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Stimulated emission with nearly 100% circular polarization at RT in GaAs-based DHs with Fe/crystalline AlO_x spin injectors

N. Nishizawa, K. Nishibayashi, and H. Munekata

Imaging Science and Engineering Laboratory, Tokyo Institute of Technology
4259-J3-15, Nagatsuta-cho, Midori-ku, Yokohama, 226-8503, Japan
Phone: +81-45-924-5178 E-mail: nishizawa@isl.titech.ac.jp

Abstract

We report the realization of room-temperature (RT) electroluminescence (EL) with circular polarization (CP) of P_{EL} = 0.987 in lateral-type spin-LEDs consisting of Fe (in-plane M)/ γ-like AlO_x tunnel contacts formed on AlGaAs/GaAs double heterostructures (DHs). The outstandingly high P value, suggesting the birth of a new light source, is inferred to result from stimulated emission occurring at relatively high current density of $J \geq 100$ A/cm^2. Newly developed Fe/γ-like AlO_x contacts seem to contribute significantly on stable charge/spin injection, making it possible to carry out reliable and systematic experiments. Our achievement indicates demonstration of new functionality at RT based on spin injection in semiconductors for the first time.

1. Introduction

Following the first demonstration of optical pumped lasing with 100 % CP in GaAs-based VCSEL [1], reduction in threshold current density in spin-VCSEL [2], as well as electrical pumping of VCSEL with 23 % CP at 50 K [3] and 8 % CP at 200 K [4], and RT-CP lasing with optical pumping [5] were reported. Furthermore, advantage of side-wall-emission with in-plane magnets has been discussed in view of practical applications [6]. In any of those works involving electrical spin injections, however, experimental data which suggest RT operation of CP lasers have not been available up to now.

In this paper, we report CP-EL emission with $P_{\rm EL} \sim 1$ at RT obtained from the stripe laser structure based on GaAs-based DHs combined with Fe/γ-like AlO_x spin injectors [7]. Despite of a rather thick spin transport layer, a 0.5-μm thick $Al_{0.1}Ga_{0.9}As$, such a prominent $P_{\rm EL}$ value is achieved.

2. Experimental

A schematic cross sectional view of a device used in the present study is shown in Fig.1 (a). The laser quality AlGaAs/GaAs/AlGaAs DH including a 500-nm thick p-GaAs active layer was grown by metal-organic vapor phase epitaxy by an external vendor, whereas 1.0-nm thick, crystalline γ-like AlO_x tunnel barrier layer was prepared by molecular beam epitaxy by the authors. See ref. 7 for details of preparation and characterization of the γ-like AlO_x. Interface state density of $D_{\rm it} \sim 3 \times 10^{11}$ cm$^{-2}\cdot$eV^{-1}, being far less than that in amorphous AlO_x/GaAs interface, has been reported recently [8]. The γ-like AlO_x/DH wafer was then transferred through the air atmosphere into an e-beam evaporator to form a 40-μm wide, 100-nm thick, stripe Fe layer on the γ-like AlO_x surface. The wafer was finally cleaved into small chips whose cavity length is around 1.09 mm. Each chip was mounted on a copper block and wire-bonded on a Au/Ti/Fe electrode. Experimental configuration is shown schematically in Fig.1 (b). The Fe layer was fully magnetized along the in-plane, GaAs[110] direction prior to the EL experiments.

3. Results and discussion

When a forward current is sent to the Au/Ti/Fe electrode, intense CP-EL can be observed at RT from the cleaved edge. The peak photon energy and the $P_{\rm EL}$ value are, respectively, around 1.36 eV and 0.11 at $J \sim 1.4$ A/cm^2 which is slightly higher than the emission threshold of $J_{\rm threshold} \sim 1.0$ A/cm^2. Here, $P_{\rm EL} = \{I(\sigma^+) - I(\sigma^-)\} / \{I(\sigma^+) + I(\sigma^-)\}$. EL intensity increases with increasing J, whereas $P_{\rm EL}$ decreases monotonously up to $J \sim 85$ A/cm^2. Shown in Fig. 1(c) are CP-resolved EL spectra at three different J beyond 10 A/cm^2. At $J = 28$ A/cm^2, the CP value is $P_{\rm EL}$ = 0.052, and the EL spectral width decreases to some extent. At $J = 85$ A/cm^2, $P_{\rm EL} = 0.031$ whereas the width further decreases. These behaviors can not be explained simply by an increase in sample temperature due to high current density. At $J = 184$ A/cm^2, the intensity of σ^- – EL component is suppressed significantly, yielding large circular polarization of $P_{\rm EL} = 0.987$. The spectral width is further reduced, as noticeable in data shown in Fig.1 (c). Comparison of EL spectra between σ^+ and σ^- components are shown in the inset Fig. 1 (c).

