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Au/GaAs magnetoresistive-switch-effect devices fabricated by wet etching

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1. Introduction

Magnetoresistance (MR) effects, for example, giant MR (GMR), colossal MR (CMR) and tunneling MR (TMR) had been intensively studied for their potential applications in various magnetic devices [1-3]. Furthermore, extraordinary MR (EMR) with 100,000% (40,000 Oe) were observed in InSb embedded in Au [4], and ballistic MR (BMR) as high as 700% were discovered in a device with a few Ni-atom contact [5].

In our previous works [6-9], huge magnetoresistance switching (MRS) effect with thousand fold MR change at room temperature was found in MnSb granular films [6,7,9]. Latterly, similar effects were also observed in Au and Al granular film fabricated by molecular beam epitaxy method [8]. By applying voltage above a critical voltage, the films switch from high resistance state (HRS) to a low resistance state (LRS). If a magnetic field is applied subsequently, the films will return to HRS, which result in a huge MR ratio, about 1000,000% at 1 T. The origin of MRS effect was explained in terms of magnetic-field-sensitive avalanche breakdown [9]. In order to apply MRS effect in magneto-electronic devices, a low threshold voltage which is needed for switching and a high MR ratio at small magnetic field are desired. To decrease the threshold voltage, one effective way is to decrease distance of the electrodes, because electric field is the intrinsic physical parameter of the MRS effect which gives electron enough energy to jump through HRS to LRS. Experimentally the threshold voltage was found to decrease largely with the distance of the electrodes (for Au film, the threshold voltage decrease from about 70-100 V for 8mm apart to 30 V for 500 nm gap). In order to fabricate a very small trench (from 100 nm-1000 nm) in the Au film, focus ion beam (FIB) lithography was previously employed [8]. However, the smooth interface of Au/GaAs, which is important to magnetic-field-sensitive avalanche breakdown, were more or less damaged by the bombing effect of focus ion beam. So in this paper, we applied wet-etching method instead of dry etching to fabricate the MRS devices. A 2μm - gap were successfully fabricated by this method. Electronic transport properties and MRS effect were studied. The critical voltage is 45 V, which is little higher than that of samples fabricated by FIB lithography. The device had a MR ratio reached 2.3×10^{6} % at small magnetic field (500 Oe), which was more sensitive than the devices fabricated by FIB lithography at same magnetic filed.

2. Experimental and Results

Granular Au films were grown on semi-insulating (111) B GaAs substrate 32P MBE system. The nominal thickness of Au film is 10 nm. Before the growth of Au film, GaAs buffer layer with the thickness of 10nm was grown to flatten the GaAs surface.

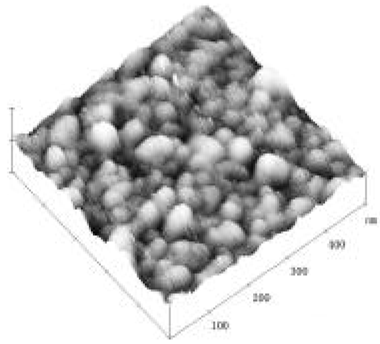

Fig.1 Atomic force microscopy image of Au clusters grown on GaAs (111) substrate. The scan size is 500 nm. The average diameter of clusters is about 40 – 50 nm.

Surface morphologies of the Au films were investigated by ex-situ atomic force microscope at room temperature in air. As shown in Fig.1, the 10 nm-Au film is composed of dense Au clusters with an average diameter 40-50 nm. The surface roughness is about 2.3 nm. The height of cluster is about 5-10 nm. From previous experiment [8], the surface morphologies of Au film drastically changed at 1 nm thickness from terrace structure to a cluster structure.

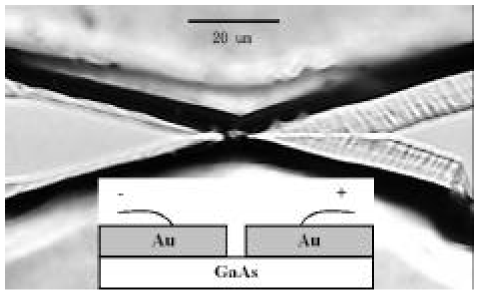

Fig. 2 The illustration of two Au electrodes fabricated by photolithography using wet etching. The inset is a schematic drawing of the Au/GaAs sample that was used for transport measurements. The scale is 20 μm.

