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

Stecher, Matthias; Dürrschmidt, Stefan F.; Nielsen, Kristian; Stefani, Alessio; Rasmussen, Henrik K.; Jepsen, Peter Uhd; Bang, Ole; Town, Graham E.; Koch, Martin

Published in:

2011 36th International Conference on Infrared, Millimeter and Terahertz Waves (IRMMW-THz)

Link to article, DOI:

[10.1109/irmmw-THz.2011.6105088](https://doi.org/10.1109/irmmw-THz.2011.6105088)

Publication date:

2011

[Link back to DTU Orbit](#)

Citation (APA):

Stecher, M., Dürrschmidt, S. F., Nielsen, K., Stefani, A., Rasmussen, H. K., Jepsen, P. U., Bang, O., Town, G. E., & Koch, M. (2011). Mode profiling of THz fibers with dynamic aperture near-field imaging. In *2011 36th International Conference on Infrared, Millimeter and Terahertz Waves (IRMMW-THz)* IEEE. International Conference on Infrared, Millimeter and Terahertz Waves <https://doi.org/10.1109/irmmw-THz.2011.6105088>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

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

Matthias Stecher¹, Stefan F. Dürschmidt¹, Kristian Nielsen², Alessio Stefani², Henrik K. Rasmussen³, Peter Uhd Jepsen², Ole Bang², Graham E. Town⁴, and Martin Koch¹

¹Philipps-Universität Marburg, Department of Physics, Germany

²DTU-Fotonik – Department of Photonics Engineering, Technical University of Denmark, Denmark

³DTU-Mechanics – Department of Mechanical Engineering, Technical University of Denmark, Denmark

⁴Department of Electronic Engineering, Macquarie University, NSW, Australia

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 $\Lambda = 370 \mu\text{m}$, giving a relative hole diameter of $d/\Lambda = 0.77$, which means that it becomes multi-moded at high frequencies [2, 6]. For a relative hole size of $d/\Lambda = 0.77$ the PCF becomes multi-moded for wavelengths below $\lambda/\Lambda \approx 1.1$ [6], corresponding to frequencies above $\approx c/(1.1 \Lambda) = 737 \text{ GHz}$. 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 3a. 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.

REFERENCES

- [1] C. Jördens, K. Chee, I. Al-Naib, I. Pupeza, S. Peik, G. Wenke, and M. Koch, "Dielectric Fibres for Low-Loss Transmission of Millimetre Waves and its Application in Couplers and Splitters," *Journal of Infrared, Millimeter and Terahertz Waves* **31**, 214-220.
- [2] K. Nielsen, H. K. Rasmussen, A. J. Adam, P. C. Planken, O. Bang, and P. U. Jepsen, "Bendable, low-loss Topas fibers for the terahertz frequency range," *Opt. Express* **17**, 8592-8601 (2009).
- [3] M. Rozé, B. Ung, A. Mazhorova, M. Walther, and M. Skorobogatiy, "Suspended core subwavelength fibers: towards practical designs for low-loss terahertz guidance," *Opt. Express* **19**, 9127-9138.
- [4] J. Anthony, R. Leonhardt, A. Argyros, and M. C. J. Large, "Characterization of a microstructured Zeonex terahertz fiber," *J. Opt. Soc. Am. B* **28**, 1013-1018.
- [5] Q. Chen, Z. Jiang, G. X. Xu, and X. C. Zhang, "Near-field terahertz imaging with a dynamic aperture," *Opt. Lett.* **25**, 1122-1124 (2000).
- [6] M. Koshiba and K. Saitoh, "Applicability of classical optical fiber theories to holey fibers," *Opt. Lett.* **29**, 1739-1741 (2004).