Nanoscale carrier flow in an operating GaAs p-n junction imaged by Light-Modulated Scanning Tunneling Spectroscopy

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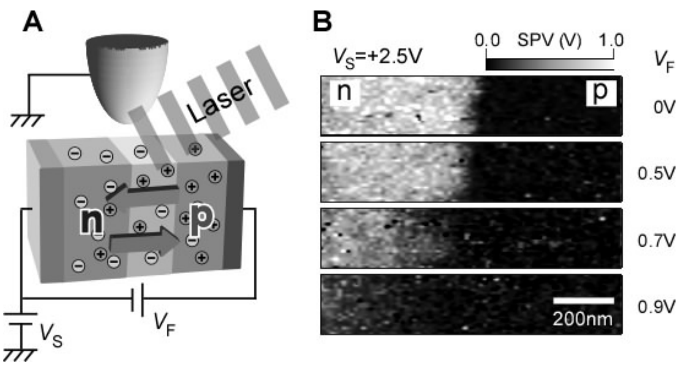
The microscopic behavior of carrier flows inevitably affects the macroscopic electrical properties in many semiconductor devices, thus, direct observation of the characteristics, which provides us with the basis of the results of the macroscopic analysis, is of great importance.

In this study, we applied “Light Modulated Scanning Tunneling Spectroscopy” [1] (LM-STS) to the analysis of nanoscale surface photovoltage (SPV) on a cross-sectional surface of a GaAs p-n junction. The SPV reflects the amount of tip-induced band bending (TIBB), the value of which is governed by the bias voltage between tip and sample, doping characteristic and the dynamical behavior of excess carriers injected by the external bias voltage and optical excitations. By taking advantage of these characteristics, we quantitatively determined the doping profile at a p-n junction interface with ~10 nm resolution, and succeeded in real-space imaging of flowing minority carriers in a forward biased p-n junction. Experimental setup is illustrated in Fig. A. All measurements were performed on a cleaved clean GaAs(110) surface. The n- and p-GaAs layers are doped with Si ($2.0 \times 10^{18} cm^{-3}$) and Be ($2.0 \times 10^{18} cm^{-3}$), respectively. Electrodes were formed on the both sides and the STM bias voltage and the forward bias voltage were applied as shown in Fig. A to perform the *in situ* observation of the sample under device-operating conditions. Figure B shows a series of SPV images obtained around the p-n junction interface with different forward bias voltages. Change in SPV across p-n junction interface was clearly observed with the short-circuit condition. From the analysis of the change at V_F = 0V, the p-n junction interface was determined with ~10nm resolution. When the forward bias voltage was applied, SPV in the vicinity of the interface was reduced as a result of the injection of minority holes into the n-type region. Since the excess minority carriers effectively screen the electric field applied between tip and sample, TIBB and SPV decrease as a function of the minority carrier density. Thus, real space drift-diffusion properties of minority carrier with various V_F can be quantitatively measured from these SPV images.

Microscopic basis for the characteristic of minority carrier dynamics in a p-n junction has been obtained successfully.



*http://dora.bk.tsukuba.ac.jp/

[1] O. Takeuchi, S. Yoshida and H. Shigekawa, Appl. Phys. Lett. 84(18), 3645-3647 (2004)