Low Loss Silicon Waveguides for the Terahertz Spectral Region

B. Kuyken[1,2], A. Pagies[3], M. Vanwolleghem[3,4], D. Yarekha[3], J.-F. Lampin[3,4], G. Roelkens[1,2]

[1]Photonics Research Group, Department of Information Technology, Ghent University–imec, Ghent, Belgium
[2] Center for Nano- and Biophotonics (NB-Photonics), Ghent University, Ghent, Belgium
[3] Institut d'Electronique, Microelectronique et Nanotechnologie, Université Lille 1, Villeneuve-d'Ascq, France
[4] CNRS, UMR 8520, Villeneuve d'Ascq, France,
Email: Bart.Kuyken@intec.ugent.be

***Abstract*— Chip scale terahertz dielectric waveguides, consisting out of high resistivity silicon as a core material have been fabricated. The waveguide loss is measured to be ~1dB/cm at both 1 THz and 2.5 THz.**

I. INTRODUCTION

The terahertz frequency band (ranging from 0.3 THz to 3 THz) in between the microwave frequency band and the optical frequency band has proven to be a frequency range were it is technologically difficult to develop building blocks. \ One component that is missing is a low loss waveguide. Such waveguides are a critical building block for more complex terahertz systems such as for example chip scale Terahertz gas sensors. It is the lack of highly transparent materials in the terahertz wavelength range which makes the fabrication of terahertz waveguides challenging. High-resistivity float zone silicon (High Res Si) has been proposed as the material of choice for making integrated waveguides [1]. Indeed the high refractive index of silicon (3.42 ~at 1 THz) combined with the low loss in the 0-4 THz range (<1 dB/cm) [2] makes the platform an ideal candidate for the integration of terahertz components on a chip. Here we show the experimental realization of high resistivity silicon waveguides at terahertz frequencies. The waveguide loss is measured to be less than 1dB/cm.

II. FABRICATION

The fabrication process of the waveguides is shown in Fig 1(a). The fabrication starts with depositing silicon nitride on both sides of an oxidized silicon wafer (1). Photoresist is then spin coated on the wafer, patterned and developed, after which the silicon nitride and silicon oxide layer is etched using reactive ion etching (RIE) (2). In the next step (3), trenches are etched 150 μm deep by wet-etching the silicon in a KOH solution. A high-resistivity SOI wafer is bonded on top of the processed handle wafer by using a benzocyclobutene (BCB) polymer as a bonding agent (4,5). The SOI wafer consists out of a 100 μm thick high resistivity (>10 kΩcm) silicon layer on top of a 2 μm oxide layer on a 350 μm silicon handle wafer. The substrate wafer is removed in two steps. The substrate is first partially removed in a grinding step (6) after which the remaining silicon is removed in a KOH wet-etching step (7). The remaining silicon-oxide layer is removed by HF wet etching the oxide. The waveguides are patterned in the bonded high resistivity silicon layer with the help of a thick photoresist (8) and deep reactive ion etching (9) (DRIE). In Figure 1 (b) a top view of the silicon waveguides can be seen. The rib waveguides are 70 μm wide and are etched 80 μm deep. By wrapping the waveguides in a small spiral-coil, long waveguides with lengths of 2, 7.5 and 14 cm were fabricated on a small footprint (<2.5 cm2).

