Ultrafast carrier dynamics in optically excited semiconductors probed by time-resolved scanning tunneling microscopy

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Combination of scanning tunneling microscopy (STM) with optical excitation by ultrashort laser pulses enables, in principle, to simultaneously obtain ultimately high spatial and temporal resolutions. We have developed a pulse-pair excited STM (PPX-STM) [1, 2] and succeeded in detecting time-resolved tunnel current signals from a variety of semiconductors.

In a PPX-STM measurement, the tunnel gap of an STM is illuminated by a sequence of paired laser pulses with a variable delay time t_d (Fig. 1). Since the laser repetition rate (90MHz) is much higher than the cutoff frequency (~100kHz) of the current-voltage converter (IVC) of the STM, the IVC does not resolve the instantaneous current spikes in tunnel current $I_t*(t)$ caused by the excitation of the sample by laser pulses. Instead, the IVC detects the temporally averaged tunnel current signal $I(t_d)=< I_t*(t)>$. Even in this case, $I(t_d)$ depends on the delay time t_d if the dependence of $I_t*(t)$ on the illumination intensity has any nonlinearity. This condition is satisfied for most of semiconductors where the laser illumination induces a change in surface photovoltage (SPV), because SPV, and thus photoinduced tunneling current that depends on the change in the barrier height, has a nonlinear relationship with the laser intensity; SPV saturates as the laser intensity increases.

Figure 2 shows an example of SPPX-STM signal of low-temperature-grown GaAs. The time-solved tunneling current decays with a decay time τ_0 of 2.0 ps. The value of τ_0 is quite close to the photocarrier lifetime 3.2 ps estimated from the optical pump-probe reflectivity measurement. The agreement between the values obtained with the two measurement techniques indicates that the PPX-STM signals satisfactorily reflect the photocarrier dynamics. Details, such as the underlying physics, will be discussed at the presentation.

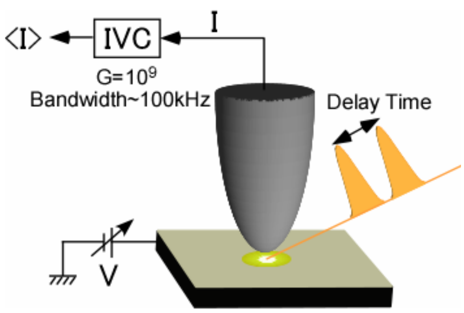

Fig. 1 Schematic of PPX measurement. The laser energy is 1.55 eV, well above the bandgap of GaAs (1.43 eV).

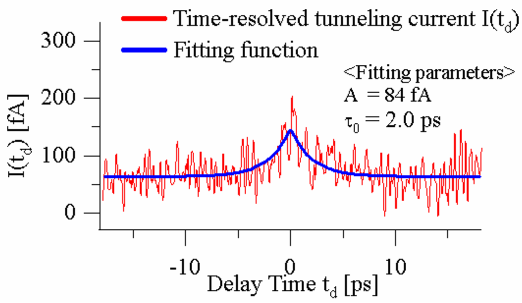

Fig. 2 An example of PPX-STM signal obtained for a low-temperature-grown GaAs, exhibiting an ultrashort decay time of 2.0 ps.

References
http://dora.ims.tsukuba.ac.jp/
[1] O. Takeuchi et al., *Appl. Phys. Lett.* **85**, 3268 (2004).
[2] Y. Terada et al., *Nanotechnology*, in press.