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Spin-polarized electron transport in a NiFe/GaAs Schottky diode

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Abstract

Spin transmission across $Ni_{80}Fe_{20}$/GaAs Schottky barrier interfaces was investigated at room temperature. Circularly polarized light was used to excite electrons with a spin polarization perpendicular to the film plane. An almost constant difference in the helicity-dependent photocurrent was observed at negative bias, attributed to efficient spin filtering at the interface. The photon energy dependence indicates that the asymmetry in the photocurrent vanishes at high energy. © 2001 Elsevier Science B.V. All rights reserved.

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Interdisciplinary research between magnetism and semiconductor physics has led to the concept of magnetoelectronics which aims to develop both the miniaturization and fast operation of devices [1]. Such magnetoelectronic devices are based on two types of spin transmission processes, i.e. spin injection from a ferromagnet (FM) to a semiconductor (SC) and spin filtering from the SC to the FM. In investigating spin transmission processes, the photon helicity provides a useful means for the detection or generation of spin-polarized electrons. Significant spin injection from a ferromagnetic SC to non-magnetic SC has recently been reported by electroluminescence measurements at low temperature [2,3]. Using photoexcitation techniques, evidence for spin-polarized electron transport, which can be controlled by a bias voltage, has also been obtained for $Ni_{80}Fe_{20}$/GaAs Schottky barrier structures [4,5]. In this paper, we extended this photoexcitation study to test the photon energy dependence of the spin-polarized electron transport across NiFe/GaAs interfaces.

We fabricated 5 nm thick epitaxial $Ni_{80}Fe_{20}$ layers directly onto GaAs (1 0 0) ($n = 10^{24}\,m^{-3}$) substrates in an ultrahigh vacuum chamber. Conventional four-terminal I–V measurements across NiFe/GaAs interfaces have been performed associated with a circularly polarized laser beam ($h\nu = 1.59$ and 2.41 eV) and an external magnetic field ($H = 1.8$ T) as schematically shown in Fig. 1 [4,5]. The magnetization ($\boldsymbol{M}$) in the NiFe is aligned perpendicular or in plane by applying an external field. The helicity ($\boldsymbol{\sigma}$)-dependent photocurrent varies according to the magnetization configuration of the film ($\boldsymbol{\sigma} \perp \boldsymbol{M}$ or $\boldsymbol{\sigma} \| \boldsymbol{M}$).

Fig. 2(a) shows the I–V curves of the NiFe sample without photoexcitation. The ideality factor [6] was estimated to be 5.37, which is larger than that of usual Schottky barrier diodes due to the existence of a weak ohmic component. A small feature (A) is seen in the I–V curve, which is around the Schottky barrier height ϕ_b as previously reported [4,5].

The helicity-dependent photocurrent is shown in Fig. 2(b) with (I^n) and without (I^0) perpendicular saturation for $h\nu = 1.96$ eV. I^0 is almost constant (-67 nA), while I^n is approximately -74 nA. The difference $\Delta I = I^n - I^0$ is calculated to be -7 nA, which satisfies $I^n < I^0$ as previously reported [4,5]. The minor increase in both I^n and I^0 obtained with increasing bias is likely to be related to that observed in the I–V curve [see Fig. 2(a)].

We propose a simple model to explain the observed constant difference ΔI as schematically shown in Fig. 3.

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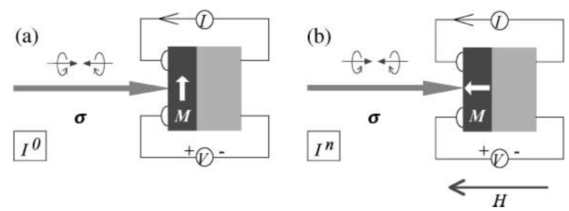

Fig. 1. Schematic diagrams of two configurations of photoexcitation set-up: (a) without and (b) with perpendicular saturation.

