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Two-photon photoconductivity in SiC photodiodes and its application to autocorrelation measurements of femtosecond optical pulses

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Abstract. By measuring the output signal of a SiC photodiode under short-pulse illumination with photon energies below the band gap, it was found that the response is determined by a second-order process, i.e., two-photon induced photoconductivity. This nonlinearity is suitable for realizing autocorrelation measurements of short laser pulses in the visible region (420–760 nm), where the nonlinear element and the photodetector are integrated in a single device. Laser pulses of 90-fs duration have successfully been measured with this technique.

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Laser pulses as short as several femtoseconds can now be generated in many laboratories all over the world [1]. Since electronic devices and even the fastest streak cameras are too slow to measure the temporal evolution of these pulses, there has been an extensive search for appropriate techniques over the past decades. All of these methods rely on autocorrelation or crosscorrelation of the pulse electric field by using various nonlinear effects. The most commonly applied are second-harmonic generation [2] and the optical Kerr effect [3]. Recently it has been demonstrated that two-photon conductivity in photodetectors [4] or even commercial photodiodes [5] can serve as the nonlinear process in an autocorrelation measurement using a Ti:sapphire laser. The wavelength region where these devices are applicable (in the case of second-order processes) is restricted to $\lambda_g < \lambda < 2\lambda_g$, where λ_g is the wavelength that corresponds to the energy gap of the semiconductor material. In order to realize such a setup for shorter and shorter wavelengths, semiconductor materials with higher bandgaps have to be used. A promising candidate for the visible region, i.e. from about 760 nm down to 420 nm, is silicon carbide SiC, which has a band gap of the order of 3.1 eV. The exact band-gap energy depends on the crystal structure of SiC and can vary between 2 eV and 3.4 eV. Using a commercially available SiC photodiode (Laser Components) a multiple-shot autocorrelator was realized and pulses with a full width at half maximum (FWHM) as short as 90 fs were measured at a wavelength of 497 nm.

Figure 1 shows the experimental setup. The femtosecond laser pulses stem from a dye laser system pumped by a XeCl excimer laser, with a temporal duration of about 500 fs and

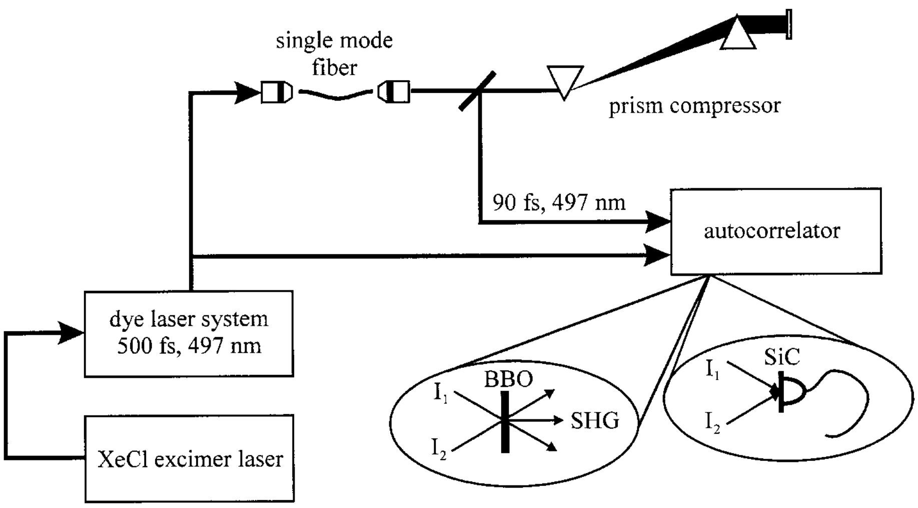

Fig. 1. The laser pulses stem from a dye laser system, pumped by XeCl excimer laser, that delivers pulses at 497 nm with a temporal duration of about 500 fs. The pulses were directed into a single-mode fiber and subsequently compressed by a SF14 prism compressor down to about 90 fs. The pulses were subsequently analysed by a background-free intensity autocorrelator using second-harmonic generation or a SiC photodiode

