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Pulse Compression by the Use of Deformable Mirror for Ultrafast Scanning Near- field Optical Microscopy System

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[Introduction] Spatial and temporal characterization of plasmons is essential to understand unique optical properties of noble metal nanostructures. Spatial scale of plasmons is usually much smaller than that of the diffraction limit of light, and thus conventional optical microscope is of little use. Near-field method can overcome the diffraction limit, and can explore plasmons in real space. Time scale of plasmons is typically of order of a 10-20 femtosecond (fs), and time-resolved technique is of great use to study dynamic properties of plasmons. By combining the near-field method with the ultrafast time-resolved technique, we can construct an ultrafast near-field optical microscope, which enables us to study spatial and temporal behaviors of plasmons at the same time.

We have already reported ultrafast near-field apparatus based on a fiber-probe apertured near-field optical microscope, whereas the time resolution was limited to 100 fs by the light source. In this study, we are improving the time-resolution as short as lifetime of plasmons by using a short light source and a pulse shaping technique.

[Experimental] Figure 1 shows a schematic diagram of experimental setup. In this setup, the near-field microscope was replaced by second-harmonic (SH) generation optics to examine the performance of the pulse shaping system. Output of a Ti:sapphire laser with 15 fs pulse duration was dispersed by a grating and collimated by a cylindrical lens, and incident on the deformable mirror. Reflected beam was again incident on the grating after passing through the cylindrical lens. These optical components act as a 4f optical configuration, and are utilized for pulse shaping. A prism pair (SF14) was also used to manipulate the pulse shape, especially to pre-compensate pulse broadening effects arising from optical components before the beam was coupled to a 350-mm long optical fiber. Output of the fiber was collimated by an objective lens and focused onto a BBO crystal. BBO crystal was used to generate SH photons. SH photons were detected by a photomultiplier tube and were fed to the computer. A genetic algorithm was used to optimize the SH intensity, by controlling surface shape of the deformable mirror in an adaptive manner.

[Results and Discussion] As long as a femtosecond pulse is concerned, pulse duration is broadened due to group velocity dispersion (GVD) occurred in every optical components. In an apertured near-field microscope, such broadening effect is significant especially in the optical fiber, and the pulse width broadens to a few picoseconds. In our previous setup, the broadening effect was compensated by a grating pair, and we could recover the original pulse width at the near-field tip. Time-resolution was limited by light source (100 fs). In this study, we replaced the light source to a 15 fs one, and we tried to shorten the pulse width with a grating pair or a prism pair. Figure 2a shows a typical auto-correlation trace of pulses obtained using a prism pair compensator. It is found that the pulse width obtained (320 fs) in this setup is much broader than that of the original pulse. It is probably due to higher order GVD occurred in the fiber. Such higher order GVD contribution becomes significant, as the pulse width is extremely short.

In order to get rid of the higher order GVD contribution, we utilized a pulse shaper, which consists of a grating and a deformable mirror. The grating is used for dispersing the light spatially, and the deformable mirror finely tunes optical path length of the light depending on the wavelength by tuning the surface shape of the mirror. Figure 2b shows an autocorrelation trace of pulses obtained using the pulse shaper and the prism pairs. The pulse width is much shorter than that obtained without the pulse shaper. However, it is still broader (75 fs) than that of the original pulse. The reason for this is not clear, but might be due to geometrical limitation of the deformable mirror. We are currently improving the limitation by changing the optical alignment. We are going to combine the system with a near-field microscope.

