L.13: Development of GaAs based spin-Hall devices with low power consumption

Spin-photonics is one of the frontline research area where a lot of exotic developments are currently being made. For a long time, inclusion of electronic spin degree of freedom with charge have been aimed for improving the functionality of semiconductor devices. One example is a spin-Hall device, which generates electrical voltage corresponding to the degree of circular polarization of incident light. It works on the principle of Inverse Spin Hall Effect (ISHE), where generation of transverse electrical voltage occurs as a function of photo injected spin current. Traditionally, near band edge lasers (E_{ex}~1.5 eV) are used to orient electronic spin in Γ valley of conduction band of GaAs. A spin current and subsequently a transverse electrical voltage (V_{ISHE}) are thereafter generated because of ISHE. Though such devices are fast, compact, operate at room temperature and can be integrated into existing optoelectronics platform, a low signal-to-noise-ratio (SNR) is a major bottleneck. Efforts are being made worldwide for enhancing the signal strength of spin-Hall devices. The magnitude of V_{ISHE} depends critically on a parameter called spin Hall angle (γ_{SH}). A small value of γ_{SH} in GaAs is the limiting factor for generating V_{ISHE} with large SNR. It is realized that the L-valley of GaAs has two orders larger value of γ_{SH} as compared to Γ-valley due to a large contribution of higher lying p-orbitals. Owing to this, attempts are being made to involve the spin polarized electrons in L-valley.

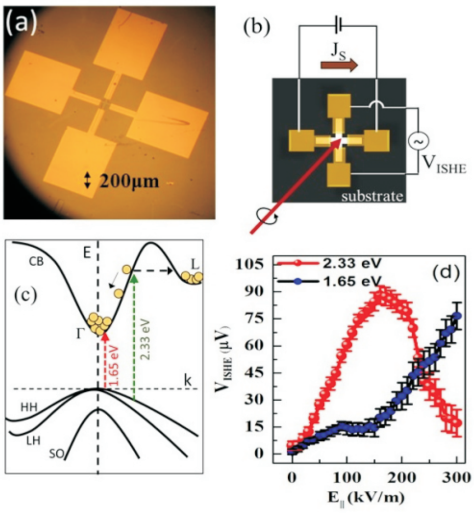

Fig. L.13.1: (a) Photograph of a spin-Hall device, (b) schematic diagram to show ISHE experiments, (c) band structure of GaAs to show optical excitation at two energy and, (d) plot of V_{ISHE} versus *appied bias at the two values of excitation energy.*

An indirect excitation of electrons to L-valley is not favorable because of the momentum selection rules. Thus, the application of high electric field is sought to initiate the inter-valley electron transfer, which enhances the magnitude of V_{ISHE} significantly. However, it worsens SNR due to excessive Joule heating. Though a large value of V_{ISHE} is desired, it should be achieved preferably at low bias. Development of spin-photonic devices have been carried out in our lab for the past ten years where systematic efforts are put for enhancing the strength of ISHE signal in high crystalline quality GaAs. By utilizing optically injected hot-electrons at 2.33 eV, a spin-Hall device is recently demonstrated by us that can provide high V_{ISHE} at relatively low bias. The devices consume less power and yield better signal-to-noise ratio.

For this work, 1 µm thick high crystalline quality n-GaAs epitaxial layers are grown by MOVPE technique. A Hall bar type structure is fabricated by using mask-less photolithography, chemical etching and Ohmic contact metallization as shown in Figure L.13.1(a). The laser beam of ~50 µm diameter is focused at the center of the sample, whose degree of circular polarization is modulated as shown in Figure L.13.1(b). Subsequently, longitudinal electric field ($E_{||}$) is applied and V_{ISHE} is measured for the two values of optical excitation energy as shown in Figure L.13.1(c). In particular, spin polarized hot electrons are injected in GaAs at 2.33 eV. It leads to a steady state electron accumulation in L valley. By involving simultaneous energy, spin and inter valley relaxation processes, it is estimated that nearly 1% electrons are accumulated in L-valley, and about 40% of them are spin polarized. A monotonous rise of V_{ISHE} is seen with electric field, which starts to fall beyond a critical electric field as shown in Figure L.13.1(d). A rapid increase in the signal magnitude is observed at lower electric field at 2.33 eV corresponding to a larger magnitude of γ_{SH} in L-valley. From a careful comparison between the two cases, it can be appreciated that the same maximum magnitude (~80 µV) of V_{ISHE} can now be achieved at half the applied electric field. Further, the power consumption and SNR improves by 2.5 and 1.5 times, respectively. One of the possible reasons behind such reduction in power consumption is the optical excitation of spin polarized hot electrons in the L-valley. These findings are highly encouraging for the development of next generation spin-optoelectronic devices. For more details please see *Mudi et al., Phys. Status Solidi, RRL, 14, 2000097 (2020).*

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