a maximum energy of 150 μJ [6]. The center wavelength of the dye laser was 497 nm and the repetition rate was 1 Hz. Intensity fluctuations, resulting mainly from energy fluctuations in the excimer pump laser, were below 10 %. Part of the laser output was coupled into a 28-cm-long single-mode fiber in order to spectrally broaden the pulse by self-phase modulation (SPM) [7]. As a result of SPM and group velocity dispersion the pulses emerging from the single-mode fiber had an almost linear chirp and could be compressed by a prism compressor (SF14 prisms) down to about 90 fs. One of the two pulses (90 fs or 500 fs FWHM) was directed into a conventional intensity autocorrelator using a BBO crystal cut for type-I second-harmonic generation (SHG) and a photomultiplier for measuring the second harmonic signal. In the correlator the incoming pulse was split into two pulses I_1 and I_2 with an intensity ratio of 60 : 40 by a beam splitter. The beams incident on the nonlinear crystal were noncolinear, therefore leading to a background-free second-order intensity autocorrelation. These measurements served as a reference for the experiments with the SiC photodiode. Prior to the measurement of the FWHM of the laser pulses, the response signal of the SiC photodiode was recorded as a function of the input intensity as displayed in Fig. 2. The slope of the straight line in the double-logarithmic plot is 2.1 ± 0.1 over two orders of magnitude in intensity, indicating that the nonlinear response is due to a second-order process, i.e. two-photon induced conductivity. Then the BBO crystal in the autocorrelator was replaced by the SiC photodiode and the diode signal was recorded as a function of the delay time between the two pulses I_1 and I_2. This arrangement yields the second-order intensity autocorrelation trace with background. The contrast ratio in the case of a 50 : 50 beam splitter is 3 : 1. For these investigations a 60 : 40 beam

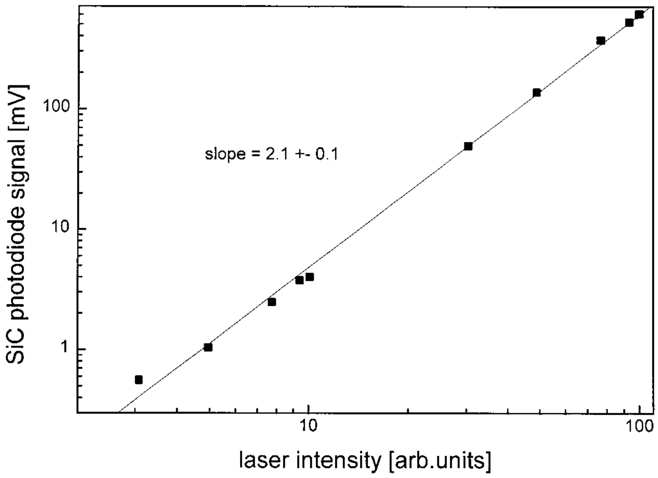

Fig. 2. Double logarithmic plot of the SiC photodiode signal as a function of the incident laser intensity. The slope of the straight line is 2.1 ± 0.1, indicating that the nonlinearity is a second-order process, i.e. two-photon induced conductivity

