

## Near-field photocurrent measurements on GaAs/AlGaAs multiple quantum wells

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**Abstract** – Near-field photocurrent experiments were performed for GaAs/AlGaAs MQWs at room temperature. Heavy hole and light hole related peaks are clearly resolved even under extremely low power of near-field excitation. By scanning laterally  $2\ \mu\text{m} \times 2\ \mu\text{m}$  area on the surface, minority carrier diffusion process in the well region was qualitatively studied.

Near-field spectroscopy demands very carefulness and rigorous efforts to obtain reliable spectra and good signal-to-noise ratio due to its extremely low excitation power (within a range of a few nanowatts) at the end of apex of fiber probes. When one tries to detect luminescence from a sample, the situation goes more inferior and low-temperature system should be employed for enough amount of luminescence from a sample. The whole disadvantages commented above should be compensated for the resolution-larger apex size of a fiber probe.

Near-field photocurrent experiment rapidly expands its application area including imaging of electrically active defects on semiconductor surfaces [1, 2], carrier transport processes [3], microscopic aging processes in optoelectronic devices [4], imaging layer composition in quantum wells [5], determination of minority carrier diffusion length [6], and determination of slant angle of p-n junction interface [7].

A sample studied in this experiment is GaAs/Al<sub>0.3</sub>Ga<sub>0.7</sub>As multi quantum wells with 80 Å well width, grown by molecular beam epitaxy (MBE) on GaAs substrates and nominally undoped. The growth of GaAs samples by MBE brings about p-type and doping concentration was estimated on the order of  $\sim 10^5$ . Si-doping concentration in the buffer layer is  $2 \times 10^{18}$  and growth temperature was 650°C.

For photocurrent measurements, electrodes are formed on the sample surface by photolithography (Fig. 1). The gap width between two electrodes is 40  $\mu\text{m}$  and line width of electrodes is 100  $\mu\text{m}$ . Deposi-

tion material is 425-Å Au-Ge and 500-Å Au is overlaid. After formation of electrodes, samples were annealed at 500 for 30 seconds in Rapid Thermal Annealing system, so that germanium diffuses into the well region and contributes the detection of photocurrent signal.

Typical setup for PC measurements are combined with the previously described near-field system (Fig 2). Excitation source was cw Ti:Sapphire laser (700 ~900 nm) pumped by Argon ion laser. Wavelength of Ti:S was detected at spectrometer and automatically matched with the corresponding PC signal by a personal computer. Excitation light was chopped at 90 Hz and synchronously read in lock-in amplifier.

Fiber probe was located between electrodes and illuminates the region. In our scheme of the experiment, photo-generated carrier contributes to the current only by the diffusion process because there is neither external bias nor built-in potential. Hence we can study the lateral diffusion process in QW structure.

Since near-field photocurrent (NPC) experiment, however, employs the scheme using a sample as a detector, it provides very sensitive response even under near-field excitation. Hence, better signal-to-noise ratio and enhanced resolution (by using smaller apex size probes) can be achieved in NPC. For illustrations, near-field luminescence and far-field luminescence (Fig. 3), and near-field photocurrent and far-field photoluminescence excitation spectrum (Fig. 4) are presented. What should be noted in



Fig. 1. Photograph of electrodes on GaAs/AlGaAs MQWs sample.

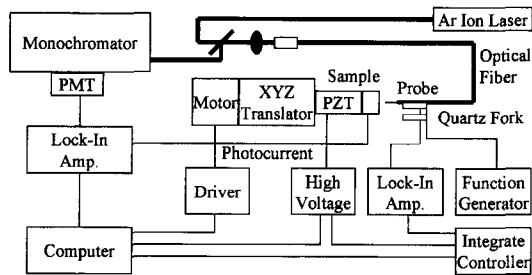


Fig. 2. Schematic diagram of NSOM.

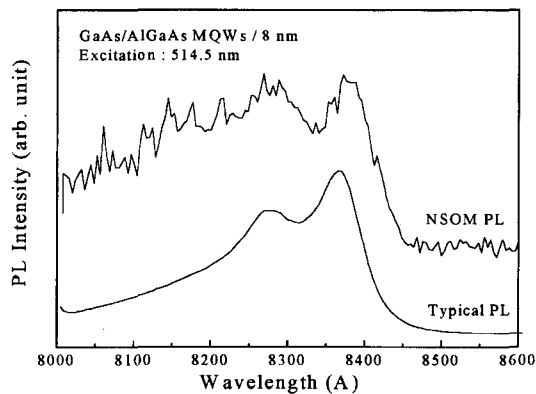


Fig. 3. The NSOM PL and typical PL spectra for GaAs/AlGaAs MQWs.