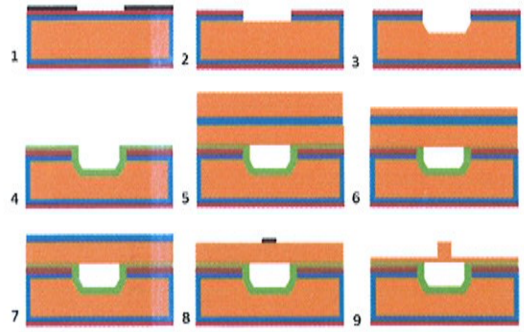

Figure 1: Fabrication processing steps

III. LOSS MEASUREMENT

The waveguides were characterized in a cut back measurement. A terahertz continuous wave methanol gas laser pumped by a CO_2 laser is used as a source. The light is coupled in and out of the chip using polymer lenses with a focal length of 2.5 cm. A bolometer is used to measure the output power. The terahertz gas laser is first tuned to 2.5 THz and the horizontal polarization of the emitted light excites the quasi TE-mode of the waveguide. In a next experiment the gas laser is tuned to 1 THz, where the vertical polarization excites the quasi TM mode of the waveguide. In both the experiments the insertion loss of waveguides with a length of 2, 7.5 and 14 cm are measured. The loss was found to be less than 1 dB/cm at both wavelengths.

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08:45 - 09:15	**Welcome and Opening Remarks** **Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;**	**Lecture Theatre 1**

The mode conversion and the resonant absorption of electromagnetic waves occurring in inhomogeneous chiral media are studied theoretically. The resonant absorption is found to occur when the inhomogeneous medium contains a region where the effective refractive index vanishes.

Close-space Sublimation Growth And Characterization Of ZnTe Epitaxial Thick Film **MS-48**

Jiawei Li; Gang qiang Zha; Yadong Xu; Shouzhi Xi; Yingrui Li; Rui Yang; Wanqi Jie

ZnTe epitaxial film with thickness of 200μm was grown on the GaAs substrate by close-space sublimation(CSS). The surface topography of ZnTe film was analyzed by SEM, and the evolution of growth pit was observed, which revealed the mechanism of epitaxial growth. The structure was analyzed by X-ray radiation diffraction (XRD) θ-2θ scan and rotary Φ-scan, and the results suggested that the ZnTe thick film is epitaxial film. The crystalline quality of ZnTe thick film was characterized by X-ray rocking curve and Raman spectrum, and the results suggested that ZnTe epitaxial film obtained by CSS could be as a replacement of ZnTe single crystal, especially for thinner and larger requirement.

Silk Foam Terahertz Waveguides **MS-49**

Hichem Guerboukha; Guofeng Yan; Olga Skorobogata; Hang Qu; Maksim Skorobogatiy

Silk foam-based terahertz waveguides are fabricated using lyophilisation and casting techniques. This work is motivated by the lack of biocompatible waveguides for low-loss guidance of THz for applications in remote sensing in biomedical and agro-alimentary industries.

Terafluidics Devices: Perspectives And Problems **MS-50**

Sergey Pasechnik; Dina Shmeliova

The new approach to an elaboration of liquid crystals (LC) tuned THz devices, based on usage of shear flows, is proposed. Flows are considered as more universal tool for LC orientation in the comparison with the action of properly treated surfaces. In particular, they can be used for an orientation of both thin and thick (of order 1mm) LC layers. High sensitivity of LC to the flows makes possible to elaborate LC devices of new types -- terafluidics.

High Performance Solar Selective Absorbers Constructed By Multilayers **MS-51**

Shaowei Wang; Feiliang Chen; Xiaoshuang Chen; Liming Yu; Wei Lu; S.C. Shen

High-performance solar absorbers need to have high solar absorptivity and low infrared thermal emissivity at the same time. They are core part for architecture integratable solar thermal technologies such as solar water heaters and solar thermoelectric generators. In this work, we presented a kind of solar absorber with TiNxOy-based multilayers. Its solar absorbance can be as high as 97.5% and infrared thermal emissivity as low as is 4.3% with total thickness less than 300 nm. The solar absorbance can maintain above 90% for a broad incident angle to 65°.

