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SpinFET on Epitaxial Graphene

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1. Introduction

Spin transport in graphene (Gr) has attracted intensive interest [1-4] in recent years for potential applications in spintronics due to its weak spin-orbit and hyperfine interactions [5]. In this paper, we report on the first SpinFET (spin valve transistor) fabricated on an epitaxial Gr film grown on a SiC substrate by high temperature sublimation. Spin dependent magneto-resistance (MR) is observed from 400mK to 3K, showing a maximum spin signal of 0.25% and a maximum spin relaxation length of 200 nm at 400 mK.

2. Experiments and Results

The epitaxial growth of Gr on semi-insulating SiC substrates was carried out in a commercial Epigress VP508 SiC CVD reactor. The multi-layer Gr film investigated in this paper was formed on the C-face SiC at 1550 ^{o}C. AFM and SEM inspection confirms that it's possible to have a 2-10 μm domain size atomically-smooth Gr films at that growth temperature. Fig. 1 shows the SEM image of one of the fabricated $Ni_{0.80}Fe_{0.20}$/Gr spin valve devices. All patterns were defined by electron-beam lithography. Ti/Au bonding pads were deposited on the Gr film, followed by an oxygen plasma dry etching to isolate the central Gr area with a width (*W*) of 2 μm and a length of 5 μm. Two $Ni_{0.80}Fe_{0.20}$ electrodes were evaporated for spin injection and detection. They are 400 nm and 1 μm wide, with a separation gap (*L*) of 400 nm.

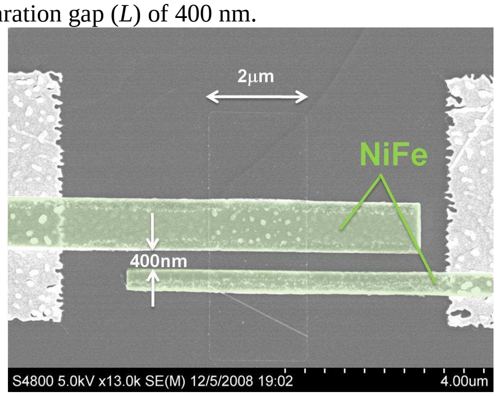

Fig. 1 SEM image of a SpinFET fabricated on the epitaxial graphene film on SiC.

Fig. 2 presents a typical spin dependent MR measured at 400 mK. The magnetic field is applied parallel to the

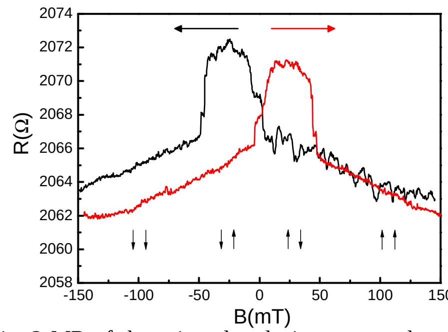

Fig. 2 MR of the spin valve device measured at 400 mK. The magnetic field is aligned parallel to the ferromagnetic electrodes. The small vertical arrows show the magnetization of electrodes at different B fields. Horizontal arrows indicate the B field sweep polarity.

ferromagnetic electrodes and swept firstly from +0.5T to -0.5T and then from -0.5T to +0.5T. The MR curve exhibits a clear spin-valve hysteresis loop with steep change at around ±5mT and ∓50mT. The increase of MR is due to the magnetization reversal of the wider ferromagnetic electrode. The switch can occur before the zero-field condition due to multi-domains in the ferromagnetic electrodes, as discussed in Ref. [6].

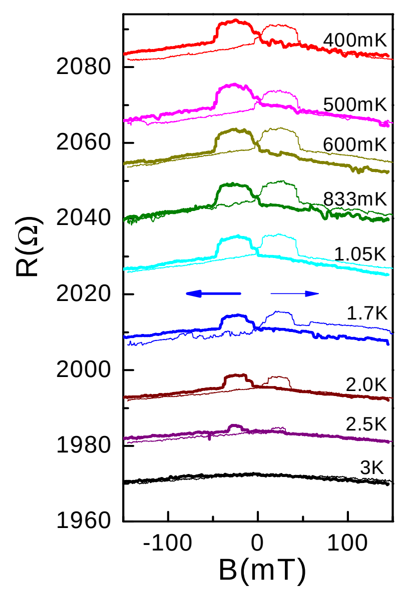

Fig. 3 MR of the spin valve device measured at different temperatures from 400mK to 3K. The curves are shifted vertically for clarity.

