Helicity dependent photocurrent at RT from a Fe/x-AlO$_x$/*p*-GaAs Schottky junction

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A semiconductor-based spin photodiode (spin PD) is expected to resolve the degree of circular polarization of light by combining the optical selection rules and spin dependent tunneling. Here we report the helicity dependent photocurrent at room temperature in a lateral-type spin PD consisting of Fe/crystalline- (x-) AlO$_x$/*p*-GaAs Schottky diode, in which the light is focused onto the cleaved sidewall of the sample. This lateral geometry is essential for device integration (e.g. intra-chip optical communication). Instead of the *p-i-n* junction [1], the *p*-Schottky diode has been used to collect spin-polarized electrons closer to the Fe/x-AlO$_x$ tunnel barrier.

Samples consist of an MBE-grown 100-nm *p*-GaAs layer on a *p*-GaAs (001) substrate, a 1-nm x-AlO$_x$ tunnel barrier [2], and a ferromagnetic Fe (100 nm) / Au (20nm) / Ti (10nm) contact. The representative size of tested chips was 3 mm × 1 mm rectangles.

Photocurrent (PC) measurements were performed by impinging (near-infrared) circularly polarized light (CPL) of λ = 785nm from a laser onto the sidewall of the sample, as seen in the inset Fig. 2. All measurements were carried out using the lock-in technique at the chopping frequency of f = 400 Hz. We first measured the PC of right circular polarization $I^{\sigma+}$ through a quarter wave plate (QWP), and then manually rotated the QWP to measure the PC of left circular polarization $I^{\sigma-}$.

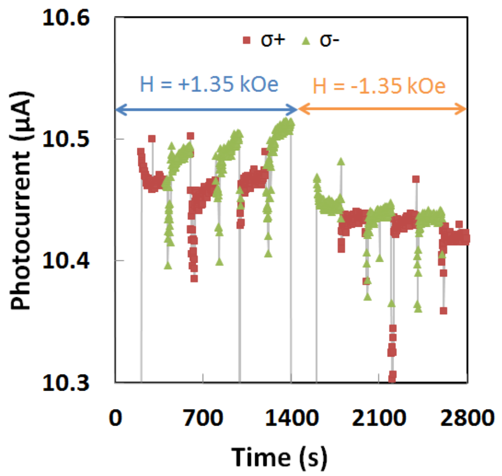

Fig. 1: Photocurrent as a function of helicity and magnetic field.

Shown in Fig. 1 is the CPL-dependent photocurrent data measured at in-plane H = +1.35 kOe and −1.35 kOe. It can be seen that the photocurrent changes when we switch either the helicity of light (σ^+ or σ^-) or direction of external fields. These results not only confirm results from [1], but also indicate that helicity dependent spin photocurrent can be extracted at room temperature in lateral-type devices composed solely of a *p*-type III-V semiconductor.

Normalized CPL-dependence PC, $\Delta I/I$ ($\Delta I = I^{\sigma+} - I^{\sigma-}$), is shown in Fig. 2, together with magnetization data of the Fe/Ti/Au structure. The saturated $\Delta I/I$ at and above H ~ 1000 Oe coincides with the *M*-*H* characteristics. For |*H*| < 1000 Oe, almost linear $\Delta I/I$ - H response was observed, and no CP-dependent PC was obtained at H = 0 Oe. We infer that degradation of the magnetic quality of the Fe electrode takes place at the area close to the cleaved edge.

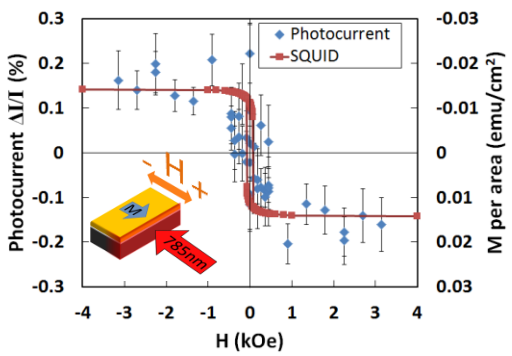

Fig. 2: Photocurrent $\Delta I/I$ and M as a function of applied H.

A model based on the ideal diode and Julliere tunneling [3] has been employed to estimate the ratio of surviving spin polarization at the tunnel barrier $\gamma = P_{tunnel}/P_{initial}$ where $P_{initial}$ = 0.5. For the values in our device, the model roughly simplifies to $(\Delta I_{sat}/I) \approx \gamma * P_{Fe}$ when used with the appropriate load resistance, where P_{Fe} = 0.45 is spin polarization of Fe. From $\Delta I_{sat}/I \approx$ 0.144 %, the value of $\gamma \approx$ 0.32 % was extracted. On the other hand, the theoretical maximum value based on carrier diffusion length $L_n \approx$ 21.3 μm and spin diffusion length $L_{spin} \approx$ 1.2 μm [4] is estimated to be $\gamma_{max} \approx$ 5.6 %. Since the model assumes that the magnetic quality of the Fe contact is uniform, the discrepancy suggests a degraded magnetic quality or possibly the formation of magnetic domains in the Fe close to the edge.

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