Effects of Electrical Field on Spin-related Optical Properties in InGaAs-based Coupled Nanostructures of Quantum Dots and Well

○Hang Chen, Hee Dae Kim, Junichi Takayama, Yuto Akei, Satoshi Hiura, Agus Subagyo, Kazuhisa Sueoka, and Akihiro Murayama
Graduate School of Information Science and Technology, Hokkaido University
E-mail: chen@nano.ist.hokudai.ac.jp

Advances of III-V compound semiconductors grown by an epitaxy technique make it possible to fabricate optical devices using quantum wells (QWs) and quantum dots (QDs), in which strong confinements act on the electronic and spin states. Coupled QW/QD structures were proposed for demonstrating ultrafast spin injection from the 2-dimentional QW into QDs [1]. In this work, external electric-field effects on the spin injection in the InGaAs based QW/QD tunnel-coupled structure are investigated. Optically excited spin-polarized electrons in the QW tunnel into the QDs through a GaAs barrier layer. We report observations of spin-dependent circularly polarized photoluminescence (PL) from QDs after optical generation of spins in the QW part as a function of strength of applied electrical field.

QW/QD coupled structures were grown by molecular beam epitaxy on (001) *p*-GaAs substrates. The QW and QD are separated by GaAs tunneling barrier layers. The $In_{0.1}Ga_{0.9}As$ QW of 20 nm in thick was grown prior to the growth of tunneling barrier. The $In_{0.5}Ga_{0.5}As$ QD layer was grown on the tunneling barrier and covered with a GaAs layer. This QW/QD coupled structure was sandwiched by AlGaAs barrier layers. The top AlGaAs layer was capped with a GaAs layer on which Ti/Au electrode was deposited. Growth conditions for QD layers were discussed in our previous work [1], the areal dot density of the QD layer used in the work was 5.5×10^{10} cm^{-2}. A circularly polarized light with a wavelength of 850 nm was used as an excitation source, which tuned to the bandgap of QW. The circularly polarized PL was detected from QDs after spin injection [Fig. 1 (a)]. In Fig.1 (b), the PL intensity was measured to decrease gradually with increasing reverse bias voltage below -1.4 V, resulting from the hole localizing in the QW by applied voltages. The PL intensity increased significantly from -1.4 V to 0 V, which can be attributed to the efficient carrier injection from the QW into the QDs via tunneling and remained constant from 0 V to 2 V. At forward bias voltages above 2 V, the PL intensity decreased steeply, where electrons are likely confined in the QW due to the conduction band bending and thus are not efficiently injected into the QDs. In Fig. 1 (c), the circularly polarized PL spectra with corresponding the degree of circular polarization (CPD) have been observed at 1.0 V. Here, we calculate the CPD, i.e., CPD = $(I_{\sigma+} - I_{\sigma-}) / (I_{\sigma+} + I_{\sigma-})$, where $I_{\sigma+}$ and $I_{\sigma-}$ are σ^+ and σ^- polarized PL intensity with σ^+ excitation. This circular polarization in PL will be discussed in terms of spin injection and the resultant spin states in QDs as a function of electrical field.

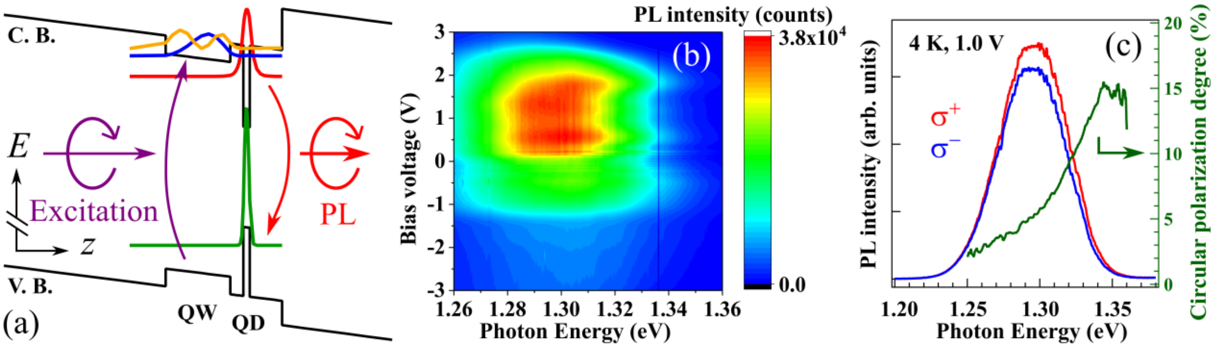

Fig. 1 (a) One dimensional calculations of band line-up (black lines) and wave-functions of an electron (2nd. excited state: yellow, 1st. excited state: blue, and ground state: red lines) and hole (a green line) in the QW/QDs coupled structure under no external elctrical field. (b) Contour plot of PL intensity as functions of applied electric-field as well as photon energy with the laser power of 1.18 mW at 4 K. (c) Circularly polarized PL spectra and the corresponding CPD as a function of photon energy from QW/QDs coupled structure with the bias voltage of 1.0 V.

[1] X. J. Yang, et al., Appl. Phys. Lett. **104**, 012406 (2014).