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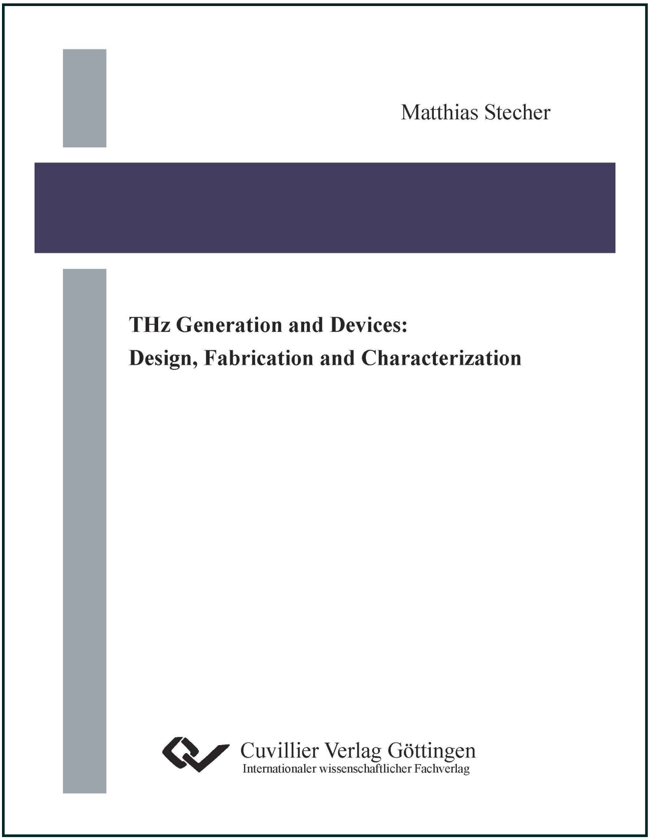
THz Generation and Devices: Design, Fabrication and Characterization



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1 Introduction

The terahertz (THz) frequency band of 100 GHz up to several THz is located in between the well explored optical frequencies and the microwave or millimeter wave band. Despite increasing research efforts over the last two decades, THz sensing and spectrometer systems are far from being robust and cost effective. This lack of miniaturization is mostly due to bulky laser systems driving these optically generated THz systems. Electronic generation forms like GaAs mixers or GUNN diodes are more compact and smaller in size. However, efficient generation is only possible for the lower THz window.

Sources for higher THz frequencies are spacious far infrared gas lasers or quantum cascade lasers (QCLs), which work best for frequencies at the top end of the THz window (10 THz and above). One of the more versatile techniques to generate pulsed or continuous wave (CW) THz is the use of photoconductive switches (antennas). Optically exciting the gap region of these structures allows for inducing a short current pulse or for the modulation of the electrical current within the antenna of a CW spectrometer. This abrupt or periodic change in current flow emits electromagnetic waves in the THz frequency range. Both generation principles have been studied and investigated thoroughly over the last twenty-five years.

Yet, the development of passive devices for THz applications like waveguides, filters, reflectors and modulators is just in the beginning of being established. Mirrors made out of different kinds of metals, ceramics or different polymers have been analyzed for THz characteristics. Frequency selective surfaces have also been proposed for narrow band mirror designs. Solutions of guiding THz radiation with low loss and negligible dispersion have been based on their counterparts in RF electronics as well as in the optical world. Examples of these cross-over designs are metal planar waveguides which have been demonstrated in various designs, as well as thin metal or polymer wires have been proposed as guiding schemes.

All metallic waveguides rely on propagation of the electrical field through the surrounding matter, which is air in most of the cases. This means that the metallic structure only provides fixed guiding boundaries and is therefore per definition weakly guiding with a low confinement factor. Another downside is the resulting high bending loss through such weak guiding waveguides. Thus, for proper guiding and the ability to tailor the dispersion and confinement, an index guiding scheme is necessary. Polymer based fibers are a perfect alternative for THz waveguiding due to their potential mass production capability and their low absorption in the THz frequencies. In this work, polymer based THz filter and fiber designs are discussed and characterized in detail.