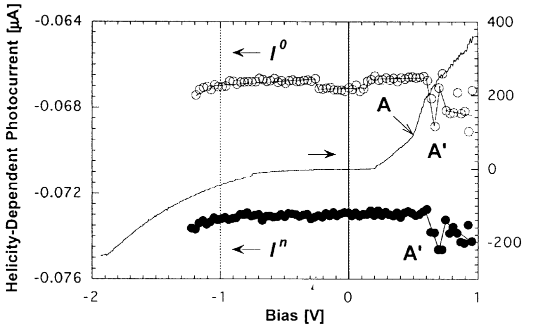

Fig. 2. (a) Bias dependence of current through the $Ni_{80}Fe_{20}$/GaAs(1 0 0) ($n = 10^{24}\,m^{-3}$) interface obtained without photoexcitation (I–V curve). (b) Bias dependence of the helicity-dependent photocurrent without (open circles, I^0) and with the applied magnetic field (closed circles, I^n) with the same sample in the case of the photon energy of $h\nu = 1.96\,eV$. The feature A and A′ are associated with the Schottky barrier.

The predominant spin-polarized electron transport process occurs in two steps: (i) the valence band electrons in the SC are first excited into the conduction band by the circularly polarized light and (ii) tunnel through the Schottky barrier into the FM. The photoexcited electrons in the conduction band are partially spin-polarized, dependent upon $\boldsymbol{\sigma}$, due to the dipole selection rules. In the remanent state [see Fig. 3(a)], since the magnetization in the FM is orthogonal to the photoexcited spin polarization, both up- and down spin electrons in the SC can flow into the FM. At perpendicular saturation [see Fig. 3(b)], on the other hand, the up-spin electrons from the SC are filtered due to the spin-split density of states at the Fermi level of the FM, i.e. only minority states are available to electrons tunneling from the SC. This means that more net current flows into the FM in the remanent state than at perpendicular saturation, resulting in $I^n < I^0$. The observation that $I^n < I^0$ provides clear evidence that spin filtering at the FM/SC interface occurs under the application of a perpendicular magnetic field.

We introduce an asymmetry in the helicity-dependent photocurrent $(I^n - I^0)/(I^n + I^0)$ as a measure of the spin polarization in the photocurrent. Fig. 4 shows the bias dependence of the asymmetry for $h\nu = 1.96$ and 2.41 eV.

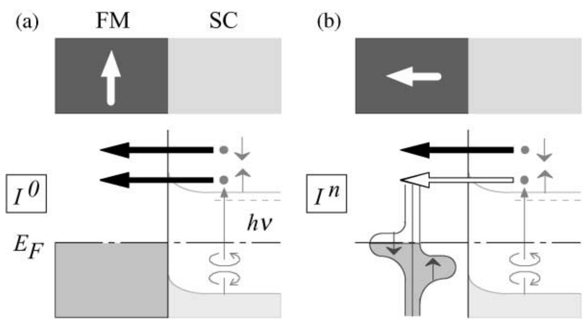

Fig. 3. Schematic diagrams illustrating the spin filtering mechanism for photoexcited electron transport across the FM/SC interface (a) without and (b) with the applied magnetic field.

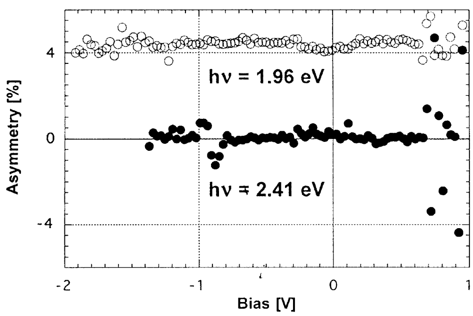

Fig. 4. Bias dependence of the asymmetry with $Ni_{80}Fe_{20}$/GaAs(1 0 0) ($n^+ = 10^{24}\,m^{-3}$) for (a) $h\nu = 1.96$ and (b) 2.41 eV.

A clear trend of decreasing asymmetry with increasing the photon energy is observed, corresponding to the photon energy dependence of the spin polarization in GaAs [7].

In conclusion, we observe unambiguous spin filtering across the NiFe/GaAs interface according to the configuration of the photon helicity with respect to the magnetization in the NiFe at room temperature. The photoexcitation techniques allow the investigation of both spin filtering and spin injection, controlled by bias voltage, in a Schottky diode.

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