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Spin injection into GaAs from Fe/GaO$_x$ Tunnel Injector

Hidekazu Saito[1], Jean C. Le Breton[2], Vadym Zayets[1], Yusuke Mineno[1,3], Shinji Yuasa[1] and Koji Ando[1]

[1] Spintronics Research Center, National Institute of Advanced Industrial Science and Technology
Umezono 1-1-1, Tsukuba Central 2, Tsukuba Ibaraki 305-8568, Japan
Phone: +81-29-861-5457 E-mail: h-saitoh@aist.go.jp
[2] Present address: MESA Institute for Nanotechnology, University of Twente
7500 AE, Enschede, The Netherlands
[3]On leave from Toho University, Funabashi Chiba, 274-0072, Japan

1. Introduction

Spin-polarized light-emitting diodes (spin-LEDs) represent one of the most powerful tools for analyzing electrical spin injection into semiconductors [1, 2]. Inserting a thin insulating layer between the 3*d*-ferromagnetic (FM) metal and semiconductor layers has great potential for achieving effective spin injection even at room temperature (RT). AlO$_x$ [3-5] and MgO [6, 7] have attracted a great deal of attention as tunnel-barrier materials. However, the interface between these oxides and GaAs has quite high recombination velocities for GaAs-based semiconductors[8], resulting in much lower charge-injection efficiency than that of ohmic injectors [5, 9]. Conventional oxide GaO$_x$ would be a good candidate for the high-quality tunnel-barrier material [8]. Our previous electroluminescence (EL) study revealed that the charge-injection efficiency of an Fe/GaO$_x$ injector is comparable to that of the conventional ohmic injector of Fe/n^+-AlGaAs [9]. In this study, the circular polarization-dependent EL measurements were conducted by using spin-LEDs with the Fe/GaO$_x$ tunnel injector [10].

2. Experiments

The film for the spin-LEDs was grown by molecular-beam epitaxy (MBE). The film structure was a Au (5 nm)/Fe (5 nm)/GaO$_x$ (4 nm)/n-Al$_{0.2}$Ga$_{0.8}$As (100 nm, n= 5 × 10^{16} cm^{-3})/ Al$_{0.2}$Ga$_{0.8}$As (10 nm)/ GaAs quantum well (QW) (10 nm)/ Al$_{0.2}$Ga$_{0.8}$As (20 nm)/p-Al$_{0.2}$Ga$_{0.8}$As (200 nm, p = 1 × 10^{18} cm^{-3})/p-GaAs (001) (p ~ 1 × 10^{18} cm^{-3}) substrate. Surface emitting spin-LEDs with an active area of 150 × 150 μm were prepared with conventional micro-fabrication techniques.

3. Results

Figure 1 shows a high-resolution cross-sectional transmission electron microscopy (TEM) image of the Au/Fe/GaO$_x$/(Al)GaAs layers. The image reveals that the GaO$_x$ layer is amorphous and the Fe layer is polycrystalline, which are both consistent with the RHEED observations.[9,11] No interdiffusion was identified at either of the GaO$_x$/AlGaAs or the GaO$_x$/Fe interfaces.

Figure 2 shows the left (σ^+) and right (σ^-) circular polarization components of the EL spectra at 2 K under magnetic fields of 0 and 3 T. At a zero magnetic field, no differences were confirmed in the intensity of either of the components. It should be noted that a remarkable difference appeared between the σ^+ and σ^- components at 3 T, suggesting that the injected electrons are highly spin-polarized. The dependence of magnetic field on the $P_{\rm circ}$ is plotted in Fig. 3. Here, the $P_{\rm circ}$ is defined as $(I_+ - I_-)/(I_+ + I_-)$, where I_+ and I_- are the intensity of the σ^+ and σ^- components of the free exciton peak. The $P_{\rm circ}$ roughly tracks the magnetization measured in a perpendicular magnetic field with a SQUID magnetometer, indicating that the observed $P_{\rm circ}$ was derived from the Fe electrode. With increasing mag-

