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Fabrication and magnetotransport properties of nanoscaled MnSb dots

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We report the fabrication and magnetotransport properties of nanoscaled clusters of manganese antimonide (MnSb) grown on sulfur-passivated GaA(001) substrates by molecular-beam-epitaxy (MBE). The typical diameter and height of dots were about 22 nm and 4 nm, respectively. Uniform dots in size were formed in a self-assembled mode. Magnetotransport properties of MnSb granular films were investigated, and the anisotropic magnetoresistance were observed at room temperature. Large jumps appeared at 9 K in magnetoresistance curves, and the jump structure depends on the sweep rate of the magnetic field. These magnetotransport properties describe well the magnetic behavior of MnSb dots. © *2000 American Institute of Physics.* [S0021-8979(00)38308-6]

I. INTRODUCTION

The fabrication of magnetic dots has attracted significant attention due to the fact that their novel magnetic properties induced by the quantum size effect in the nanoscaled dots are expected. Some studies of magnetic dots fabricated on metallic substrates or insulators have been reported.[1,2] The quantum size effect was implied in the magneto-optical (MO) properties of Co (cobalt) magnetic dots.[3] These studies associated with magnetic properties are significant in terms of the application to magneto-electronic devices. It is also thought to be desirable for the application combined with semiconductor-based electronic devices that these dots can be fabricated on semiconductors such as GaAs or Si with the abrupt interlayer. As the formation technique of ‘‘dot’’ structures, sulfur passivation is expected to be a useful method because the self-assembled growth of III–V semiconductor dots has been demonstrated.[4,5] This mechanism is that dangling bonds of the sulfur passivated surface are diminished by sulfur atoms, and that the surface energy is suppressed at the very low level. In this paper, we applied the sulfur passivation technique to the fabrication of MnSb dots, and successfully obtained the self-assembled dots. Measurements of magnetic transport properties revealed some interesting effects occurring at both room temperature and the lower temperatures.

II. EXPERIMENT

GaAs (001) epiready wafers are used as the substrate. Before the growth of MnSb dots, GaAs wafers were passivated by sulfur. Wafers were dipped into a $(NH_4)_2S_x$ solution for 1 h, and rinsed by pure water. Then they were loaded into the growth chamber and annealed at 500 °C in an ultrahigh vacuum. It is known that the GaAs surface terminated by one monolayer sulfur atoms is obtained by this process. The growth was performed in a custom molecular beam epitaxy system. The growth of MnSb was performed at 250 °C at the base pressure below 1.0×10^{-9} Torr. The flux ratio of Sb/Mn was kept at 4–5, where the growth rate of MnSb was estimated to be 0.17 Å/s. A Sb cap layer was grown over the MnSb dots only for samples which were used for measurements of magnetoresistance (MR) properties. This cap layer was grown at 50 °C, and the thickness of the layer was 10 nm. After the samples were taken out to air, the surface morphology of samples was evaluated by *ex situ* atomic force microscopy (AFM) using the tapping mode. The MR effects were measured in the van der Pauw configuration at room temperature and 9 K. In this report, we introduce MR properties of MnSb dots with a nominal thickness of 7 Å.[6] Indium solder was used-as the electrical contacts. The constant current of 20 mA was passed along the surface plane.

III. RESULTS AND DISCUSSION

Figure 1 shows the AFM image of MnSb dots with a nominal thickness of 7 Å. The average size in diameter of MnSb dots was estimated to be 22 nm from the AFM images. The average density (the number of dots in a unit area) was estimated to be about $9.3\times10^{10}/\mathrm{cm}^2$. The average height of dots was estimated by a cross-sectional analysis to be about 4 nm. The size distribution of these dots was fitted by a Gaussian function. The standard deviation of this dispersion was as narrow as about 4.8 nm. The small deviation indicates the formation of very uniform dots in size.

Magnetotransport properties of the MnSb granular film with a nominal thickness of 7 Å were investigated in the sample capped with the Sb polycrystalline layer. We believe that conductive carriers go through MnSb dots via the Sb cap layer. At first, the measurements were performed at room temperature. The MR effect depending on the angle between the current (which is parallel to the substrate) and the magnetization direction was observed as shown in Fig. 2. The MR effect changed from positive to negative with increasing the angle. The transition occurs at around 60°. Since the

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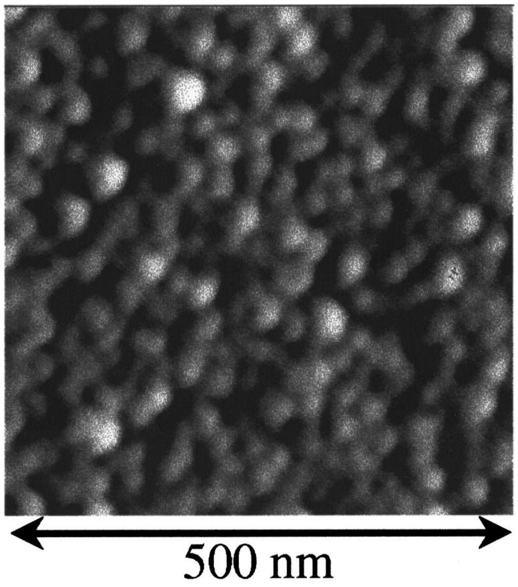