these figures is near-field luminescence spectrum is obtained using 500 nm probe, while 100 nm probe was used in near-field photocurrent experiment. As shown in the Figure 4, two peaks related with heavy hole and light hole are clearly resolved and better signal-to-noise ratio is achieved when compar-

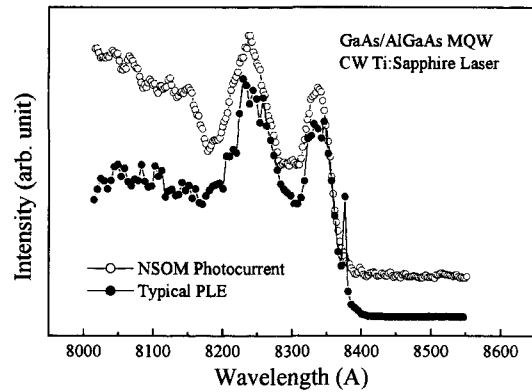


Fig. 4. Comparison of near-field photocurrent and far-field PLE spectra.

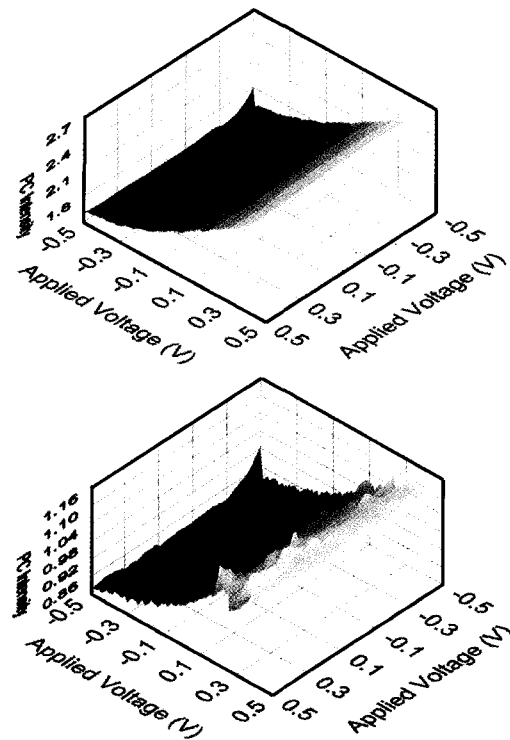


Fig. 5. Near-field photocurrent maps of GaAs/AlGaAs MQWs (upper : heavy hole, lower : light hole).

ing PL spectrum.

NPC signal was obtained at an arbitrary point of the gap between two electrodes (Fig. 1). Heavy and light hole related peaks are appeared at 8340 (1.487 eV) and 8243 (1.504 eV) Å, respectively. Shear-force topographic image of  $2\ \mu\text{m} \times 2\ \mu\text{m}$  are was simultaneously taken with NPC, in order to identify

the area under consideration. Unit of X and Y axes is the voltage applied to PZT (Gain :  $\times 100$ ). For conversion to extension(negative value of voltage)/reduction(positive value) length, a factor of 21 nm/V should be multiplied to the corresponding value of voltage. Spatial mapping is performed at the wavelength of 8337, and 8239 Å (Fig. 5). Common characteristic in the figures are NPC signal increases as tip approaches the electrodes. This point explained by diffusion current model. As mentioned above, there is neither external bias nor built-in potential in this sample, so that the NPC signal is absolutely originated from the diffusion current. In general, minority carrier diffusion lengths are more longer than that of majority carrier in semiconductors. In the case of this sample (p-type well), electrons mainly contribute the NPC.

If the tip is located at the center of the gap between the electrodes, there will be no currents since photo-generated carriers diffuse into every direction evenly so that counterbalance each other. Though it is the ideal case, it must be true that the NPC signal falls to the minimum. As a tip moves toward one of electrodes, however, there occurs the difference in the number of carriers so that the voltage difference between two electrodes is triggered.

In this sample, consistent increase of NPC confirms that there is no electrically active defects within the area under investigation. It can be also inferred that relatively regular signal in the constant y-direction ensures the interface flatness between a

well and a barrier. Quantitative treatment of the above dissertation need more study.

In conclusion, for the application to the semiconductor nanostructures, near-field photocurrent experiments were performed for GaAs/AlGaAs MQWs sample. In the room temperature setup, near-field photocurrent measurements shows better signal-to-noise ratio since it employs the scheme using specimens as detectors. Heavy hole and light hole related peaks are clearly resolved even under extremely low power of near-field excitation. By scanning laterally  $2\text{ }\mu\text{m}\times 2\text{ }\mu\text{m}$  area on the surface, minority carrier diffusion process in the well region was qualitatively studied.

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