Nanoscale carrier dynamics in GaInNAs p-n junction investigated by Laser Combined Scanning Tunneling Microscopy

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Dilute nitride III-V semiconductor: GaInNAs has attracted a great deal of attention due to its potential in device application such as long-wavelength lasers and high efficient solar cells. Taking advantage of the extremely large bowing coefficient between III-N and III-As binaries, band gap energy of GaInNAs can be controlled widely while keeping lattice match to GaAs. However, its actual performance has been degraded due to the shortening of carrier lifetime caused by such as high defect density, alloy disorder, and roughness of interface.

To understand this issue from microscopic point of view, Light-Modulated Scanning Tunneling Microscopy (LM-STM) and femtosecond time-resolved Scanning Tunneling Micorsocpy (Shaken-Pulse-Paired excited STM: SPPX-STM) were applied to map nanoscale carrier dynamics in a GaInNAs p-n junction. In LM-STM experiment, the tunnel gap of STM is illuminated by chopped CW laser (Fig.1) and Surface Photovoltage (SPV) was measured as a function of the tunnel bias voltage. The magnitude of SPV reflects the local carrier dynamics, such as carrier diffusion and carrier recombination rate. The sample used was a GaInNAs p-n junction grown by molecular beam epitaxy. Measurements were performed on a cleaved clean surface at room temperature in ultrahigh vacuum. Figure 2 shows a STM image of cleaved GaInNAs p-n junction interface (a) and corresponding SPV image (b). Compared to the n-GaAs substrate, a smaller SPV was observed on the n-GaInNAs region, which indicates a shorter carrier lifetime in tn-GaInNAs than n-GaAs. On the other hand, in SPPX-STM experiment, the tunnel gap of STM was illuminated by a sequence of paired pulses and the corresponding change in tunneling current ΔI was measured as a function of delay time between the pulses in a pair. SPPX-STM directly measures the local decay process of minority carriers, also showing a shorter carrier lifetime for the n-GaInNAs (55ns) region compared to that in the n-GaAs (90ns). Furthermore, a nanoscale inhomogeneity of carrier lifetime was observed for the n-GaInNAs, which is attributed to the higher defect density and the compositional fluctuation in the GaInNAs region.

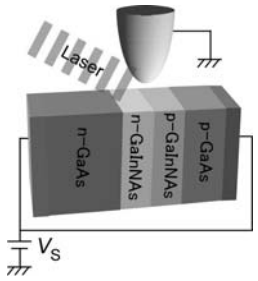

Fig.1 Schematic of experiment

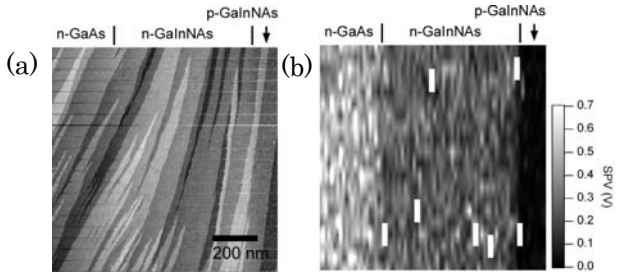

Fig.2 (a) STM image of a cleaved GaInNAs p-n junction interface. (b) SPV image obtained for the surface with V_S = +1.9V.