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Mode profiling of THz fibers with dynamic aperture near-field imaging

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***Abstract*—We present terahertz near-field mode profiling of different polymer THz fibers. Images with a resolution below the THz wavelength show the fundamental mode profile and higher order modes appearing at higher frequencies.**

Introduction And Background

Along with the fast and steady increasing advances in terahertz (THz) technology over the last decade, there has been a broad development in THz waveguiding schemes, inspired from their counterparts in the RF and optical domains. Various polymers were tested for their absorption and dispersion characteristics. Jördens et al. [1] showed, for example, that polyethylene wires can act as THz waveguides and splitters. Nielsen et al. [2] presented a non-dispersive, THz photonic crystal fiber (PCF) based on TOPAS©, a cyclic olefin copolymer. Other porous or microstructured fiber have been proposed [3, 4] and their respective mode profiles have been analyzed by different methods.

In this paper we demonstrate a fast and accurate way to measure mode profiles with sub-wavelength resolution in custom made THz waveguides. Several different TOPAS THz fibers, fabricated at DTU Fotonik were investigated. In particular we show results obtained on triangular structured TOPAS PCFs with varying pitch. The cross section of such a fiber with a four ring lattice can be seen in Figure 2(a).

Experimental Setup And Results

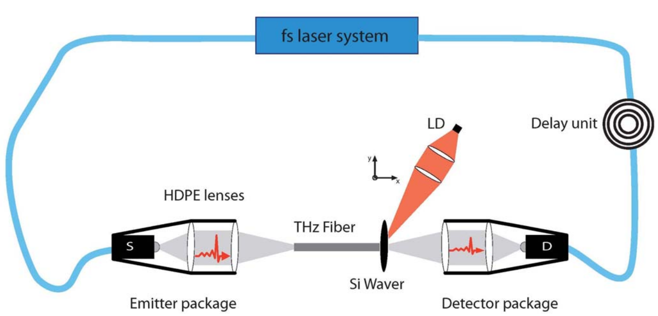

Fig. 1 Schematic of the THz near-field setup

The setup used is a standard THz Time Domain spectrometer (TDS) driven by a femtosecond fiber laser emitting 85 fs pulses at 1550 nm. The THz beam was focused into the polymer fibers under inspection and detected by a photoconductive antenna. A one end of the fibers and was locally excited by a continuous wave 808 nm laser diode. Our setup is similar to that introduced by Zhang's group in 2000 [5]. Yet, for simplicity we use a continuous wave laser diode, which is chopped and focused to a spot size of approx. 200 µm. By scanning the optical excitation across the HR-Si wafer near-field images of 101 x 101 pixels are recorded, acquiring a full THz wave form for each pixel. A schematic of the near-field TDS setup is depicted in Figure 1.

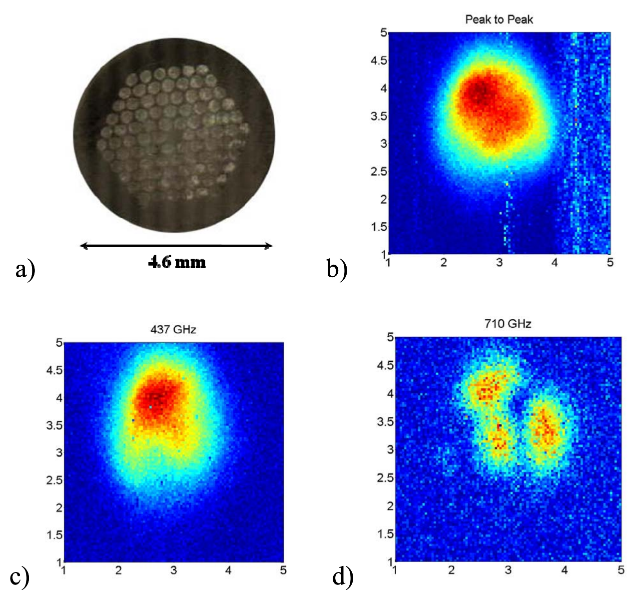

Fig. 2 Cross-section (a) and near-field images of a four ring triangular structured TOPAS fiber: peak-to-peak THz pulse amplitude (b); Mode intensities at 437 GHz (c) and 710 GHz (d)

