2 port vectorial THz electro-optic sampling system

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Abstract—**We present a fiber-based 2-port THz electro-optic sampling system at 1.55 µm wavelength. Frequency components are extended up to 2 THz and the dynamic range is larger than 40 dB regardless of the direction of the electromagnetic wave propagating in the waveguide. The symmetrical 2-port pigtailed electro-optic probe allows to determine the direction of propagation of the guided picosecond electromagnetic pulses.**

I. Introduction And Background

Guided wave picosecond measurement techniques based on femtosecond optical pulses are well-established technique for high frequency characterization of electrical circuits[1] and integrated time-domain terahertz (THz) spectroscopy [2]. In many experiments, important information are contained in echoes of the reference picosecond electromagnetic pulse. In conventional EO sampling system, their amplitude and phase are measured in the same way as those of the main picosecond pulse, whereas their direction relative to the reference electromagnetic signal is not directly accessible. Here, we present a fiber-based EO sampling system, which offers the unique functionality to provide unambiguous information on the direction of electromagnetic pulses propagating on the waveguide.

The EO system uses Er:doped fiber laser that delivers 1.55 µm wavelength femtosecond pulses, an ultra-fast photoconductive switch that generates subpicosecond transient electric pulse, and a freely positionable electro-optic probe that optically detects the electric field. The whole system is fiber-integrated and the overall dispersion is precompensated by using a 18.5-cm-long negative dispersion fiber with a chromatic dispersion coefficient of –123 ps/(nm.km). With a fiber of 6.2 m long, the FWHM width of the pulses at the output of the system is 130 fs, measured by autocorrelation technique. Without dispersion compensation, pulse broadening is important and the FWHM of optical pulses reaches 3.6 ps. The ultra-fast photoconductive switch, which operates at 1.55 µm wavelength, includes a 1-µm-thick ion-irradiated $In_{0.53}Ga_{0.47}As$ photoconductive layer. The electro-optic probe consists in a 200-µm thick ZnTe crystal, sandwiched in two prisms. Two identical lensed optical fibers are used both for injection and collection of the optical pulses in the EO probe. The optical probe pulse undergoes two total-internal reflections on the two prisms. Since each fiber can be used either for injection or collection, the optical probe pulse can propagate along two opposite directions. EO probe and fibers were attached to the same supporting motorized 3-axis translation stage. This allows the pigtailed EO probe to be independently positioned from the other optical components.

II. Results

The insert of Figure 1 shows the transient electrical waveform, generated by the $In_{0.53}Ga_{0.47}As$ based photoconductive switch excited by femtosecond optical pulses at 1.55 µm wavelength and measured by the electro-optic probe. The direction of optical pulse probe is chosen to ensure a collinear propagation with the electromagnetic signal during the interaction within the ZnTe crystal. The rise time at 10-90% is 420 fs. The fall time at 1/e is 1 ps indicating that the decay of the transient is essentially governed by the electron lifetime. The Fourier transform in amplitude of electrical waveform is represented in Fig. 1. The pulse spectrum extends beyond 2 THz. The group velocity of the optical pulses quasi matches the phase velocity of the electromagnetic pulses, so that an efficient interaction is obtained over the whole length of the EO crystal, providing a signal-to-noise ratio higher than 40 dB. These performances are preserved regardless of the direction of electromagnetic signal since the direction of the optical probe pulse can be easily reversed.