The experimental results, especially sudden enhancement in $P_{\rm EL}$ value and narrowing of EL spectra, strongly suggest the occurrence of stimulated emission and mode narrowing at relatively high current density of, say, $J \geq 100$ A/cm^2.

Finally, we state here potential applications of CP light source: those are ultrafast polarization modulation [9], all-optical magnetization reversal [10], 3D display [11], circularly polarized ellipsometry [12], and optical secure communications [13]. Experimental results disclosed here indicate feasibility of developing spin-laser-diodes.

4. Conclusion

We have demonstrated electroluminescence of nearly 100 % CP at room temperature using laser quality GaAs-based DH and γ-like AlO_x. tunnel barrier. Our results would pioneer the realization of semiconductor-based spintronic and spin-photonic devices.

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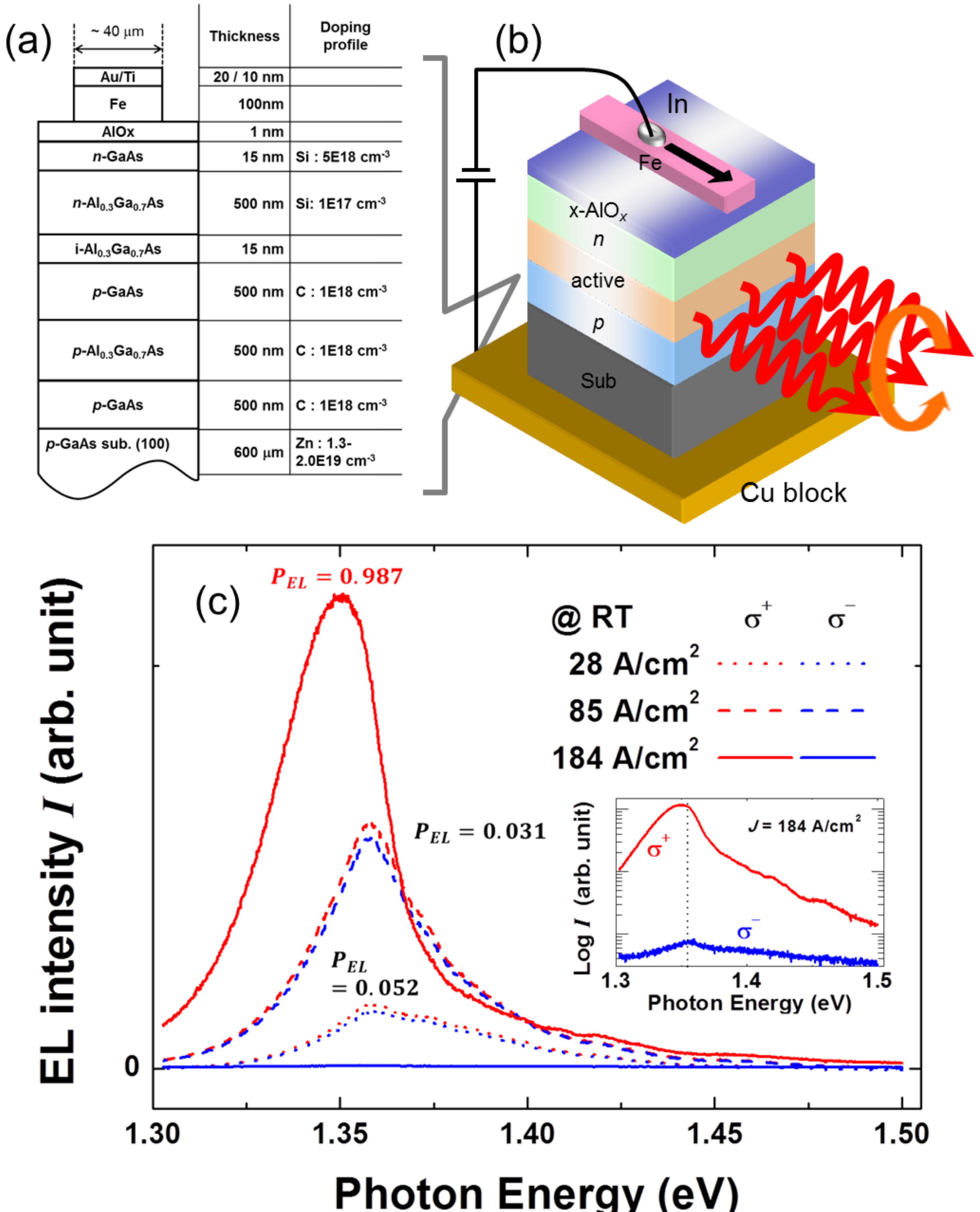

Fig. 1 : (a) Schematic device structure, (b) experimental configuration, and (c) σ^+ and σ^- components of EL spectra emitted from spin-LED at three different current densities, J =28, 85, and 184 A/cm^2. The inset shows the same EL spectra at J = 184 A/cm^2 in logarithmic scale to emphasis the spectral shapes.