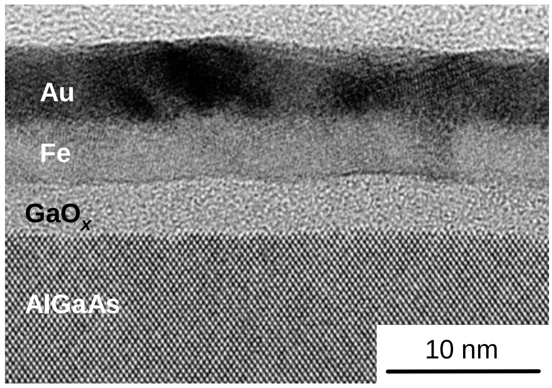

Fig. 1 Cross-sectional TEM image of Au/Fe/GaO*x*/(Al)GaAs layers [10].

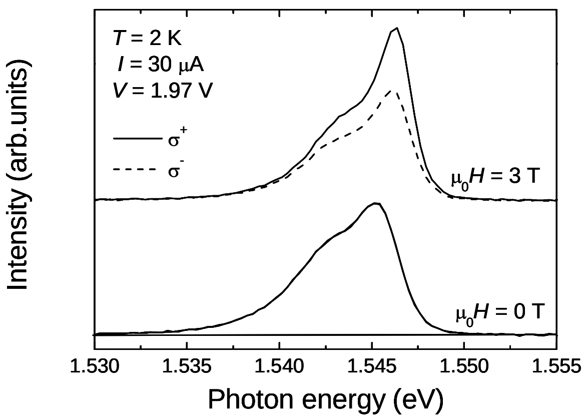

Fig. 2 Left (σ+) and right (σ–) circular polarization components of EL spectra at 2 K. [10].

netic field, the P_{circ} increased rapidly and saturated at about 20 % above 2 T, which corresponds to the demagnetizating field of the Fe layer. Adopting the reported value of $\tau_{re} / \tau_s \sim 1$ at low temperatures [12], the P_{spin} [= P_{circ} $(1 + \tau_{re} / \tau_s)$] was roughly estimated to be 40 %, which is in excellent agreement with the expected value. This indicates that GaO_x is an important tunnel-barrier material for developing GaAs-based spintronic devices.

4. Conclusions

We examined the electrical injection of spin-polarized electrons into a GaAs-based light-emitting diode structure from a Fe/GaO_x tunnel injector whose electron-charge injection efficiency was comparable to that of a conventional Fe/n^+-AlGaAs ohmic injector. A high circular polarization of electroluminescence up to 20 % was obse rved at 2 K. The combination of effective spin- and charge-injection efficiencies makes GaO_x a promising tunnel barrier for GaAs-based spintronic devices.

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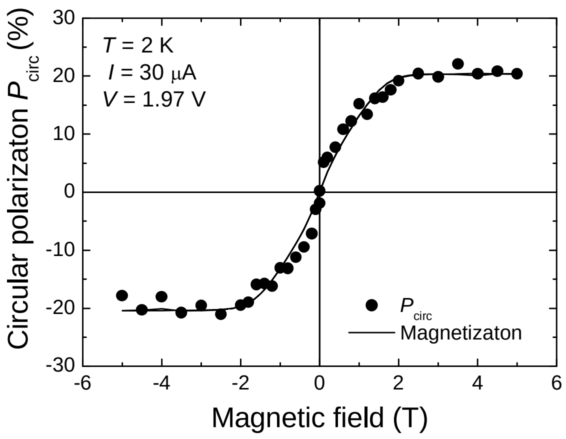

Fig. 3 Dependence of P_{circ} on magnetic field at 2 K. The solid line plots the magnetization curve of the film for the spin-LED at 6 K, which has been scaled to allow comparison with P_{circ}. [10].