Growth and Optical Properties of InGaAs QW on c-plane Sapphire for Laser Development

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Epitaxial growth of III-V semiconductors on c-plane sapphire would potentially allow the integration of microwave photonics on a single sapphire chip [1]. We will report on the growth of high-quality crystalline InGaAs quantum well on a trigonal c-plane sapphire substrate by molecular beam epitaxy (MBE). For fabrication on sapphire, an AlAs nucleation layer was followed by a two-step GaAs growth method including an early-stage low temperature (LT) GaAs layer and a high-temperature GaAs growth layer. The high temperature GaAs buffer growth incorporates two annealing steps during the growth. An InGaAs quantum well (QW) with GaAs cap layer was epitaxially grown on the 70 nm GaAs buffer [1]. We will discuss the surface morphology, structure quality, and the optical properties of the MBE grown samples. Two structures with 20 nm wide quantum well (QW), S1 and S2, were grown with indium molar fraction of 0.15 and 0.10, respectively. The QW energy transitions were observed at 1.46 eV and 1.48 eV from low temperature (10 K) photoluminescence spectra (Figure 1). Excitingly, the optical results were comparable with the same structure grown on a GaAs substrate. Overall, these observations exhibit potential to achieve an integrated microwave photonic chip on a sapphire platform.

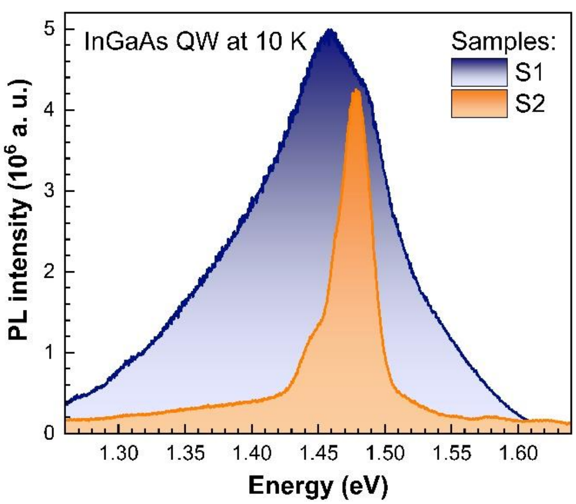

Fig. 1. Low Temperature (10 K) Photoluminescence of InGaAs QW.

[1] R. Kumar, S. K. Saha, A. Kuchuk, Y. Maidaniuk, F. M. de Oliveira, Q. Yan, M. Benamara, Y. I. Mazur, S.-Q. Yu, G. Salamo, Applied Surface Science, **542**, 148554(2021).

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Figure 2 depicts the nominal structure of the InGaAs QW. A 5 nm AlAs nucleation layer was grown at 700 °C whereas, the buffer GaAs layer consists of 200 nm GaAs grown at 600 °C and 500 nm GaAs grown at 700 °C. Samples were annealed at 800 °C for 45 seconds after every 200 nm of high temperature GaAs growth. A 20 nm $In_xGa_{(1-x)}As$ QW was grown at 600 °C on top this GaAs buffer, followed by a 50 nm GaAs cap layer. The values for x are 0.15 and 0.10, respectively. The thickness and composition values are nominal. The cap layer comprises of 5 nm GaAs grown at 600 °C and 45 nm GaAs grown at 700 °C. All the growth temperatures were measured by the thermocouple. However, the actual substrate temperature may be 30 to 100 °C less than the thermocouple temperature since the thermocouple is not touching the substrate. Figure 4 illustrates the reflection high energy electron diffraction (RHEED) images at different stages during the growth. Prominent streaky RHEED images are evident from for the GaAs buffer just before the growth of the QW (figure 3(a) and 3(d)), after the InGaAs QW figure 3(b) and 3(e) and final cap layer figure 3(c) and 3(f). From fig. 4, the root mean square (RMS) surface roughness of the samples, S1 and S2, on the scan area of 5 µm x 5 µm are 1.44 nm and 1.15 nm, respectively.

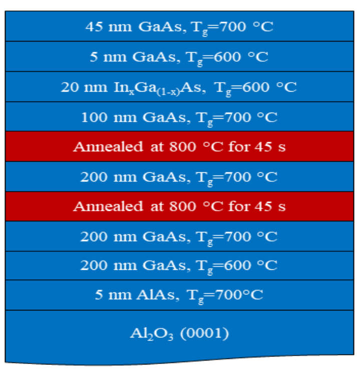

Fig. 2. Schematic structure of InGaAs/GaAs QW.

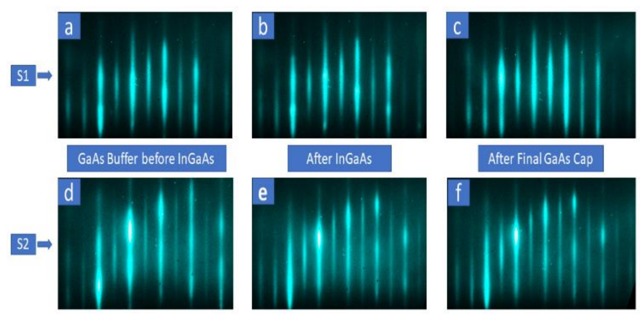

Fig. 3. RHEED images at different stages of growth.

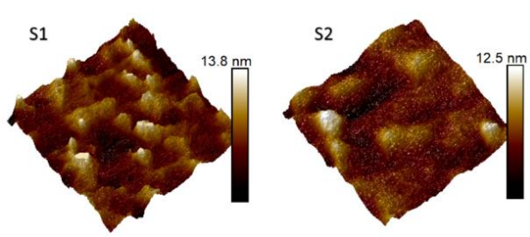

Fig. 4. AFM image (5 µm x 5 µm) of InGaAs/GaAs QW structure.