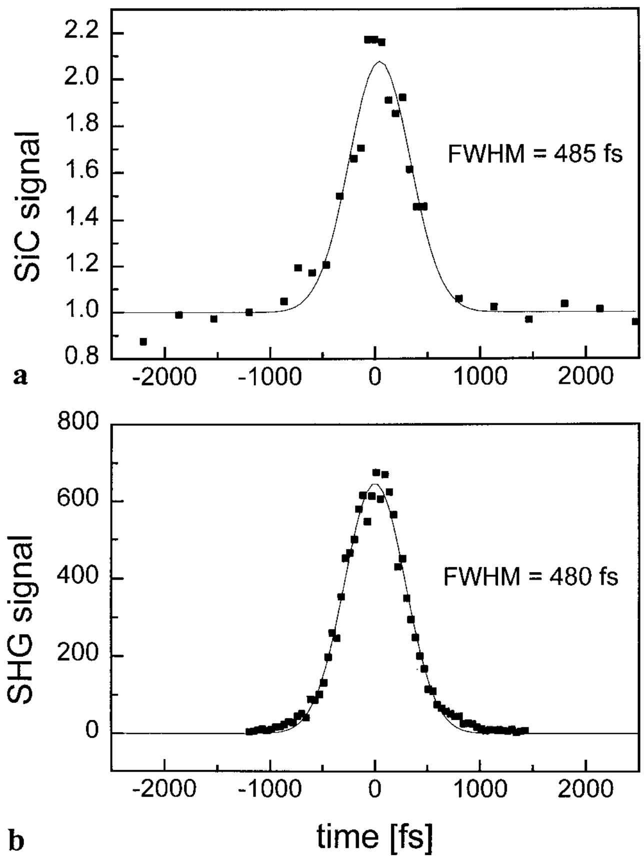

Fig. 3. Autocorrelation of a laser pulse without pulse compression: (**a**) with SiC photodiode and (**b**) with the BBO crystal. In both cases the temporal width is about 480 fs

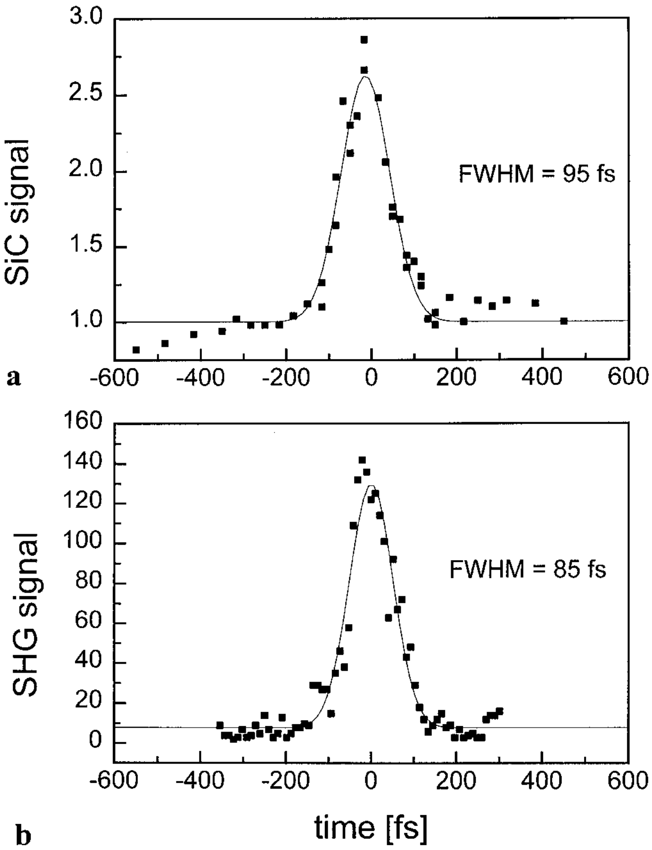

Fig. 4. Autocorrelation measurement of a laser pulse after the single-mode fiber and the prism compressor: (**a**) with the SiC photodiode and (**b**) with the BBO crystal. The FWHM in both cases is about 90 fs

splitter was used, leading to a contrast ratio of 2.5 : 1. Figure-Fig. 3 shows a comparison between the laser pulses recorded with (a) the BBO crystal and with (b) the SiC photodiode. The agreement is obvious and in both cases a pulse width of about 480 fs is inferred if a Gaussian pulse shape is assumed. The result of an equivalent measurement is shown in Fig. 4. The pulses now passed the single-mode fiber and the prism compressor prior to the autocorrelator and the extracted FWHM with the BBO crystal is 85 ± 10 fs and with the SiC photodiode 95 ± 10 fs.

In conclusion, we have shown that the response of a SiC photodiode is nonlinear under short-pulse irradiation provided that the excitation photon energy is between half the band-gap energy and the band-gap energy (420 nm to 760 nm). Using the SiC photodiode as the nonlinear device in a typical autocorrelation measurement it is possible to determine the temporal duration of ultrashort laser pulses in the visible region by recording the second-order autocorrelation function. Pulses as short as 90 fs have been successfully measured.

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