Autocorrelation Measurement of Femtosecond Optical Pulses Using Two-Photon-Induced Photocurrent in a Photomultiplier Tube

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Abstract. Very sensitive intensity autocorrelation measurement of 15-fs, 800-nm pulses from a Ti:sapphire laser has been achieved by using two-photon-induced photocurrent in a photomultiplier tube.

1. Introduction

Recent progress in intensity autocorrelation measurements of femtosecond optical pulses based on two-photon-induced processes in photodetectors, such as photodiodes (PDs) and light-emitting diodes, has made the pulse-width measurement of ultrashort pulses very simple and easy [1]. Sensitivity of these methods are generally better than the conventional technique based on second-harmonic generation in a nonlinear crystal. However, more sensitive measurements are required in many areas of application of femtosecond optical pulses, such as pulse shaping and ultrafast spectroscopy. Here, we present our recent results of very sensitive autocorrelation measurement of 15-fs optical pulses based on two-photon-induced photoemission in a photomultiplier tube (PMT).

PMTs are very sensitive photodetectors because of the secondary-emission multiplication of photoelectrons. Use of a PMT, therefore, as a nonlinear detector in autocorrelation measurements should lower the required input light power to a considerable extent. Autocorrelation measurements of picosecond optical pulses have already been reported [2,3]. However, no studies have been reported on the femtosecond response of the two-photon-induced processes in PMTs, or on autocorrelation measurements of 800-nm light from Ti:sapphire lasers, which are widely used as femtosecond pulsed light sources.

2. Experiment

Attenuated output of a Ti:sapphire laser generating 15-fs, 800-nm pulses at a repetition rate of 89MHz was sent to a Michelson-type interferometer. The output of the interferometer was loosely focused by a concave mirror with a focal length of 200 mm onto the photocathode of a PMT with a spot size of 80 μm. Two-photon-induced photocurrent of the photodetector was measured by scanning the

delay time of one arm in the interferometer. Two PMTs were used in the experiment: 1P28 (Hamamatsu Photonics), with a reflection-mode Cs_3Sb photo-cathode and R2557 (Hamamatsu Photonics), with a transmission-mode Na_2KSb photocathode. Both of these PMTs have one-photon response spectra similar to that of a GaAsP PD, which was used by Ranka *et al*. in the autocorrelation measurement based on the two-photon-induced photocurrent in the PD [1]. A GaAsP PD was also used in the present experiment for comparison.

Interferometric autocorrelation traces obtained with the GaAsP PD at two values of input power are shown in Fig. 1. Figure 1(a) shows an autocorrelation trace with a very good signal-to-noise ratio, which was obtained with 70 mW incident light. On the other hand, with incident light of 500 μW, traces obtained with the PD were not only very noisy but also deformed by a considerable contribution of one-photon-induced photocurrent, as shown in Fig. 1(b).

With similar input power of 410 μW, very good autocorrelation trace was obtained with the PMT as shown in Fig. 2. No broadening of the pulse is observed in the figure.

Signal traces obtained with a PMT R2557 show tails which decay at time constant of 270 fs, as shown in Fig. 3. This suggests existence of an intermediate state in the two-photon transition, and the decay time observed here is attributed to the relaxation time of the inter-mediate state. It has been re-ported that the bandgap energies of the photocathode materials Cs_3Sb and Na_2KSb are 1.6 eV and 1.0 eV, respectively, although the sum of the

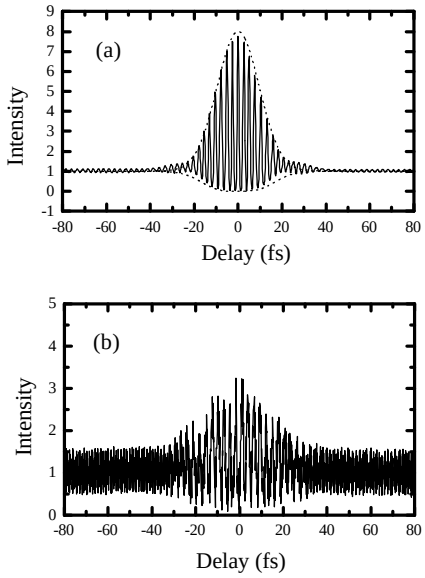

Fig. 1. Interferometric autocorrelation trace of 15-fs, 800-nm pulses from a Ti:sapphire laser obtained by measurement of two-photon-induced photocurrent in a GaAsP photodiode at input power of (a) 70 mW and (b) 500 μW.

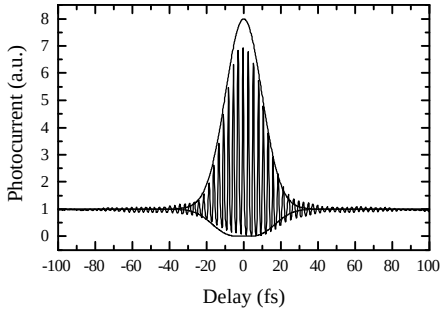

Fig. 2. Interferometric autocorrelation trace of 15-fs, 800-nm pulses from a Ti:sapphire laser obtained with a 1P28 photomultiplier tube at input power as low as 410 μW. Simulated envelopes of the autocorrelation trace of 15-fs Gaussian pulses are also shown.

bandgap energies and the electron affinities are 2.0 eV for both materials [4]. These facts explain the observed results. Since the 800-nm incident light has photon energy of 1.55 eV, it can induce interband transition with one photon in Na_2KSb, and electrons reach the vacuum level by two-photon absorption via a two-step process. Simulation by perturbation calculation based on the optical Bloch equation showed the intermediate state lifetime of 270 fs and the dephasing time less than 5 fs [5].

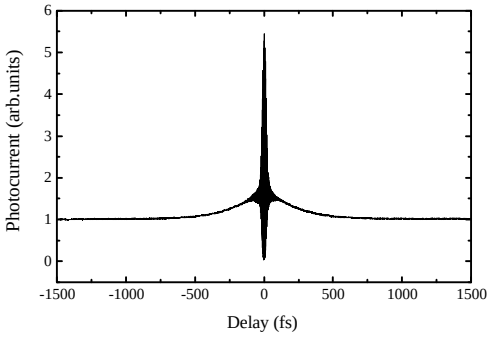

Fig. 3. Signal trace obtained with a PMT R2557. It has tails with a decay time of 270 fs, which can be regarded as the lifetime of the intermediate state of the two-photon-induced process.

3. Conclusions

In summary, very sensitive autocorrelation measurement of 15-fs, 800-nm optical pulses has been achieved by using two-photon-induced photoemission processes in a PMT [6]. Ultrafast relaxation of electrons excited in an intermediate state of the two-step two-photon transition was observed in a different type of PMT with the same measurement setup [5].

References

1 J. K. Ranka, A. L. Gaeta, A. Baltuska, M. S. Pshenichnikov, and D. A. Wiersma, Opt. Lett. **22**, 1344 (1997).

2 W. R. Bennett, Jr., D. B. Carlin, and G. J. Collins, IEEE J. Quantum Electron. **QE-10**, 97 (1974).

3 Y. Takagi, Appl. Opt. **33**, 6328 (1994).

4 W. E. Spicer, J. Appl. Phys. **31**, 2077 (1960).

5 T. Hattori, Y. Kawashima, M. Daikoku, H. Inouye, and H. Nakatsuka, Jpn. J. Appl. Phys. **39**(8), (2000) in press.

6 T. Hattori, Y. Kawashima, M. Daikoku, H. Inouye, and H. Nakatsuka, to be published in Jpn. J. Appl. Phys.