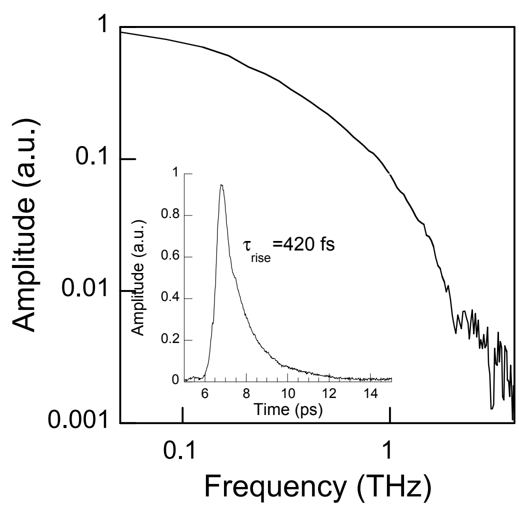

Figure 1 Fourier-transformed spectrum amplitude of the waveform represented in insert. Insert: Amplitude of the electric field waveform generated by ion-irradiated $In_{0.53}Ga_{0.47}As$ photoswitch excited by femtosecond optical pulses at 1.55 µm wavelength.

Figure 2 shows the EO response when the optical pulse is either co-propagating or counter-propagating with respect to the electromagnetic pulse passing through the ZnTe crystal In the collinear configuration, the mismatch between the group velocity of the optical pulses and the phase velocity of the electromagnetic pulses is very small and the time resolution is essentially limited by the duration of the optical pulse. In return, for the counter-propragating configuration, the temporal shape is significantly enlarged and the amplitude of the maximum of the electro-optic signal is reduced by a 1.5

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factor[3]. This distortion of the EO signal is due to the high mismatch between the group velocity of the optical pulses and the phase velocity of the electromagnetic pulses, which arises in the counter-propagating configuration, and leads to a strong reduction of the length over which the two waves efficiently interact. A comparison between the two measurements allows to determine the direction of the electromagnetic transient.

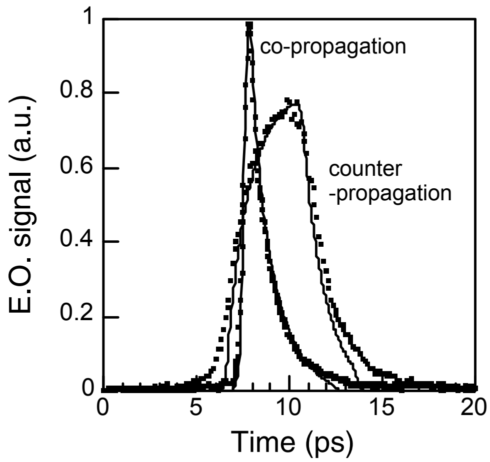

Figure 2 Temporal waveforms measured in a co-propagating and counter-propagating configurations. The solid lines represent the measured waveforms and the dashed lines the calculated waveforms.

This waveform evolution has been compared with theoretical predictions (plain lines), using the model given by G. Gallot et al.[4]. The only adjustable fitting parameters of the model are the amplitude, the lifetimes of electron and hole in the $In_{0.53}Ga_{0.47}As$ photoconductive layer and their mobility ratio. As shown in Fig. 2 (plain lines), a good agreement is obtained in the co-propagating configuration, between the experimental data and the simulation results, for an electron lifetime of 900 fs (which is close to the value deduced from time-resolved differential transmission measurements) and a hole lifetime of 2 ps. The only parameter which differs between the co- and counter-propagating theoretical waveforms calculated in co- and counter-propagating configurations is the amplitude of the EO signal. The excellent fit of the experimental data obtained by the model confirms that the prismatic EO probe allows the determination of the direction of the picosecond electrical transient. This result gives good hopes to be able to improve the diagnostic of parasitic echoes in complex high speed electronic circuits, and the characterization of stratified media by time-domain terahertz spectroscopy.

In conclusion, we have developed and fully characterized a 2-port fiber-based electro-optic sampling system at 1.55 µm wavelength based on a freely positionable prismatic pigtailed EO probe. The pulse spectrum extends beyond 2 THz. The dynamic range is larger than 40 dB. The system allows the determination of the propagation direction of picosecond electromagnetic signals. This electro-optic system can provide information on the passive element or sample implemented in the waveguide and shows great potential for THz spectroscopy investigation.

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