Measurements of interfacial spin-polarization of ferromagnetic materials with the use of epitaxial NbN junctions

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Epitaxial NbN/ferromagnetic material (Co and Co₂MnGe) multilayers have been grown on MgO (100) substrate and the spin polarization of the ferromagnetic materials has been investigated by using the multilayer junctions. The Co₂MnGe layers have been deposited on MgO//NbN and the inverted structure (NbN layers on Co₂MnGe films) has been also made. The epitaxial relationship between NbN and Co₂MnGe layers with an in-plane 45° rotation was confirmed for the two types of multilayer structures. Andreev reflection measurements on these junctions and the modified Blonder-Tinkham-Klapwijk (BTK) analysis have shown that the spin polarization values of Co and Co₂MnGe are 0.38 and 0.51, respectively. These values are in good agreement with previous data obtained by using the point-contact Andreev reflection (PCAR) technique. The results suggest the potential of the epitaxial NbN junction method as a measurement technique of spin polarization.

Key words: spin polarization measurement, hetero-epitaxial multilayer, Andreev reflection, Heusler alloy,

1. INTRODUCTION

Recently, magnetic tunnel junctions (MTJ) and current-perpendicular-to-plane giant magnetoresistance (CPP-GMR) junctions using fully epitaxial multilayer ferromagnetic layers of half-metal Heusler alloys have attracted much attention^{[1],[2],[3]}. The effects based on half-metallicity of these Heusler alloys have been observed, i.e. high magnetoresistance (MR). On the other hand, it has been suggested that coherent electronic conduction in the hetero-epitaxial multilayers also have contributed to these effects^[2]. In order to clarify spin conduction of these junctions, it is important to divide the origin of these effects between interface spin polarization of Heusler alloy layers and coherent electronic conduction in the hetero-epitaxial multilayers. Therefore, we need the measurement method, which can directly determine the spin polarization values of epitaxial Heusler alloy layers in the junction structures, and divide two contributions for spin conduction. Traditionally, spin polarization of Heusler alloys have been measured by point contact Andreev reflection (PCAR) method where superconductor needle is contacted on the surface of samples^[4]. To measure interfacial spin polarization of ferromagnetic layers in the junction structures directly by means of Andreev reflection method, to use superconductor films on the ferromagnetic layer, instead of using superconductor needles, this problem can be solved. We have already reported spin polarization measurements on polycrystalline superconductor / half-metal (NbN / La_{0.67}Sr_{0.33}MnO₃) junctions^[5].

In order to investigate contribution of coherent electronic conduction in the hetero-epitaxial multilayers, it may be useful to utilize both superconducting quasiparticle tunneling spectroscopy^[6] and Andreev reflection in hetero-epitaxial superconductor / (MgO) / Heusler alloy junctions. It is known that MgO has

epitaxial relations with Heusler alloys^[2], and also with superconducting NbN^[7]. Therefore, it is expected that high quality hetero-epitaxial structures are obtained using Heusler alloys, MgO and NbN films. Moreover, it has been reported that electronic structures of top and bottom electrodes can be different due to the B2 and L2₁ ordering of top electrode in the MTJ with the Heusler alloy. If the both NbN / (MgO) / Heusler alloy and Heusler alloy / (MgO) / NbN junctions are fabricated, we can independently investigate the electronic structures of the top and bottom electrodes in MTJ. In this paper, we will report the fabrication of hetero-epitaxial NbN / Heusler alloy (Co₂MnGe) and spin polarization of Heusler alloy Co₂MnGe measured by using the Andreev reflection in epitaxial NbN / Co₂MnGe junctions.

2. EXPERIMENTAL PROCEDURE

Three groups of samples were prepared. The first group is films (250 nm) deposited onto MgO (001) substrates, in order to optimize NbN deposition conditions. These films were grown by reactive sputtering of Nb in Ar + N₂ gas of which N₂ gas ratio from 10 to 18%, at substrate temperatures of from R.T. to 600 °C. The second group is multilayer samples, for investigating the relationship of epitaxial growth between NbN and Heusler alloys. As the samples of this group, we prepared the multilayers of Co₂MnGe layer (50nm) / NbN layer (100 nm or 150 nm) deposited onto Cr buffered MgO (100) substrates, and the multilayers of NbN layer (100 nm) / Co₂MnGe layer (100 nm) deposited on MgO (100) substrates. The Cr and Co₂MnGe layers are prepared by ion beam sputtering methods with the optimized deposition condition^[8]. The crystal structures and orientation of NbN films and multilayers have been analyzed by X ray diffraction (XRD) with a four-axis goniometer. The surface

roughnesses of NbN films have been estimated by atomic force microscopy (AFM). The magnetic properties of multilayers have been measured by vibrating sample magnetometer (VSM). The third group is micron-sized junctions (30, 50, or 100 μm^2) in order to measure Andreev reflection of Co_2MnGe . These junctions were fabricated using photolithography and ion milling. The conductance measurements were performed using a lock-in technique at 4.2 K. The experimental conductance curves were analyzed and the spin polarization P was extracted by fitting the conductance curve with the modified BTK model. In order to confirm the reliability of this NbN junction method, the spin polarization value of typical ferromagnetic metal: Co have been also estimated by this method.

