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Temperature dependence of the electric and spintronic transport properties of Germanium on glass

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ABSTRACT

We present electrical spin injection and detection in p-type Ge channels using Ni/Al_2O_3/Ge on glass tunneling contacts. The entire structure is integrated on a glass substrate. We investigate the temperature dependence of the Hanle effect in a composite p-type Ge on glass (GeOG), using three-terminal configuration Hanle measurements; from these measurements, we observe spin accumulation up to room temperature. A spin signal of 0.3 V and a spin lifetime of 34 ps are obtained at room temperature.

1. Introduction

The electric injection and detection of spin-polarized carriers in semiconductors play an important role in understanding semiconductor-based spintronics. For this reason, many studies have been devoted to Si and GaAs systems; and these mainstream semiconductor systems have been widely studied [1–4]. Recently, Ge-based systems [5,6] have been measured extensively because of the many advantages of Ge, such as its high electron mobility, the possibility of electrical spin manipulation via non-negligible spin-orbit interaction, and spin optical pumping. Several important results have recently been reported[3–9] in the field of spintronic transport in Ge and in the field of spin detection in Ge.

In this work, we report the temperature dependence of the Hanle effect in a Ni/Al_2O_3/Ge-on-glass configuration. The Ge on glass (GeOG) [10,11] was fabricated by hydrogen implantation followed by a smart cut process. We also investigated the electric transport properties in order to demonstrate the relationship between electric transport properties and spin-polarized carriers.

2. Experiment

In this study, we used p-type (001) Ge wafers (P-doped, 1.5×10^{17} cm^{-3}), purchased from AXT Inc., as the Ge substrate. Hydrogen implantation into Ge may cause surface roughness. To eliminate the surface roughness caused by hydrogen implantation, a 10-nm aluminum oxide layer was prepared by atomic layer deposition (ALD) on top of the p-type Ge wafer. After the oxide layer had been deposited, the Ge wafer was implanted with 200 keV H_2^+ ions at a of dose 5×10^{16} cm^{-2}. The ion source (HVEE, SO-60) that we used generates more H_2^+ ion beam current than proton beam current. The H_2^+ ion beam intensity was almost an order of magnitude higher than the proton beam. Therefore, we use H_2^+ ion implantation to reduce implantation time and it is the equivalent condition for 100 keV proton implantation in Ge with 1×10^{17} cm^{-2}. According to "Stopping and Range of Ions in Matter" (SRIM) calculations [12], the range of protons in Ge is about 700 nm with 113 nm of straggling. Before the direct bonding process, the implanted Ge sample was rinsed 3 times with HCl + H_2O_2 solution [13]. This process can remove the surface oxide from the Ge sample and chemically polish the Ge surface simultaneously; it also can be used to activate the Ge surface for the bonding process. Then the Ge wafer and glass were bonded in deionized water in case the wafer and glass exposed to ambient environment that will get particle contamination on the both surfaces. This procedure improves the success rate on direct bonding process. A subsequent thermal annealing at 673 K [13] was used to cut the Ge thin film from its substrate. The thickness of the cut Ge thin film is 800 nm, as measured by scanning electron microscopy of the cross-section; this also agrees with the prediction of the SRIM calculation. Fig. 1 shows the process. After finishing the

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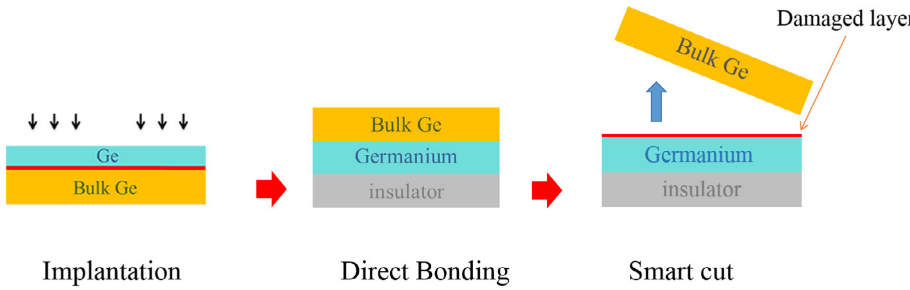

Fig. 1. Schematic diagram of the Ge on glass (GeOG) process; first we used 200 keV H_2^+ to implant Ge (001) wafers with a dose of 5×10^{16} cm^{-2}. After implantation, we used $HCl + H_2O_2$ for chemical polishing and to activate the Ge wafer surface and the glass surface. Then the Ge and glass were bonded in DI water. After the bonding process, thermal annealing was used to cut the implanted Ge film from its substrate.

process, the GeOG sample was used to make a Hall bar and a four-terminal device in the same mesa, which can be used to extract the transport properties.