The intended direction of this work was to build up dual or multi-wavelength fiber lasers as a source for continuous wave THz systems based on photomixing. For this purpose I started writing standard and sampled optical Bragg gratings in telecommunication glass fibers. By using the point-by-point inscription method, the introduction of any arbitrary pattern of refractive index changes into the core was possible. Thus, novel phase-shifted sampled Bragg gratings were written at Macquarie University in order to achieve dual wavelength fiber laser operation [1]. This technique was extended by myself in the polymer fiber regime as well; proving that multi-photon absorption is a powerful tool to induce refractive index modifications in nearly all relevant optical transparent materials [2]. After joining Martin Koch's group, one targeted intension was to further adapt this technique to form THz Bragg gratings in polymer THz fibers. In cooperation with our colleagues at the Danish Technical University (DTU Fotonik) who provided standard THz fibers, several ideas of locally modulating the refractive indexes in microstructured THz fibers were explored: Continuous wave and pulsed ultraviolet (UV) exposure through a metal mask, multi-photon excitation with a line focus scanned in transverse direction through the fiber or even high-power defocused spherical excitation. However, due to the low induced effective refractive index change, the low permitted number of grating periods and undesired coupling to higher order modes, none of these approaches did render any viable results. In the following, a scheme of near field imaging was set up in Marburg to determine electrical field distributions within THz fibers [3]. Simultaneously a new way of fabricating polymer THz filters was investigated and designs were fabricated by me at the facilities at the University of Sydney and Danish Technical University accordingly. This work contributes to the field of THz science and technology by introducing novel polymer filter structures and a new design of THz fibers. These passive devices are both fabricated by using a fiber drawing technique to scale down inscribed patterns in polymer to THz wavelengths.

Moreover, the revolutionary quasi time domain spectrometer (QTDS) approach is further extended by proving its imaging applicability and new system designs by Maik Scheller and me. In the course of that a hybrid continuous wave spectrometer was set up and characterized by myself. Expanding a standard QTDS system with additional continuous wave multimode laser diode with a slightly different center frequency allows for generating tunable inter-diode mixing frequency in the THz range. This novel approach has major potential to accustom various sensing applications.

This thesis is structured in four chapters. Chapter two lays out the fundamentals of THz generation and detection along with the introduction of state-of-the-art THz systems for common time domain spectrometer (TDS) systems and CW spectrometers. The generation and detection principles are discussed in detail and typical system designs are presented.

In the third chapter, the fabrication and design process of polymer photonic crystal THz waveguides is presented. Also, the fiber drawing method which is used for fabricating the novel THz filters presented in chapter four is explained in detail. I developed an adapted near-field THz TDS system to verify the THz mode field distributions within polymer THz fibers, which are first derived by simulations. In addition, a new approach for improving the confinement and stripping of undesired higher order modes is demonstrated.

Chapter four presents a new polymer filter structure designed by me. The fabrication process scales down inscribed features in a polymer preform by fiber drawing. Thus, it is possible to obtain hole diameters of 200 µm and below, which could not be fabricated by standard mechanical means. The structures are first simulated in collaboration between myself and M. Ahmadi-Boroujeni with the Generalized Multipole Technique (GMT). In a second step, the novel devices are analyzed by a standard pulsed THz TDS system.

The last chapter revolves around the novel quasi time domain spectrometer approach. This CW based generation and detection scheme is presented [4]. I developed in cooperation with the author, a hybrid THz spectrometer and demonstrated general imaging capability [5-7]. A second system approach with an additional multimode laser diode – a dual QTDS spectrometer - is set up by myself, demonstrating that QTDS has the potential for customized low-cost and robust THz systems.

In the last part of my thesis the new results, like first time realization of fiber drawn THz polymer filters, near-field images of novel THz fiber concepts and improved quasi time domain THz spectrometers are summarized briefly.