3. RESULTS AND DISCUSSIONS

Figure 1 shows XRD patterns for NbN (100 nm) grown on MgO under optimized substrate temperature (600 $^{\circ}\text{C}$) and nitrogen gas ratio(16%) in reactive sputtering gas. In this XRD pattern, no reflections are observed except for reflections of NbN (002), and substrates. The full width at half maximum of diffraction peak rocking curve for the NbN(002) peaks of this film is 0.5 degree, and the in-plane measurements of NbN (002) peak show the four-fold symmetry. These XRD results show that this NbN film is epitaxial grown on MgO (001) substrate. The superconducting critical temperatures of NbN films have been observed to be from 10 K to 13 K. The typical value of surface roughness of these films was 0.25 nm. The AFM result shows that the films have sufficient low surface roughness for tunneling devices in the future. As whole results about NbN films indicate that sufficient quality NbN films have been obtained to use epitaxial NbN junction method.

Figure 2 shows XRD patterns of NbN / Co_2MnGe and Co_2MnGe / NbN multilayers on MgO (100) substrates. In these XRD patterns, no reflections are observed except for reflections of NbN (002), Co_2MnGe (002) and (004), and substrates. The full width at half maximum of diffraction peaks rocking curve for the NbN(002) and Co_2MnGe (004) peaks of these film is less than 2 degree. These XRD results indicate that these multilayers have strong (001) orientation, and Co_2MnGe layers in this multilayers have at least B2 structure by the observation as found for clear Co_2MnGe (002) peaks.

In these both multilayers, pole figures of Co_2MnGe (202) peaks show the four-fold symmetry at a tilt angle of 45 degree against the NbN (202), and MgO (202) peaks. Figure 3 shows the typical results of in plane XRD diffraction patterns. The crystal structure of NbN and MgO is the same: NaCl structure, however, the lattice mismatch values for Co_2MnGe are 7.5% and 3.7%, respectively. It was reported that several Heusler alloy films are 45 degree tilted epitaxial grown on MgO substrates or MgO buffer layers.

The saturation magnetization values of Co_2MnGe layers in NbN / Co_2MnGe and Co_2MnGe / NbN multilayers on MgO (100) substrates have been measured. The saturation magnetization of Co_2MnGe layers in these multilayers show similar values near the

850 emu/cc, which is almost the same level as in the case of the single-crystal Co_2MnGe films fabricated on MgO (100) substrates. These magnetization values indicate these Co_2MnGe layers have highly ordered structure, and the result is in good agreement with XRD results of these multilayers. The result of XRD patterns and magnetization indicate that these Co_2MnGe have enough quality to be expected for the possibility of discussion about intrinsic spin conduction of Co_2MnGe measurement by Andreev reflection measurement.

FIG. 1 The X-ray diffraction pattern of a NbN (250 nm) film on MgO with the optimized deposition conditions. The asterisks indicate reflections from the substrate.

FIG. 2 The X-ray diffraction patterns of the NbN / Co_2MnGe multilayer on MgO, and the inverted structure (NbN layers on Co_2MnGe films) on Cr buffered MgO. The asterisks indicate reflections from substrates.

FIG. 3 The in plane orientation of the NbN / Co_2MnGe multilayer on MgO.

FIG. 4 The conduction curves of epitaxial (a) Co / NbN and (b) Co₂MnGe / NbN junctions (indicated by open circles), and the fitting curves of by modified BTK model (indicated by solid lines) analysis. The spin polarization value: P, and the scattering strength parameter: Z are also shown in these figure.

Next, we show the results of Andreev reflection in epitaxial NbN junctions. In this paper, we investigate the electrical properties of the junctions using the NbN layer as the bottom layer. The Andreev reflection is the phenomena, which occurs between superconductor layer and ferromagnetic metal layer interfaces, therefore resistance of junctions is very small.

Figure 4(a) and 4(b) show the conduction curves of epitaxial Co / NbN and Co₂MnGe / NbN junctions, and the fitting curves of by modified BTK model (indicated by solid lines) analysis. The spin polarization value: P, and the scattering strength parameter: Z are also shown in these figure. The super conductor gap parameter: Δ values of these junctions are around 1.5 meV. This value is reasonable against the intrinsic superconducting gap of NbN estimated by BCS theoretical value. The P value of Co obtained by this measurement is 0.38, of which value is in good agreement with theoretical value and the results of point contact Andreev reflection^[5]. This result indicates the high reliability of this measurement method. The P value of Co₂MnGe obtained by this measurement is 0.51, of which value is the same level with the point contact Andreev reflection results of other Co based Heusler alloys. The Z values of these junctions are less than 0.1. In BTK fitting method, the accurate P value can be obtained when the Z value equal 0. However, It was reported that the P values are the similar (error range is plus minus 0.05) when the Z value

less than 0.2 by junction Andreev reflection measurements on LSMO. Therefore It have been considered that the Z values of Co and Co₂MnGe of this junctions are enough small to preserve the reliability of P value in this model.

As the whole results in this paper indicated the potential of the epitaxial NbN junction method as a measurement technique of spin polarization like quasiparticle Heusler / (MgO) / NbN junction tunneling spectroscopy.

4. SUMMARY

The epitaxial NbN films have been obtained on MgO substrate, and the high quality NbN / Co₂MnGe and Co₂MnGe / NbN hetero-epitaxial multilayers on MgO (100) substrates. This is the first result of NbN and Heusler alloy hetero-epitaxial multilayers. We have measured Co and Co₂MnGe spin polarization using epitaxial NbN junctions and obtained reasonable spin polarization values.

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