The devices for transport measurement were fabricated by photolithography using wet etching. King water

($3HCl+HNO_3$) was used to etch the gold. As shown in Fig.2, the two Au electrodes are separated by a 2μm – gap. The resistivity of Au-part and GaAs-part are 500 Ωcm and 800 MΩcm, respectively, indicating that the Au film is successfully removed by wet-etching process. Except few very small pits on it (less than 100 nm in diameter), the GaAs surface is still rather smooth after etching.

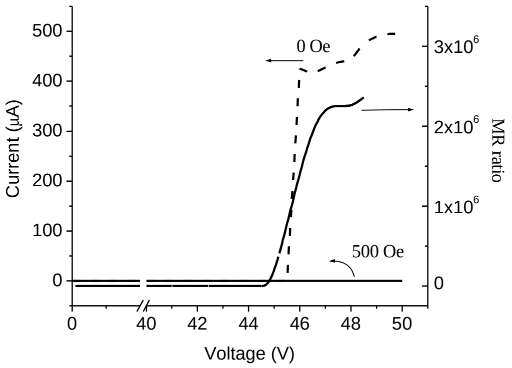

Figure 3 room-temperature Current-Voltage characteristic curve of Au film at zero magnetic filed and 500 Oe (left axis) and MR ratio versus voltage (right axis)

Room-temperature current-voltage curves measured at 0 Oe and 500 Oe respectively are shown in Fig. 3. The magnetic field was applied parallel to the current direction. At zero magnetic field, the samples remain at HRS till 45 V. Above this threshold voltage, the current suddenly increase from 0 to 400-500 μA. The corresponding resistance switch from HRS (2300 MΩ) to LRS (0.1 MΩ). The two resistance state can be clearly confirmed in Fig. 3. The threshold voltage (45 V) is a little higher than that of samples fabricated by FIB lithography (30 V for a 500 nm gap) [8]. The switch effect (threshold voltage and resistance variance) is sensitive to the sweep rate of the voltage and heat. Also we notice some hysteresis occurred when decreasing or increasing the voltage. The threshold voltage and resistance variance decrease with decreasing sweep rate, on the contrary, hysteresis became larger. These phenomena can be explained in terms of time delay of electron when charging and discharging of electron during avalanche breakdown [8,9].

When a small field (500 Oe) was applied, no jump of current can be observed up to 50 V. The sample remained in LRS till 50 V. Or in other words, the threshold voltage shifts to a higher voltage than 50 V. It means that by applying a small magnetic field, we can switch the sample from LRS to HRS again during 45-50 V. Huge changes of resistance could occur due to applying the magnetic field. If we defined the MR ratio as

$$MRratio(\%) = \left(\frac{R(x) - R(0)}{R(0)} \right) \times 100$$

Here, R (0) and R (x) are the resistance of sample at 0Oe and x Oe. The calculated MR ratio is also shown in Fig. 4. Above the threshold voltage, the MR ratio reaches about 10^6 %, the largest value is 2.3×10^6 at 47 V. This huge MR ratio at small magnetic field had not yet realized in the devices fabricated by FIB method (which is about 100% at 500 Oe) [8]. This means that although smaller threshold voltage was achieved by FIB lithography, the devise fabricated by wet etching is more sensitive to the magnetic field than the one fabricated by FIB lithography.

As shown in Fig. 2, the Au film were separated by a very small gap, so it is GaAs surface, Au/GaAs interface and configuration plays surely important roles of the transport phenomena before the breakdown [9]. The MRS effect depends on the gap width and quality of GaAs surface and Au/GaAs interface and also configuration. The observed huge MRS effect demonstrated that wet etching is also a feasible method to fabricate the MRS device with less damage to the GaAs surface. Compared with FIB method, wet etching is much more economic and simpler method. Furthermore, it is still possible to further reduce the gap width to a very small value (100 nm or less) if the etching rate and time are carefully controlled or a good pattern is proposed. This means that further decrease of threshold voltage and increase of MR ratio can be expected, which still need further works to realize this aim.

3. Conclusions

In conclusion, we successfully fabricated a MRS device with a 2μm – gap by wet etching. Large MRS effect was observed. The MR ratio is 2.3×10^6 % at 500 Oe. Although the threshold voltage 45 V is a little higher than that of samples fabricated by FIB lithography, the MR ratio reached 2.3×10^6 % at the small magnetic field (500 Oe), which was more sensitive than the latter at same magnetic filed.

Acknowledgements

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