To obtain the integrated device, we utilized ALD and e-beam evaporation to fabricate the Ni/Al_2O_3. The ALD process that was used to create the tunneling oxide consisted of 1 cycle with Trimethylaluminum (TMA) and 1 cycle H_2O to form 0.94 nm of Al_2O_3; then e-beam evaporation was used to deposit a 10-nm Ni layer, followed by a 250-nm Au layer to protect the Ni layer from oxidation in the atmosphere. The 250 nm Au was also used as an electrical contact for wire bonding. Between the deposition processes for Ni and for Al_2O_3, the sample was exposed to the ambient atmosphere for several hours. This exposure to the air did not influence the quality of spin-polarized carrier injection or detection. Fig. 2(a) shows a cut

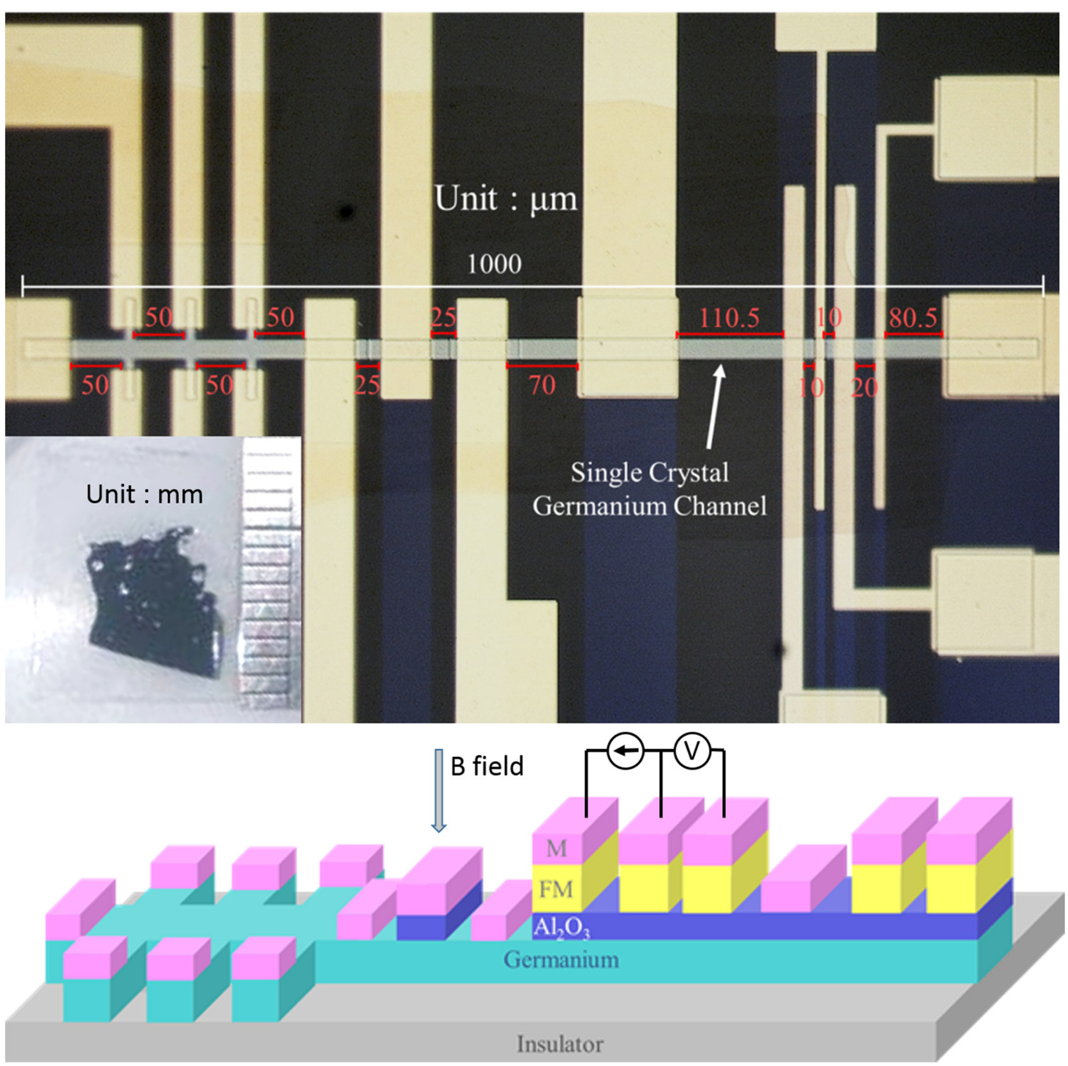

Fig. 2. (a) The cut Ge thin film on glass with a meter; the unit of the meter is mini-meter. (b) The device for transport measurements. A Hall bar is shown on the left side, and a four-terminal device for spin injection and detection is shown on the right side. (c) A lateral view of the device. The thickness of the Ge channel is about 800 nm with 0.94 nm of Al_2O_3 tunneling oxide. The ferromagnetic metal (FM) is a 10-nm nickel layer. The contact metal (M) is 250 nm Au.

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