Prospects of THz Pulse Generation with mJ-Level Energy and 100 MV/cm Electric Field

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High-energy THz pulses are enabling interesting new applications. Nonlinear THz spectroscopy requires J-level THz energies and MV/cm-scale electric fields. Significantly higher pulse energies and field strengths, up to the multi-mJ and 100-MV/cm level in the 1-THz frequency range, are required for manipulation of charged particle beams (J. Hebling et al., arXiv:1109.6852 (2011)) or the enhancement of high-harmonic generation (K. KovÃcs et al., Phys. Rev. Lett. 108 (2012) 193903). Optical rectification (OR) of fs pulses is a versatile way for THz pulse generation. Tilting the pump pulse front was proposed ten years ago by Hebling et al. (J. Hebling et al., Opt. Express 10 (2002) 1161) for phase matching, which enabled to use LiNbO3 (LN), a material with very large effective nonlinearity, for efficient and scalable THz pulse generation. The highest so far THz pulse energy from a table-top source has been demonstrated by using this technique (J. A. FÃ¼lÃ¶p et al., Opt. Lett. 37 (2012) 557). In our experiments, longer than optimal 1.3 ps pulses at 1030 nm wavelength were used to pump a LN-based tilted-pulse-front pumped (TPFP) source with optimized imaging. A THz pulse energy as high as 125 ÂµJ was measured by using only 50 mJ pump energy, corresponding to 0.25% efficiency. As this experiment and our calculations (J. A. FÃ¼lÃ¶p et al., Opt. Express (2011)) indicate, increasing further the THz energy and the focused peak electric field strength is feasible. According to our calculations, increasing the Fourier-limited (FL) pump pulse duration from the commonly used 100 fs to 500 fs, and cooling the crystal to 10 K, where the THz absorption of LN is much smaller, the field directly at the crystal output can be as high as 2.8 MV/cm, more than 10Ã— larger than for 100 fs and 300 K. For mJ-level THz energy and 100 MV/cm focused field strength, a cm-scale pump beam diameter is required. However, even in optimized TPFP setups containing imaging optics, the pump spot size is limited to about ~1 cm owing to imaging errors. A contact grating (CG) setup (L. PÃ¡lfalvi et al., Appl. Phys. Lett. 92 (2008) 171107) holds promise to allow >1 cm pump beam diameters without any significant distortion of the THz phase fronts, thereby allowing for excellent focusability. Calculations show that >90% pump diffraction efficiency can be achieved with simultaneous velocity matching by using BK7 refractive-index-matching liquid (RIML). A further interesting possibility is to use semiconductors for OR. Previously, 1.5 Î¼J THz pulse energy was reported by OR in ZnTe pumped at 800 nm, being limited by free-carrier absorption caused by multi-photon pump absorption (F. Blanchard et al., Opt. Express 15 (2007) 13212). Higher pump intensity is possible at longer pump wavelengths, where only higher-order multi-photon absorption is effective. This requires TPFP with much smaller tilt angles than in case of LN, thereby enabling easier CG fabrication. mJ-level THz energies are feasible with such ZnTe-based TPFP sources, allowing also higher THz frequencies and narrower spectrum than with LN.