Nearly pure circular polarization electroluminescence from spin-LED with significantly reduced current densities

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Electroluminescence with nearly pure circular polarization (CP) at room temperature (RT) together with electrical helicity control [1, 2] has been demonstrated by a lateral-type spin-polarized light emitting diodes (LT-spin-LEDs) consisting of AlGaAs/GaAs double-heterostructures and the crystalline AlO_x (x-AlO_x) tunneling barrier [3]. In this LT-spin-LED, relatively high current density of J > 100 A/cm^2 was required to achieve the circular polarization of P ~ 0.95. Operation with J > 100 A/cm^2, however, often resulted in irreversible breakdown and short-lived spin-LED. In order to suppress this breakdown, we have studied fabrication of LT-spin-LED devices incorporating x-AlO_x/AlAs hybrid tunneling barriers. With AlAs layers that are inserted between the x-AlO_x layer and a top n-GaAs layer of LT-spin-LED, we aim at reinforcing electrical robustness of x-AlO_x tunneling barriers that are formed by oxidation of Al epilayers at RT.

Hybrid tunneling barriers were prepared by molecular beam epitaxy method. First, a 2-nm thick AlAs layer was grown at the substrate temperature (T_S) of 590 °C on the surface of n-GaAs layers, the top surfaces of LED wafers. This was followed by epitaxial growth of 5.6-Å thick Al layers at T_S < 30 °C. Subsequently, wafers were oxidized by dry air for over 10 hours. Striped shape, 40-µm wide Au/Ti/Fe electrodes were formed on the hybrid tunneling barriers. Wafers were cleaved into rectangle chips with size of $l \times w$; l and w are the length parallel and perpendicular to the stripes, respectively. Figure 1(a) shows representative helicity-resolved EL spectra at J = 10 A/cm^2 from LT-spin-LED with device size (l, w) = (1.0 mm, 1.0 mm). The difference in intensity between σ^+ and σ^- components is very large, yielding CP values of around 0.92. Regardless of device size, all devices that were stably operated have exhibited nearly pure CP emission at around J = 10 A/cm^2. Current density dependence of CP values is shown in Fig. 2 for devices with different chip sizes. To our surprise, current density for pure CP emission decreases to about one-tenth with the hybrid tunneling barriers and the yield of device fabrication is significantly improved (~ 5 % → ~ 67 %). It is supposed that growth of AlAs layers prior to the formation of x-AlO_x layers gives rise to improvement of crystalline quality of x-AlO_x layers in terms of suppression of defects in the oxide layer and/or those across x-AlO_x/AlAs/n-GaAs interfaces.

[1] N. Nishizawa *et al.*, PNAS **114**, 1783 (2017). [2] N. Nishizawa *et al.*, APEX **11**, 053003 (2018).
[3] N. Nishizawa *et al.*, JAP **114**, 033507 (2013).

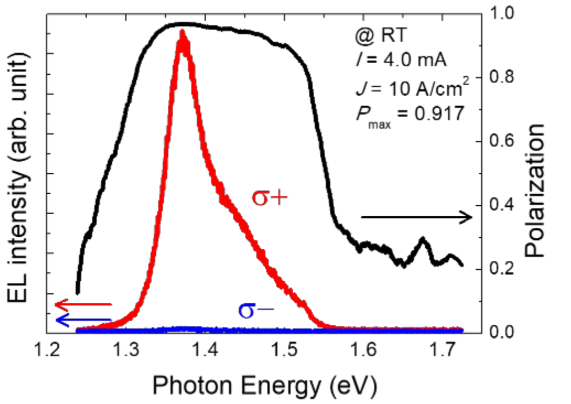

Fig. 1: (a) Helicity-resolved EL spectra obtained at RT from a LT-spin-LED at J = 10 A/cm^2 and V = 8.0 V, together with polarization data on the right axis. The device size is (l, w) = (1.0 mm, 1.0 mm).

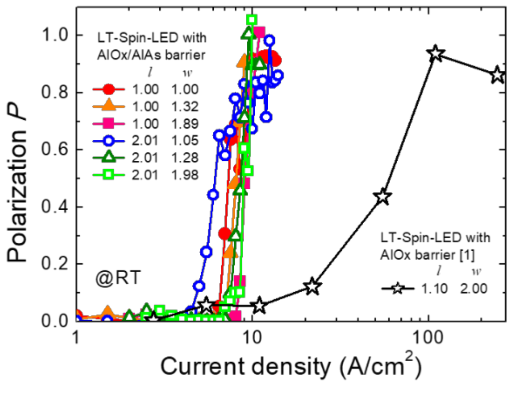

Fig. 2: Current density dependence of CP values for several LT-spin-LED devices with hybrid tunneling barrier with the different sizes $l \times w$, together with the result for a LT-spin-LED with a single x-AlO_x tunneling barrier [1] (☆).