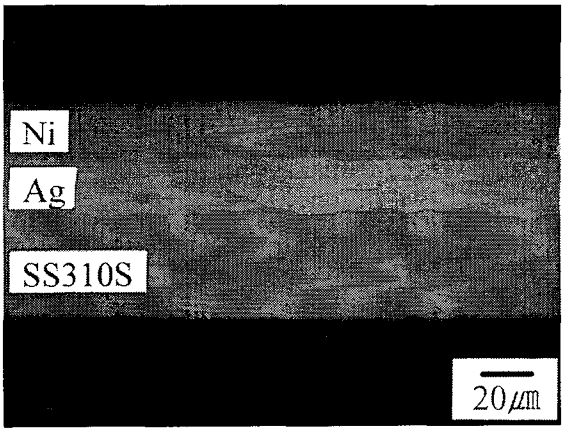

Fig.1 Cross-sectional OM microstructure of the Ni/Ag/SS310S multi-layer sheet which was cold rolled with ~98 % reduction and heat treated at 900℃ for 2h.

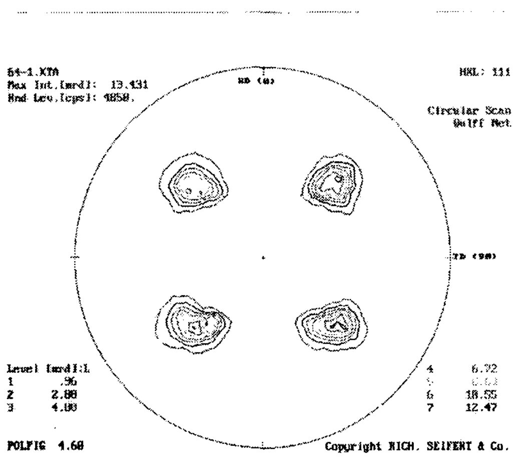

Fig.2 (111) pole figure of the nickel surface for the Ni/Ag/SS310S multi-layer sheet heat treated at 900℃ fo 2h.

the Ni/Ag/SS310S multi-layer sheet heat treated at 900℃ for 2h. The development of the cube texture, in which (100) plane is parallel to the sheet plane and <001> direction is aligned to the rolling direction is revealed. The cube texture of face centered cubic (FCC) sheets is known to be very sensitive to the presence of impurity atoms[3]. We observed that the diffusion of Fe and Cr into nickel clearly suppressed the development of the cube texture for a SS304/Ni bilayer sheet[7]. The Ag and Ni used in this study were sufficiently pure. Thus it can be said that the insertion of an Ag layer between Ni and SS310S layers clearly suppress the diffusion of alloying element of SS310S into the Ni layer across the Ag layer to the extent that the development of cube texture in the Ni layer was not hindered severely by the incorporation of impurity atoms under this process condition.

Fig. 3 shows the concentration profiles of Ag, Cr, Fe, Mn and Ni atoms obtained across the Ag/SS310S interfaces for the Ni/Ag/SS310S multi-layer sheet annealed at 900℃ for 2h. It is seen that the concentration profiles of Ag, Cr, Fe, Mn and Ni atoms are abruptly dropped across the Ag/SS310S interface. It means that the inter-diffusion of Ag, Cr, Fe and Ni atoms into each facing layer was sluggish at the texture annealing condition for the development of cube texture in the Ni layer of the Ni/Ag/SS310S multi-

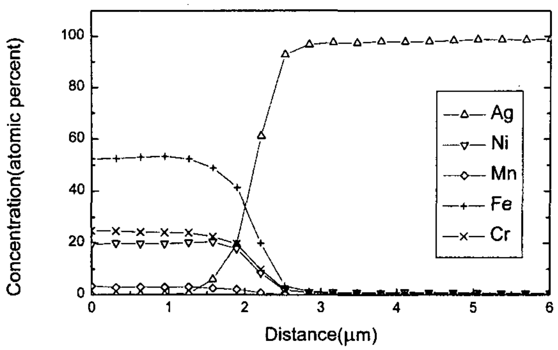

Fig.3 Concentration profiles of Ag , Cr, Mn, Fe and Ni atoms across the Ag/SS310S interface for the Ni/Ag/SS310S multi-layer sheet annealed at 900 ℃ for 2h.

layer sheet. Figure 4 shows the concentration profiles of Ag, Cr, Fe, Mn and Ni atoms obtained across the Ag/Ni interface for the SS310S/Ag/Ni multi-layer sheet annealed at 900℃ for 2h. It is seen that the concentration profiles of Ag and Ni atoms are abruptly dropped across the Ag/Ni interface. It means that the inter-diffusion of Ag and Ni atoms into each facing layer was very sluggish at the annealing condition for the development of cube textures in the severely cold deformed Ni layer. It is seen that small amounts of Cr were detected in the Ni layer whereas Fe and Mn atoms were not. All of Cr, Fe and Mn atoms have little solubility in pure Ag and are highly soluble in pure nickel at the processing condition[8].

