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AlGaAs/GaAs superlattice grown by molecular beam epitaxy for its application to semiconductor photocathode

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Abstract— **The semiconductor photocathode with AlGaAs/GaAs superlattice structures, which is a highly durable electron beam source with low energy dispersion, were grown by molecular beam epitaxy. The experimental and simulated x-ray diffraction patterns show the formation of the superlattice structures with the designed multi-layered structures and Al compositions. The sample showed step-like quantum efficiency spectrum of photoelectron emission, indicating its applicability to photocathodes. Until now, further improvement of room temperature photoluminescence on the superlattice sample was obtained, promising to provide photocathodes showing the better quantum efficiency.**

1. Introduction

Electron beam is a key technology in nano-scale observation and processing such as electron microscopy and electron beam lithography. The thermionic and field-emission electron guns are used in the industrial applications at present. They can generate direct current electron beams. The next generation of transmission electron microscopes, however, will require fine pulsed electron beams with high peak current to observe fragile and/or moving specimens in real time. Semiconductor photocathodes with a negative electron affinity state are one of the candidates of pulsed electron beam sources, which can be used to produce versatile electron beams such as large beam current, pulsed electron beam, high-polarization electron spin, and small energy dispersion. AlGaAs-based materials have high quantum efficiency with high durability [1-3]. Hence, they are promising materials for high-density pulsed electron beam sources. Further, employment of AlGaAs/GaAs superlattice structures can generate smaller energy dispersion than that of bulk AlGaAs owing to their step-like density of states in the superlattice structures. In this study, we fabricated AlGaAs/GaAs superlattice structures grown by molecular beam epitaxy and investigated their optical and photoelectron emission properties.

2. Experimental

The AlGaAs/GaAs superlattice structures were grown on GaAs (001) substrates by molecular beam epitaxy (MBE). For the growth of AlGaAs with Al fraction of 30%, the Ga flux was set to 1.1 monolayers/s. Arsenic was supplied using a valved cracker cell. The growth was carried out under As overpressure. After growth of a GaAs buffer layer at substrate temperature of 570°C, AlGaAs/GaAs superlattice structures were grown at different substrate temperatures. The superlattice structures were designed to contain 100-periods 3-nm-GaAs/4-nm-AlGaAs structure with p-type conduction by Be doping to increase the excited electron energy relative to the Fermi energy in the semiconductors. The shutter was automatically controlled to obtain accurate film width throughout the structure. The sample was evaluated by x-ray diffraction (XRD), room-temperature photoluminescence (RT-PL), and excitation photon-energy dependence of quantum efficiency of photoelectron emission measured after the surface treatments in an ultra-high vacuum chamber [4].

2. Results and Discussions

The experimental and simulated x-ray diffraction patterns for the superlattice sample are shown in Fig. 1. In Fig. 1 (a), sharp satellite peaks were observed at the same positions in both patterns, which suggest the formation of expected superlattice structures. Figure 1 (b) is an enlarged view around the main peak related to GaAs (004). The good agreement between experimental and simulated patterns indicates the controlled Al composition at 27%. Figure 2 shows the RT-PL spectrum of AlGaAs/GaAs superlattice structures. A peak was observed at 780 nm originating from the AlGaAs/GaAs superlattice structures at the quantized state energy. It is noteworthy that no emission originating from the AlGaAs/GaAs superlattice structures was observed for the sample grown at 560ºC. The optical characteristics of the superlattice could be improved by the optimization growth temperatures. Figure 3 shows the quantum efficiency spectra of photoelectron emission obtained from an AlGaAs/GaAs superlattice sample.