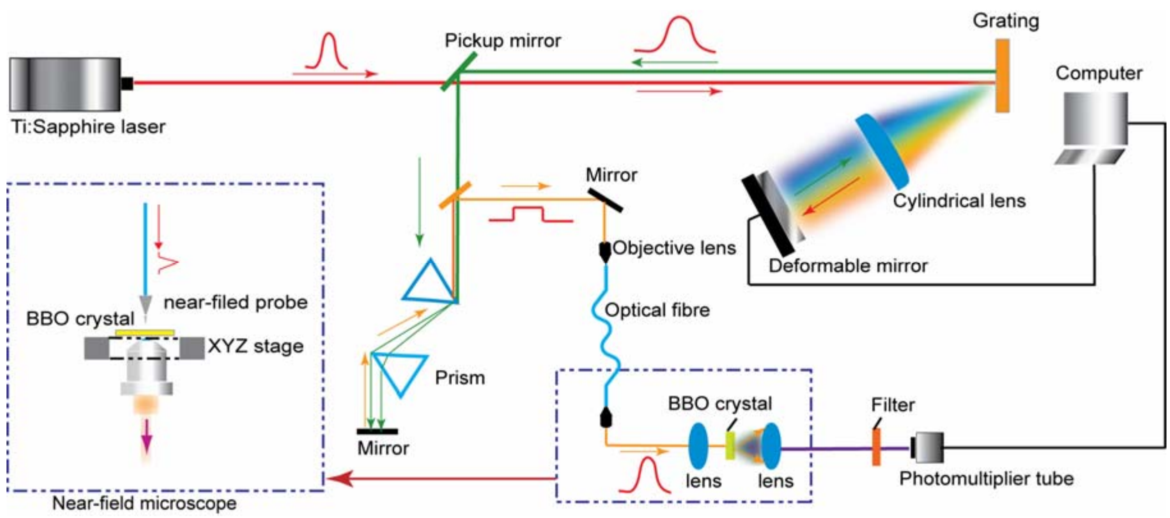

Fig 1. Schematic diagram of the experimental setup.

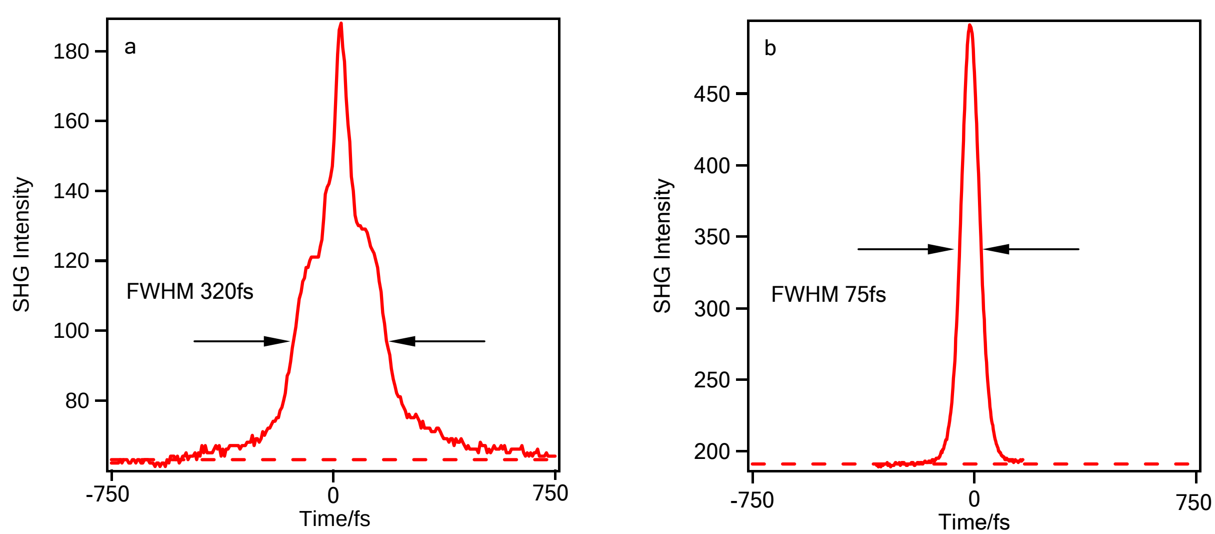

Fig 2. Autocorrelation trace before (a) and after (b) optimization. The dotted lines indicate base line of the SHG signal.