Room temperature circularly polarized lasing in (110) spin-VCSELs

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1. Introduction

We have been working on spin-controlled optical devices based on (110) quantum wells (QWs) where the D'yakonov-Perel' spin relaxation is significantly suppressed and a long electron spin relaxation time has been obtained even at room temperature (RT) [1]. Specifically, (110) spin-controlled vertical-cavity surface-emitting lasers (spin-VCSELs) are of particular importance since the device can convert electron spin information directly to coherent optical signals through circularly polarized lasing. In this presentation, we show our recent results [2, 3] on circularly polarized lasing in a (110) spin-VCSEL under optical spin injection at RT and comment on challenges for electrically pumped operation.

2. Experimental Approach and Results

An all-undoped VCSEL structure was grown on a semi-insulating GaAs (110) substrate using a molecular beam epitaxy (MBE) method. The schematic structure and SEM image of the VCSEL are shown in Fig. 1. It consists of a 36.5- (bottom) and 35- (top) pair of $Al_{0.21}Ga_{0.79}As/Al_{0.91}Ga_{0.09}As$ distributed Bragg reflectors and a 2λ-cavity that includes $Al_{0.15}Ga_{0.85}As$ spacers and nine 10-nm wide $GaAs/Al_{0.15}Ga_{0.85}As$ QWs and 10-nm barriers. The peak reflectivity was estimated to be higher than 99% from a measured reflectivity spectrum.

The VCSEL was optically pumped at RT using a mode-locked Ti:sapphire laser with a pulse duration of 70 fs, a repetition rate of 80 MHz, and an excitation intensity I_{ex} from 2.4 to 4.3 kW/cm^2. The pump light was right-circularly polarized at a 730-nm wavelength to excite the spin-polarized electrons in the spacers, well layers, and barrier layers via the optical selection rules in the Faraday geometry. We measured the right- (σ+) and left-circularly polarized (σ−) components of the VCSEL output using a cooled CCD spectrometer to evaluate the polarization characteristics. Figure 2 shows the σ+ and σ− components of the output intensities plotted as a function of I_{ex} of the σ+ pump pulses. As shown in Fig. 2, the VCSEL output had

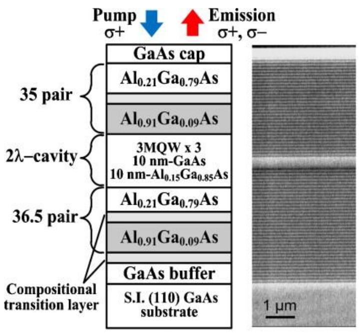

Fig. 1 *Schematic structure and cross-sectional SEM image of (110) spin-VCSEL*

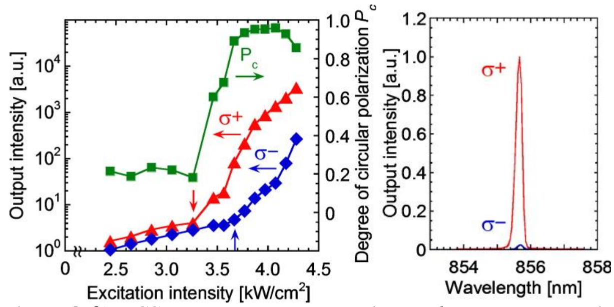

Fig. 2 *(left) VCSEL output intensities (σ+ and σ− components) and P_c as a function of excitation intensity at RT, (right) lasing spectra for σ+ and σ− components at 4.0 kW/cm^2.*

clear threshold characteristics for both the σ+ and σ− components at an I_{ex} of about 3.3 and 3.7 kW/cm^2, respectively. The degree of circular polarization $P_c = (I_{\sigma+}-I_{\sigma-})/(I_{\sigma+}+I_{\sigma-})$ is also plotted against the I_{ex} in Fig. 2. P_c reached a maximum value of 0.96 at 4.0 kW/cm^2. A P_c higher than 0.9 was maintained at the I_{ex} ranging from 3.7 to 4.2 kW/cm^2.

3. Conclusions

We fabricated a (110) spin-VCSEL with GaAs/AlGaAs QWs and characterized the lasing polarization of the VCSEL under optical spin injection. A circularly polarized lasing with a high P_c of 0.96 was demonstrated at RT.

4. Open Questions

The next step for advancing this device is obviously to demonstrate electrically pumped circularly polarized lasing. There are several challenges toward this target as follows.

- MBE Growth and device fabrication of doped (110) VCSEL for electrical pumping
- Electrical spin injection into (110) QWs in the active layers, including spin transport in semiconductor from magnetic contacts to QWs
- Perpendicularly magnetized contact for spin injection at remanence

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