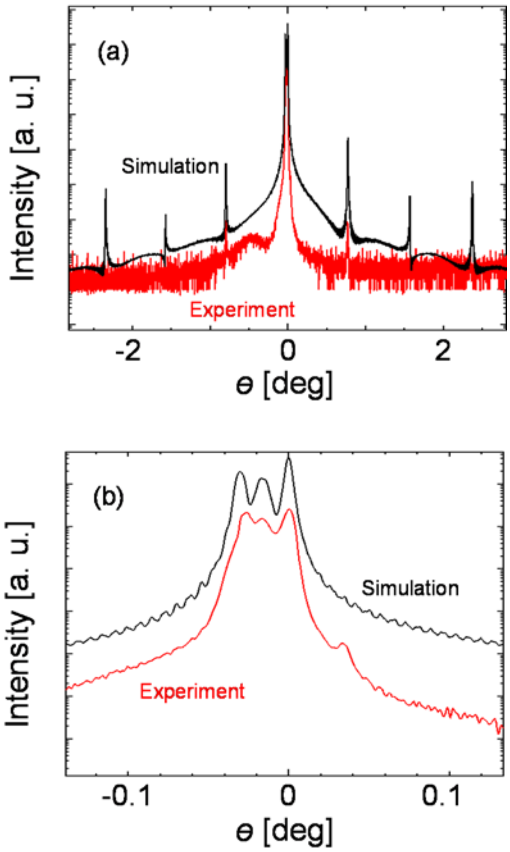

Fig. 1 Figure 1. XRD θ-2θ scan around GaAs (004) diffraction (a) and its enlarged curve (b) of the sample.

Note that the sample does not show the PL peak from the superlattice structures. Besides, a step-like spectra owing to 2-dimensional quantum confinement effect in the superlattice structures. This result suggests that the sample works as a photocathode with superlattice characteristics. Through the optimization of growth conditions, we obtained a new AlGaAs/GaAs superlattice sample which clearly shows a stronger RT-PL peak emitting at 760 nm due to AlGaAs/GaAs superlattice structures up to now. The sample is expected to show improved quantum efficiency of photoelectron emission.

2. Conclusions

We investigated molecular beam epitaxial growth of semiconductor photocathode having AlGaAs/GaAs superlattice structures as a highly durable electron beam source with low energy dispersion. The x-ray diffraction patterns show the formation of the superlattice structures with the designed multi-layered structures. The sample showed step-like quantum efficiency spectrum of photoelectron emission, indicating its applicability to photocathodes. Until now, further improvement of room temperature photoluminescence on the superlattice sample was obtained, promising to achieve photocathodes showing the better quantum efficiency.

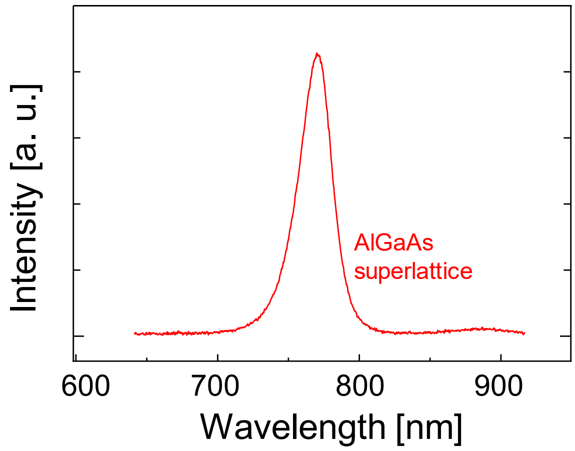

Figure 2. RT-PL spectra of the AlGaAs/GaAs superlattice emitting at the quantized state energy.

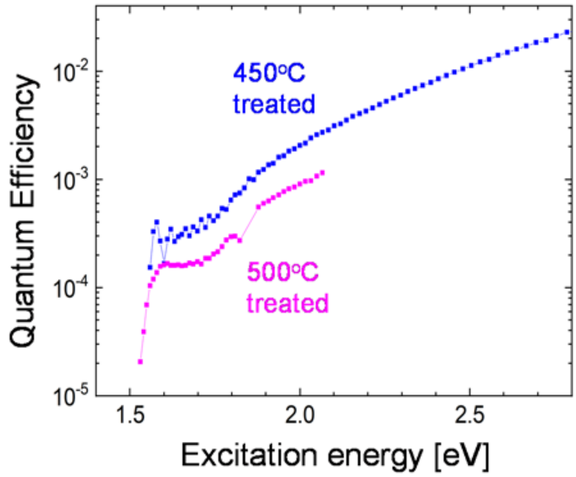

Figure 3. Excitation photon-energy dependence of quantum efficiency of photoelectron emission for the superlattice sample after surface treatments.

Acknowledgements

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