FIG. 1. Atomic force microscopy image of MnSb dots with a nominal thickness of 7 Å grown at 250 °C. MnSb self-arranged dots on GaAs have the density (the number of dots in a unit area) of about $9.3\times10^{10}\,\mathrm{cm}^{-2}$ and the average height of 4 nm. Each dot was isolated from neighboring dots.

angle almost corresponds to the hard magnetization direction when MnSb thin film is grown on GaAs (001),[7] it is reasonably considered that the present self-assembled MnSb dots have the same epitaxial relationship. This fact is also supported by the observation of transmission electron microscopy (TEM).

When the measurements were performed at the low temperature (9 K), with the different configuration (a Hall-measurement configuration but the applied magnetic field is parallel to the plane), it was found out that distinct and reproducible jumps appeared in the magntoresistance curves as shown in Fig. 3. Here, the magnetic field was applied from 1.5 T to −1.5 T, and returned to 1.5 T. The sweep rate of the magnetic field was varied from 3 to 69 mT/s. The first jump occurred at $0\sim-0.1\,\mathrm{T}$ to the direction of increasing resistance and the second jump occurred at shortly after the first jump to the direction of decreasing resistance. These series of jumps were also observed along the reverse drive from −1.5 T to 1.5 T. The magnetic field where these jumps emerged shifted toward zero with the decrease of the sweep rate of the magnetic field. Moreover, the faster the sweep rate was set, the larger the jumps became. It is very likely that these jumps are due to the sudden change in the magnetization (giant Bulkhausen effect) and related to depinning and subsequent propagation of domain walls. Since each MnSb dot is isolated as shown in Fig. 1, there are a lot of grain boundaries in the film. These boundaries may be the origin of the pinning of domain walls.

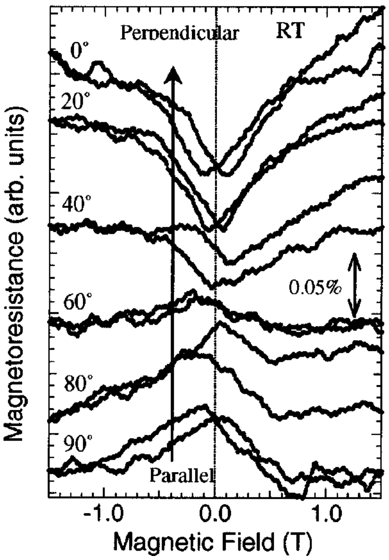

FIG. 2. Dependence of the magnetoresistance effect on the angle between the current (which is parallel to the substrate) and the magnetization direction. The surface of the sample was rotated in the magnetic field from the perpendicular to the parallel to the magnetic field direction. The vertical bar with two arrows at the opposite ends indicate 0.05% of the resistance in zero magnetic field.

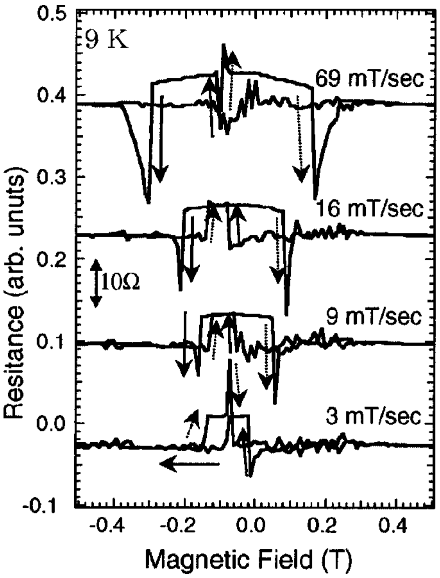

FIG. 3. Large jumps observed in magntoresistance curves in the lower magnetic field range. The magnetic field where these jumps emerged changed depending on the sweep rate of the magnetic field. Solid arrows show the scans when the magnetic field was swept from 1.5 T to −1.5 T. Dotted arrows show the opposite drives.

IV. CONCLUSIONS

We have fabricated nanoscaled self-assembled MnSb dots on sulfur-passivated GaAs substrates. It is estimated that the size of each dot is 22 nm in diameter and 4 nm in height on average. Large jumps were observed in magntoresistance curves at 9 K and the jumps depend on the sweep rate of the magnetic field. Magnetotransport measurements are thought to be a powerful method to elucidate magnetic behaviors of nanoscaled magnetic dots.

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