Muons for Spintronics: Polarized Conduction Electrons in GaAs Observed by Spin Exchange Scattering of Muonium

K. Yokoyama[1], K. Nagamine[1,2,3], K. Shimomura[2] H.W.K. Tom[1], R. Kawakami[1], P. Bakule[4], Y. Matsuda[4,*], F.L. Pratt[5], and E. Torikai[6]

[1]*Department of Physics & Astronomy, University of California, Riverside, California 92521, USA*

[2]*Muon Science Laboratory, IMSS, KEK, Oho, Tsukuba, Ibaraki 305-0801, Japan*

[3]*Atomic Physics Laboratory, RIKEN, Wako, Saitama 351-0191, Japan*

[4]*Advanced Meson Science Laboratory, RIKEN, Wako, Saitama 351-0191, Japan*

[5]*ISIS, Rutherford Appleton Laboratory, Chilton, Oxon OX11 0QX, UK*

[6]*Interdisciplinary Graduate School of Medicine and Engineering, University of Yamanashi, Kofu, Yamanashi, 400-8511, Japan*

Recently, in the field of spintronics, various injection methods of polarized conduction electrons into various semiconductors have been proposed and examined. In order to develop these studies, it is essential to establish experimental methods for the detection of conduction electron polarization (CEP). In the case of GaAs, because of a large spin-orbit interaction and a direct band gap, both CEP production and detection are routinely performed with optical methods [1]. In contrast, for Si, Graphite or Ge, there has been limited information about CEP since optical methods can not be applied due to a small spin-orbit interaction and an indirect band gap.

Polarized ortho Mu should be a sensitive probe of CEP since the spin of the bound electron is affected by a replacement with polarized conduction electrons through an exchange scattering process. The use of Mu to detect CEP was proposed and the preliminary experiment was conducted at KEK by Torikai, et al. on photo-induced polarized electrons in strained GaAs and subsequent spin transport into Si [2]. A feasibility study of this Mu method conducted in GaAs has the advantage that the physics of CEP is well known and independently verifiable by optical techniques. The properties of Mu in bulk GaAs have been well studied. An experiment of Mu spectroscopy under pulsed laser excitation was carried out at KEK by Shimomura et al. on pure GaAs [3].

The experiment was conducted at RIKEN-RAL on 200 μm thick n-type GaAs with 3x10^{16} cm^{-3} Si dopants. First, the response to linearly-polarized laser excitation (laser on-off effect) was measured. Then, the spin-dependent exchange scattering between Mu-electron and the polarized conduction electrons was measured by observing a change of polarization of the bond-centered Mu as a function of the relative conduction electron polarization produced by circularly polarized light excitation (left-circular vs right-circular polarized effect). The polarized conduction electrons with a density of 3.6x10^{16} cm^{-3} were produced by irradiation with 33% circularly-polarized 831 nm laser pulse. The effect was measured as a function of pump laser polarization, a longitudinal magnetic field, temperature change from 25 K to 50 K and injected carrier density. In the ideal case 33% circularly polarized light should produce a conduction electron polarization of 16.7% (half): our results provide a measured CEP of 15% relative to the on-off effect. This is remarkable agreement.

Further refined measurements using a strain free sample, improved laser polarization control, and extension to GaAs with other doping concentrations are in preparation.

In conclusion, encouraging data was obtained for the Mu method to be applied to probe CEP in various systems of spintronics materials.

$*$*Present Address: Graduate School of Arts and Science, University of Tokyo, 3-8-1 Komaba, Tokyo 153-8902, Japan.*

[1] J.M. Kikkawa and D.D. Awschalom, Phys. Rev. Lett. **80,** (1998) 4313 and refereces therein,

[2] E. Torikai, Y. Ikedo, K. Shimomura, K. Nagamine, T. Saka and T. Kato, Physica B **289-290** (2000) 558,

[3] K. Shimomura, R. Kadono, K. Nishiyama and K. Nagamine, Physica B **326**, (2003) 151.