A pronounced temperature dependence of the MR is observed in Fig. 3. The curves are shifted vertically for clarity. As can be seen, both the magnitude and the width of the spin signals decreases as the temperature increases, and eventually disappears at 3K. The spin relaxation length (λ_{sf}) can be estimated from the magnitude of the spin signals. The Gr sheet resistance (ρ) is estimated to be ~1kΩ/sq. and ~200Ω in this device. However, the total resistance is ~2kΩ. The contact resistance is much larger than the spin resistance. [7-8] The large contact-resistance suggests the $Ni_{0.80}Fe_{0.20}$/Gr junctions could be quasi-tunneling like. XPS studies of the $Ni_{0.80}Fe_{0.20}$/Graphite interface indicates that C-O bonds are formed if $Ni_{0.80}Fe_{0.20}$ is deposited on a DI water exposed surface. Assuming that the interfacial C-O bonding leads to tunneling-like spin injection, the spin signal for a local measurement on 2D system can be described simply as $R_s = 2P^2\lambda_{sf}\rho e^{-L/\lambda_{sf}}/W$, where the spin polarization P is 0.48 for $Ni_{0.80}Fe_{0.20}$. [7-8] The estimated λ_{sf} versus temperature is presented in Fig.4. Fig. 5 summarizes the temperature dependence of the spin signal width. The reproducible step-like features are

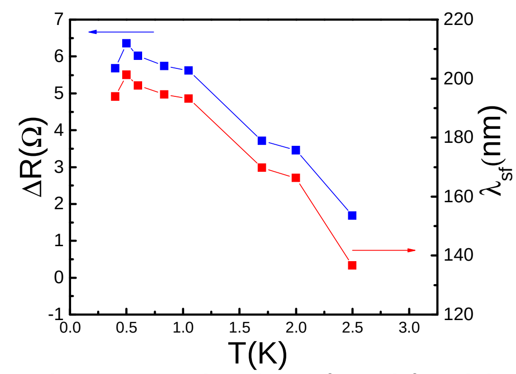

Fig. 4 The temperature dependence of MR (left) and the spin relaxation length (right).

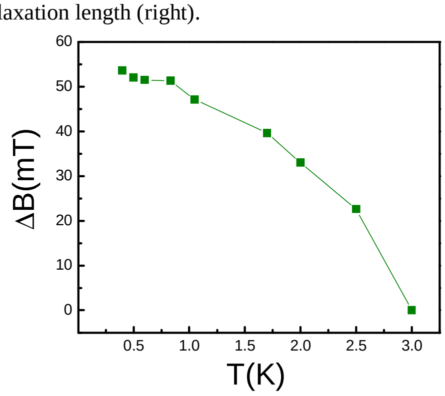

Fig. 5 The temperature dependence of the spin valve signal width in Fig. 3.

observed on up and down slopes of MR around ±5mT and ∓50mT. These may be related with a sequence of mesoscopic domain switching in the ferromagnetic electrodes. The origin of the observed strong temperature-dependent spin effect in Gr is not fully understood. Meanwhile, a parallel effort was also carried out on exfoliated Gr (x-Gr) films for a comparison. The advantage of x-Gr is that the carrier density can be modulated by back gate biases. The x-Gr and the gate (the conducting Si substrate) are isolated by 300 nm of thermal SiO_2. The λ_{sf} in x-Gr is estimated to be as long as ~1μm at 4K from the MR (not shown).

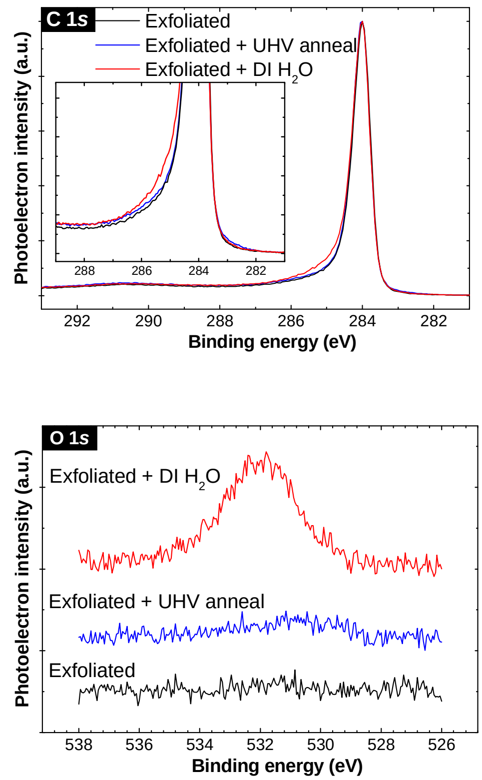

Fig. 6 XPS studies of NiFe/Graphite interfaces with (1) exposed to air (2) pre-deposition annealed with little to no physisorbed H_2O (3) exposed to DI water to mimic the process. Clear C-O bonding is observed on condition (3).

3. Conclusion

In summary, the first SpinFET on epitaxial Gr is demonstrated. The spin signal is strong temperature dependent. Much more work on Gr synthesis, process optimization and physical understanding are needed for an epitaxial Gr SpinFET operating at room temperature.

Acknowledgment

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