Matthias Stecher

THz Generation and Devices: Design, Fabrication and Characterization

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und

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Abstract

The THz frequency band (0.1 – 10 THz) is located in between the well explored optical frequencies and the microwave band. Despite growing research efforts in the last two decades, THz sensing systems are far from robust and cost effective. The development of passive devices for THz applications like waveguides, filters, reflectors and modulators is in the beginning of being established. This work contributes to the field by introducing novel polymer filter structures and a new design of THz fibers. These passive devices are fabricated by using a fiber drawing technique to scale down inscribed patterns in polymer to the THz wavelengths. Moreover, the revolutionary quasi time domain spectrometer approach is further extended to suit varying sensing applications.

This work is structured in four chapters. The first chapter describes THz fundamentals and state-of-the-art THz systems for common time domain (TDS) and continuous wave (CW) spectrometers. The generation and detection principles are discussed in detail and typical system designs are presented.

In the second chapter the fabrication and design process of polymer photonic crystal THz waveguides is presented. An improved near-field THz TDS system is introduced to verify the mode distributions. In addition, a new approach for improving the confinement and stripping of undesired higher order modes is demonstrated.

Chapter three presents a new polymer filter structure. 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 mechanically fabricated. The structures are first simulated and afterwards analyzed by a standard THz TDS system.

The last chapter is based on the novel quasi time domain spectrometer approach introduced by Scheller in 2009 [Optics Express, Vol. 17, Issue 20]. The CW based generation and detection scheme is presented and in cooperation with the author, a hybrid THz spectrometer and imaging capability is demonstrated. A second system approach – a dual QTDS spectrometer - is set up, demonstrating that QTDS has the potential for customized low-cost and robust THz systems.

Acknowledgments

This thesis arose over the course of the last four years, half of which I spent at Macquarie University, Australia and the other half at the Philipps-Universität Marburg, Germany. During that time, I have worked with a great number of people whose contribution to the research, experiments and the making of the thesis deserves special mentioning. I am very grateful that both my supervisors, Graham E. Town and Martin Koch, gave me not only the opportunity to work in the fascinating field of lasers and THz technology, but also for welcoming and integrating me in their groups and giving me the opportunity for teaching and lecturing.

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Marburg, April 2012 Matthias Stecher

Contents

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