Time Resolved Scanning Tunneling Microscopy; principles of measurement

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Understanding and control of carrier dynamics in nanoscale structures are the key factors for advancing nanoscale science and technology. Recently we have developed a femtosecond time-resolved scanning tunnel microscope (STM), shaken-pulse-pair excited STM(SPPX-STM), which enables us to visualize ultrafast carrier dynamics of semiconductor devices in nanoscale spatial resolution. In the case of SPPX-STM measurement on semiconductor, exponential decay of tunneling current ΔI against delay time reflects the lifetime of minority carriers in semiconductor. According to current physical model, two carrier decay processes are expected to be observed (fig.1); carrier decay due to direct recombination in bulk and surface carrier decay due to thermionic emission from surface to bulk. However, this model has not been yet supported enough by past experiments. In this study, we have examined the model by investigating the influence of photo-carrier density on these two relaxation process appeared in SPPX-STM spectra.

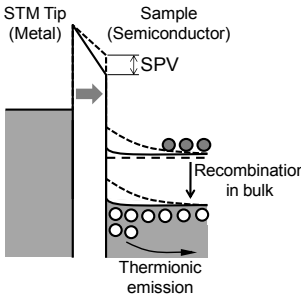

Fig.1: Band diagram of STM tunnel junction with two photocarriers relaxation processes

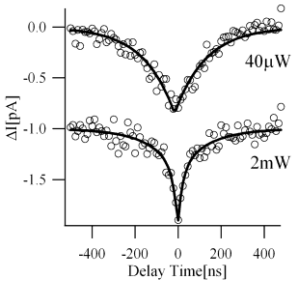

Fig.2: SPPX-STM signals in two different optical intensity

Fig.2 shows SPPX-STM spectra of n-type GaAs (110) with different optical intensity. Under lower optical intensity, single exponential decay (τ ~ 100ns) could be observed, whereas two exponential decay (τ ~10nS and 100nS) under higher optical intensity. Especially, fast decay was only observed under very high optical intensity which suggests adsorption saturation of excess photo-carriers involved in the mechanism. Furthermore, decay time τ ~ 10ns is close to the lifetime of minority holes of n-GaAs. We concluded that fast decay component reflect bulk side carrier recombination. In contrast, lifetime of accumulated holes at the surface was assumed to be slower decay, because they cannot recombine due to depletion of electrons at the surface under upward band bending. They can decrease only through thermionic emission from surface to bulk. Therefore, their lifetime is controlled by the amount of bandbending. Actually, decay time of slower component became longer as decreasing optical intensity. In this condition, large upward bandbending is expected even under optical excitation, which causes slower thermionic emission. In this way, current physical model can give clear explanations of SPPX-STM spectra.