

Time-resolved atomic force microscopy using delay-time modulated pump-probe method

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Currently, many kinds of researches and developments are underway to drive changes in the structure and electrical/mechanical properties of material systems at high speed in the nanoscale region. Atomic force microscopy (AFM) is a powerful tool for clarifying nanoscale properties of conductive/insulating materials. Generally, the time resolution of dynamic AFM is limited to the resonance period of the cantilever(ms-us). On the other hand, recent technological developments are progressing, such as combining the optical pump probe method and AFM technology to achieve ultrafast time resolved measurements[1]. However, these methods all relied on the intensity modulation of the excitation light, similar to the macroscopic optical pump-probe method.

Here, we demonstrate a time-resolved atomic force microscopy method by combining a tuning-fork-type FMAFM with the delay time modulation method[2]. We successfully obtained the photoexcited carrier dynamics in bulk WSe₂, which are challenging in time-resolved STM owing to the effect of tunneling current[3]. As shown in Fig. 1, a time-resolved signal was measured by irradiating optical pulse pairs with delay time modulation onto the AFM tip and the time-resolved force signal Δf_{tr} was detected by lock-in amp as frequency shift amplitude. Figure 2 shows a time-resolved signal obtained on bulk WSe₂ sample. We succeeded in extracting lifetimes of $\tau_{fast} \sim 17$ ns and $\tau_{slow} \sim 390$ ns from biexponential fitting analysis. Details of the detecting principle and signal origin will be discussed on this presentation. This developed method makes a key role for local dynamics research of a varieties of target.

[1]. Z. Schumacher et al, *Appl. Phys. Lett.* 110, 05311 (2017) [2]. K. Iwaya et al, *Sci. Rep.* 12, 818 (2023)

[3]. H. Mogi et al, *Appl. Phys. Express* in print. (2023)

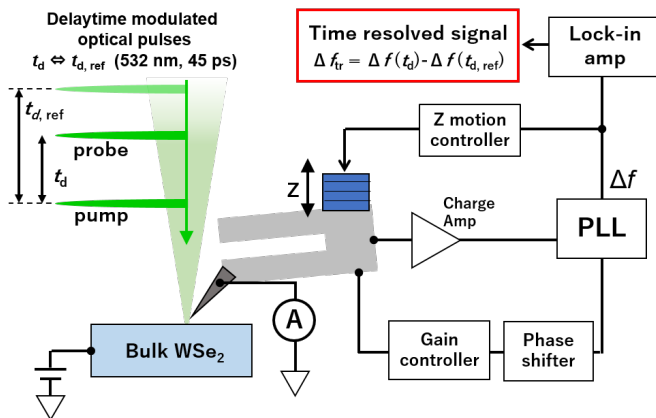


Fig. 1 A Schematic diagram of pump-probe FMAFM

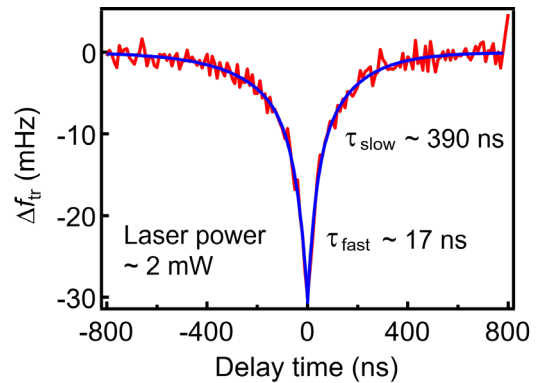


Fig. 2 A time resolved signal measured on a bulk WSe₂ sample.