Compact Transmission Line Design In A Multi-Metallization Nano-CMOS Process For Millimeter-Wave Integrated Circuits **MS-52**

Sang Lam; Mansun Chan

A compact transmission line design based on the conventional microwave stripline is presented for implementation of millimeter-wave CMOS integrated circuits. In a 65-nm process, the design gives a low insertion loss of 2.2 dB/mm at 60 GHz as determined by 3D electromagnetic (EM) simulations. A 50-Ω characteristic impedance is achieved resulting in a reflection coefficient of about -27 dB up to 80 GHz. The transmission line structure occupies minimal space of less than 17 μm in width and it accommodates active devices beneath it unaffected by any possible EM interference.

A Metal Mesh Flat Prism For MM-wave Applications **MS-53**

Paul Moseley; Giorgio Savini; Giampaolo Pisano; Peter Ade; Elena Saenz; Jin Zhang

By using the previously unwanted dispersive properties of metal mesh artificial dielectrics, we propose a novel design for a flat prism. This is a device that steers an incident plane wave by a given angle based on its frequency. This is achieved by using existing graded index theory and further understanding of the dispersion effects in metal mesh grids. Such a device would act as an alternative to diffraction gratings and operate over the frequency range of 100-200 GHz.

Preliminary Design Of Powerful Gyrotrons For IGNITOR And DEMO **MS-54**

Vladimir Zapevalov; Alexey Chirkov; Gregory Denisov; Andrey Kuftin; Alexander Litvak; Mark Moiseev; Nikolay Zavolsky

Design development of continuous-wave 240 GHz gyrotron and 300 GHz gyrotrons with output power about 200-1000 kW for fusion research at advanced plasmas with intense magnetic field is presented. Main goal of such gyrotrons is application for EC complexes of IGNITOR and DEMO tokamaks. This paper includes task motivation and existing technical basis, results of calculation, design, technical requirements and pre-prototype experimental tests for main subsystems of gyrotron.

Effect Of Non-ideal Beam Splitters In THz Electro-optic Detectors **MS-55**

John Mabon; Roger Lewis

We extend a mathematical study to multiple THz electro-optic detectors to determine the detector with the lowest noise floor. We do this by using "real world" optics where polarisers and beam splitters have non-ideal properties. We find that certain detectors are not sensitive to non-ideal beam splitters while other detectors are.

Plasmonic Detection Of Wide Band Modulated THz Radiations In GaAs Technology **MS-56**

Shamsun Nahar; Mona M. Hella; Stephane Blin; Annick Penarier; Philippe Nouvel; Wojciech Knap; Dominique Coquillat

A fully integrated THz detection system consisting of an on chip dipole antenna, a plasmonic detector and a wide band amplifier in 130 nm AlGaAs/InGaAs pHEMT technology is reported. The fabricated chip achieves an absolute responsivity of 3 V/W, while maintaining a 50 dB signal to noise ratio (SNR) over a modulation bandwidth of 8.5 GHz at ~ 0.3 THz.

Low Loss Silicon Waveguides For The Terahertz Spectral Region **MS-57**

Bart Kuyken; Antoine Pagies; Mathias Vanwolleghem; Dmitri Yarekha; Jean-Francois Lampin; Gunther Roelkens

Chip scale terahertz dielectric waveguides, consisting out of high resistivity silicon as a core material have been fabricated. The waveguide loss is measured to be ~1dB/cm at both 1 THz and 2.5 THz.

High-Efficiency Planar Schottky Diode Based Submillimeter-Wave Frequency Multipliers Optimized For High-Power Operation **MS-58**

Jose V. Siles; Erich Schlecht; Robert Lin; Choonsup Lee; Imran Mehdi

We report on a new series of millimeter and submillimeter-wave frequency multipliers specifically optimized for very high-power operation in order to meet the requirements of next generation terahertz instruments for Astrophysics, Planetary science, Earth science and radar imaging applications. New frequency multiplier chips have been designed and fabricated in the 100 GHz to 1 THz range focusing on higher power operation. Initial tests have shown efficiencies of around 30% for a single-chip 105-120 GHz tripler, and 25% for a single-chip 170-200 GHz doubler, when pumped with 500 mW. These results

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