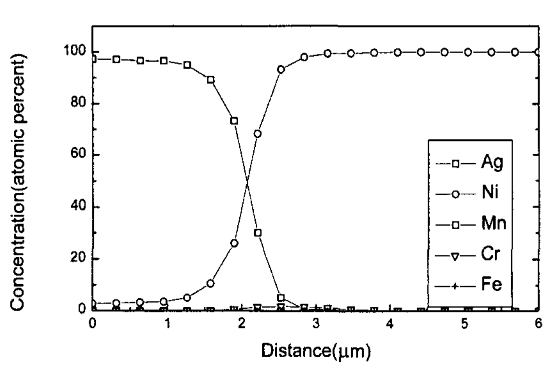

Fig.4 Concentration profiles of Ag , Cr, Mn, Fe and Ni atoms across the Ag/Ni and Ag/SS310S interfaces for the Ni/Ag/SS310S multi-layer sheet annealed at 900℃ for 2h.

In order to explain why the Cr atoms diffused in Ni through the Ag layer, further thermodynamical and kinetical works is needed. From the above observations, it can be said that the Ag layer successfully carried out the role as a chemical barrier for the Ni/Ag/SS310S multi-layer structure even though a small amount of Cr was diffused into the Ni layer via Ag layer.

As described earlier, the joining between dissimilar materials leads to the modification of the properties of the joined materials. By varying the component and the volume fraction of the joined materials, the properties of the bilayered structure can be modified mechanically, electrically, magnetically, thermally etc.

In general, the physical properties of the bilayer sheet will be expressed as a simple equation using the physical properties of two components.

Choi et al.[9] reported that the tensile deformation behavior of the clad bilayer sheet followed the rule of mixture.

$$\sigma_u = \sigma_{uA} V_A + \sigma_{uB} V_B \quad (1)$$

where σ_u and V indicate the uniaxial flow stress and volume fraction, respectively. Subscripts A and B stand for bi-layer components A and B layers, respectively. Thereby, the tensile deformation behavior of the clad tri-layer sheet followed the rule of mixture.

$$\sigma_u = \sigma_{uA} V_A + \sigma_{uB} V_B + \sigma_{uC} V_C \quad (2)$$

where σ_u and V indicate the uniaxial flow stress and volume fraction, respectively. Subscripts A, B and C stand for tri-layer components A, B and C layers, respectively.

Magnetic hysteresis loss will also follow the rule of mixture because magnetic hysteresis loss is linearly proportional to the volume fraction of material component.

Thereby, the magnetic hysteresis loss of the clad tri-layer sheet followed the rule of mixture.

$$W_h = W_{hA} V_A + W_{hB} V_B + W_C V_C \quad (3)$$

where W and V indicate the magnetic hysteresis loss and volume fraction, respectively. Subscripts A, B and C stand for tri-layer component A, B and C layers, respectively.

However in the case of electrical and thermal conductivity, we have to consider the anisotropy; the direction parallel or normal to the sheet plane. In the direction parallel to the sheet plane, electrical and thermal resistance of the trilayer sheet shows series resistance of the components A, B and C. In the direction normal to sheet plane, electrical and thermal resistance of the bilayer sheet shows parallel resistance of the components A, B and C. The yield strength of the annealed Ni/Ag/SS310S trilayered sheet was measured as high as about double compared to that of annealed cube textured Ni sheet[10]. Therefore, it can be said that the physical properties of the bilayer sheet can be modified by the proper combination of different materials. Characterization of the Ni/Ag/SS310S trilayered sheet is on progress systematically.

IV. Conclusions

A Ni/Ag/Stainless steel 310S(SS310S) multi-layer sheet has been fabricated by a combination of vacuum brazing, cold rolling and texture annealing processes. After heat treating the thin Ni/Ag/SS310S multi-layer sheet at 900℃ for 2h, a Ni (111) pole figure for the nickel surface demonstrated the development of (100)<001> cube texture. Qualitative and quantitative chemical analysis of EPMA were made for the cross-section of the Ni/Ag/SS310S multi-layer sheet. EPMA results showed that Ag diffusion into the Ni layer, which may suppress the cube texture development, was negligible. No diffusion of Mn, Fe atoms into the Ni layer was detected. It showed that the role of Ag as a chemical barrier of alloying element atoms in Ni layer for the Ni/Ag/SS310S multi-layer sheet was so successful as to induce the cube texture development for the Ni layer in the Ni/Ag/SS310S multi-layer sheet.

Acknowledgements

This work was financially supported by Ministry of Science and Technology (MOST).

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