Raster scanning the laser beam across the silicon wafer makes it possible to locally modulate the amplitude and phase of the THz pulse. The maximum pulse amplitude distribution, containing all frequency components, for the four ring structured fiber is shown in Figure 2(b). Taking the full waveforms for each pixel under consideration one can obtain field distributions for single frequencies of interest. A mode profile measured at the end of a 5 cm long fiber for frequencies of 437 and 710 GHz is presented in Figs. 2(c) and 2(d), respectively. The PCF has an average hole diameter of d =

285 µm and an average pitch of Λ = 370 µm, giving a relative hole diameter of d/Λ = 0.77, which means that it becomes multi-moded at high frequencies [2, 6]. For a relative hole size of d/Λ = 0.77 the PCF becomes multi-moded for wavelengths below λ/Λ ≈ 1.1 [6], corresponding to frequencies above ν ≈ c/(1.1 Λ) = 737 GHz. The high-resolution images clearly show the transition to a higher-order mode with three maxima at 710 GHz, which is reasonably close to the theoretically predicted 737 GHz.

For comparison a fiber designed to restrict higher order modes from being guided was also measured. The fiber was 4 mm in diameter and had a triangular lattice with a lower relative hole size of 0.44 (hole diameter 245 µm), which makes it single-moded for all frequencies [6].. A picture of the fiber's cross-section is shown in Figure 3(a). It can be seen that the fiber offers a better mode confinement and that no higher order modes are present at 751 GHz.

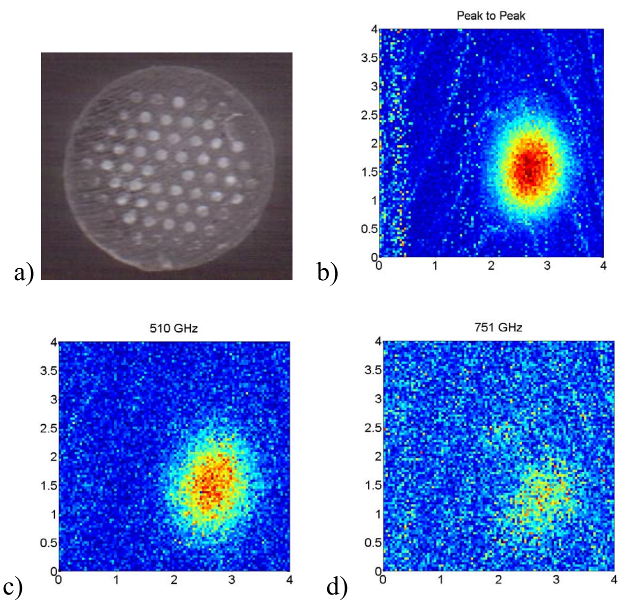

Fig. 3 (a) Cross-section (a) and near-field images of a triangular structured TOPAS fiber: maximum THz pulse amplitude (b); Mode distribution at 510 GHz (c) and 751 GHz (d)

The versatile method might also be used for analyzing mode profiles of other waveguide structures, like parallel plate or ribbon waveguides. By reducing the focal spot size one can reach even higher spatial resolutions, but there will be a trade-off between spatial resolution and interaction with the passing THz field. So depending on the available THz power there is an optimum optical excited spot size to have sufficient signal to noise ratio for the task at hand.

SUMMARY

In conclusion, we have demonstrated a powerful tool to analyze THz fibers and waveguides by terahertz time domain spectroscopy. Modulating the optical excitation allows sub-wavelength resolution for the THz mode profile imaging and the verification of cut-off frequencies in these waveguides. Adjusting the optical excitation power and the focal spot size enables higher resolution, but also lowers the interaction between the induced modulation and the electric THz field. Mode profile images of different THz fiber waveguides have been presented and analyzed.

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