

Time-resolved STM on carrier dynamics at metal-nanoparticle/GaAs(110)

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With the miniaturization of semiconductor devices, gap states formed by a small amount of defects and impurities will affect entire device performance through their carrier capture, emission, and recombination processes. In this study, we visualized nanoscale carrier dynamics around localized gap state using shaken pulse-paired excited scanning tunneling microscopy (SPPX-STM)¹. We employed 3d transition metal nanoparticles of Fe and Co on GaAs(110) substrates as ideal model systems of localized gap states since they build deep acceptor states in the GaAs bandgap.

In SPPX-STM measurement, the tunnel gap of STM is illuminated by a sequence of paired pulses (inset of Fig.1) and the corresponding change in tunneling current ΔI is measured as a function of delay time between the paired pulses (t_d). Since the magnitude of ΔI obtained under a certain delay time t_d reflects the density of photo generated carriers at t_d after 1st pulse excitation, ultrafast carrier decay process can be measured from delay time dependence of ΔI . Figure 1 shows ΔI vs delay time spectra obtained above a bare GaAs(110) surface and a Fe nanoparticle. The lifetimes of photo-generated minority holes captured at the surface were estimated by fitting with exponential functions. The estimated lifetime at Fe nanoparticles (5ns) was found to be much shorter than that at bare GaAs surface (55ns). At Fe nanoparticles, photo-generated holes captured by gap states recombine immediately with electrons provided by STM tip (Fig.2). Since tunneling rates of electrons (J_e) were sufficiently large in our measurement condition, carrier lifetimes were determined by the carrier capture rate of minority holes (J_h) into gap state. Figure 3 shows the carrier capture time measured for Fe and Co nanoparticles against their particle sizes. Carrier capture time similarly have a nearly inverse relationship with particle sizes for the both metals, but the capture time for Fe nanoparticle was shorter than that for Co nanoparticle. Details will be discussed at the conference.

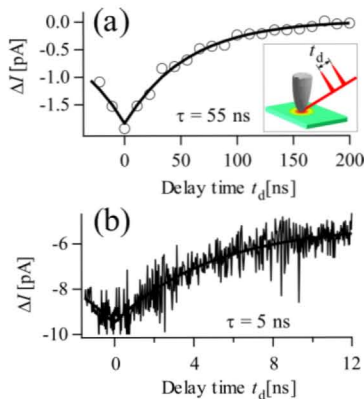


Fig. 1: ΔI vs delay time obtained above (a) a bare GaAs surface and (b) a Fe nanoparticle.

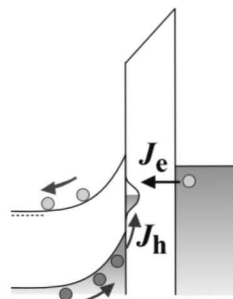


Fig.2: carrier recombination mechanism via gap states.

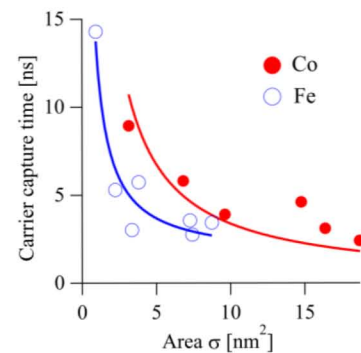


Fig.3: Carrier capture time of hole via gap states as a function of nanoparticle size.

¹Y. Terada, S. Yoshida, O. Takeuchi and H. Shigekawa Nature Photonics, 4, 12, 869 (2010)