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Direct Measurement of Surface Recombination Lifetimes in GaAs Quantum Wires by Time Resolved Spectroscopy

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We report the first direct measurement of surface recombination lifetimes in MOCVD grown GaAs quantum wires by using a femtosecond laser system and ultrafast streak camera.

Arakawa and Sakaki (1,2) have initially proposed quantum wire and quantum dot structures with two and three dimensional confinement of electrons and holes. Arakawa et al (3) have theoretically examined the important application of quantum wire and quantum dot structures to semiconductor lasers.

We have grown the free standing GaAs quantum wires by MOCVD technique. The SEM micrograph of GaAs quantum wire crystals is shown in Figure 1. The photoluminescence and time resolved spectroscopy were investigated by using a femtosecond laser system comprising a 82 MHz Nd:YAG laser, fiber optic pulse compressor, KTP frequency doubling unit and a synchronously pumped dye laser. The luminescence signal was detected by a high speed streak camera. Quantum wires of diameters 200, 100, 70 and 50 nm were studied. Experiments were conducted from liquid Helium to room temperature. In the PL spectra at 6K for quantum wires of different diameters the quantum confinement induced blue shifts were observed. In Figure 2 the PL decay curves at 7K for 100, 70 and 50 nm quantum wires are shown. It can be seen that the PL intensity decays very fast in the beginning and then rather slowly afterwards. The fast component is interpreted as due to surface recombination and the slow component is attributed to the free exciton recombination. Yablonovitch et al (4) have investigated the surface recombination dynamics in semiconductors. When the sample thickness is sufficiently small, the decay of the carrier density n is due to sum of a bulk contribution and a surface recombination:

$$\frac{dn}{dt} = -\left(\frac{1}{\tau_r} + \frac{1}{\tau_s}\right)n$$

In this equation $1/\tau_s = 2S/L$, τ_r is the radiative lifetime and τ_s is the surface recombination lifetime.

We estimated the surface recombination lifetimes, τ_s, as 342, 269 and 117 picoseconds for the 100, 70 and 50nm quantum wires respectively. This physically means that as the diameter of the wire decreases the surface recombination enhances and the lifetime decreases. The surface recombination velocities (SRV) defined as $S=L/2\tau_s$ were found to be 146,185 and 427 cm/s for 100, 70 and 50nm quantum wires respectively. The variation of SRV as a function of wire diameter is shown in Figure 3. This shows that SRV drastically increases as the wire diameter becomes smaller than 50nm, which means that the surface states in the recombination dynamics of the quantum wire are important

The effects of surface treatment with sulphur on the quantum confinement and surface recombination dynamics in the 200nm quantum wire were studied. The blue shift was found to decrease after surface treatment. This was interpreted as due to the reduction in the depletion potential. PL decays for 200nm quantum wire were studied before and after surface treatment. An increase in surface recombination lifetime was found after surface treatment. This was in agreement with the results we discussed before, viz, the surface recombination lifetime increases with increase in diameter.

In summary, the direct measurement of surface recombination lifetimes and surface recombination velocities in GaAs quantum wires was demonstrated. The recombination dynamics was discussed in terms of changes in the recombination velocities as a function of wire diameter and changes in the surface depletion potential, which leads to the importance of surface states of the wire crystal.

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References
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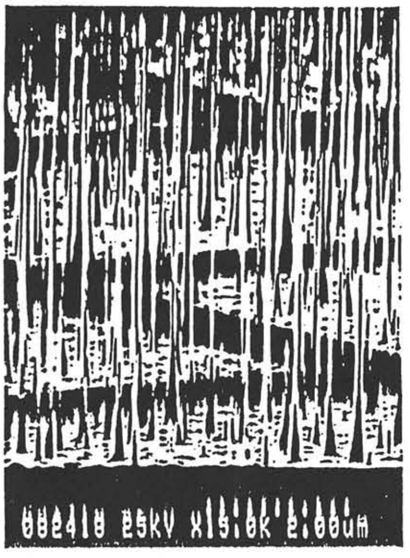

Fig.1. SEM micrograph of GaAs qunatum wire crystals

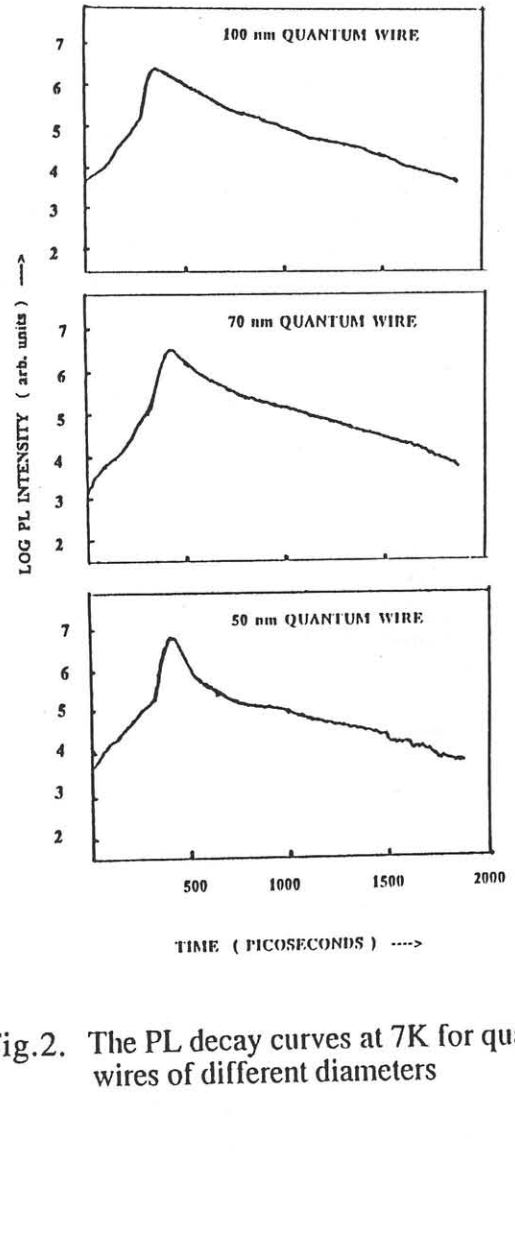

Fig.2. The PL decay curves at 7K for quantum wires of different diameters

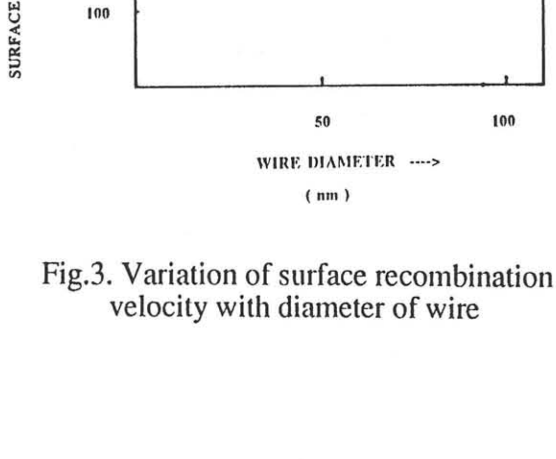

Fig.3. Variation of surface recombination velocity with diameter of wire