Micro fabricated spoof surface plasmon polariton structures for THz applications

Andreas K. Klein, Yi Pan, Claudio Balocco, Dagou Zeze and Andrew J. Gallant
School of Engineering and Computing Sciences, Durham University, Durham, DH1 3LE UK

Abstract— **A low-cost process for the fabrication of spoof surface plasmon polariton (SPP) structures, designed to operate in the THz frequency region, is shown. The process uses microfabricated templates for the fabrication of structured surfaces which are sputter coated with metal. The propagation of the THz radiation along the structured surfaces, coupled using knife-edge scattering, is characterized using a THz Vector Network Analyzer in the frequency range 0.75-1.1 THz.**

I. Introduction

THE progressive closure of the so-called THz gap through recent advances in sources and detectors now needs to be accompanied by the development of ancillary devices to effectively manipulate the radiation. With a typical length scale in the order of hundreds of microns, the required aspect ratio is often too high to be realized using conventional semiconductor processing techniques. Suitable methods, such as deep reactive-ion etching or focused ion beam milling [1], may be able to produce samples with the desired specifications, but are very costly and have limited flexibility for large device areas and production volumes. In this paper, we present and discuss a low-cost, high-throughput approach which offers a route to inexpensive and flexible device fabrication.

This technique is suited for features such as grooves, pillars and, more generally, structures which are realizable with a pouring process, where a mould is filled with a liquid polymer which, after curing, is peeled away to form the device. The moulds can be manufactured with a micro milling system to create more complex structures or, alternatively, a thick layer lithography process with SU8 can be used when the structures do not require significant variations in height. The micromilling system offers lateral feature sizes in the order of tens of microns with depths of up to several hundred microns. All moulds have been coated with gold, so that the polymers can be peeled off after moulding. Additionally, the moulds itself can serve as a plasmonic structure as well. PDMS is used to form the devices and are sputtered with gold afterwards. The target application is for slow light (1D groove) structures [2]. A knife-edge scattering experiment is used for the characterization.

II. Experimental procedure

The experiment uses knife-edge scattering to couple SPPs into the structured surfaces. As both a source and detector, a Vector Network Analyzer (VNA) from Agilent Technologies is used in combination with two full band multipliers (type WR-1.0 from Virginia Diodes) to extend the frequency range from the original 10 MHz to 43.5 GHz of the VNA to 0.75 to 1.1 THz. The full band multipliers have antennas for free space measurements, the sample is placed in the middle, between the two antennas, which are less than 5 cm apart, and the blades are placed over the sample as shown in figure 1. One blade is placed to scatter the incoming THz radiation into the grooves of the SPP structure and a second blade is used to decouple the SPPs so that they can propagate as a free wave again. The full scattering parameters matrix is recorded with he VNA. Since the VNA produces a continuous wave and has a fast scan rate, it is a comparatively straightforward experimental setup versus the more commonly used THz-Time Domain Spectroscopy method; the results are shown in near real time as the blades approach the surface and a suitable distance for the waves to scatter into the structure can be easily optimized.

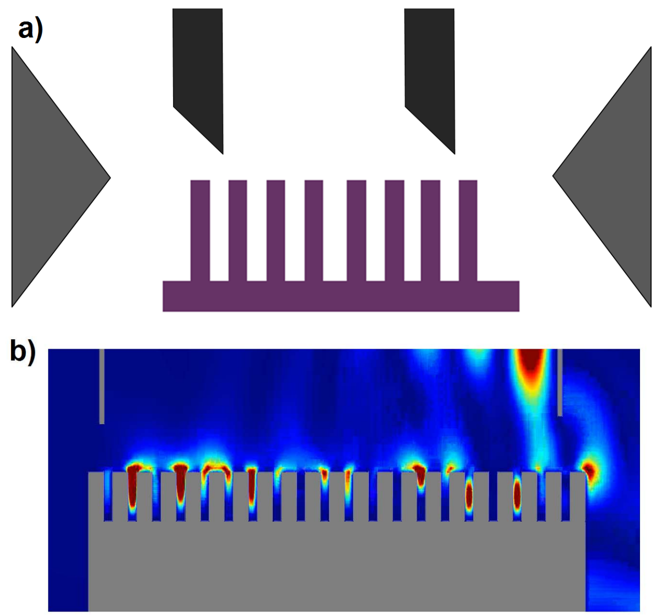

Fig. 1. a) Schematic of the experimental setup with the horn antennas of the VNA on both sides, the 1D groove sample structure (purple) in the middle and the blades coming from the top. b) Snapshot from a FDTD simulation where the wave is already scattered into the grooves. A resonance can be observed and the wave has propagated so far that it is coupled out by the second knife edge and is emitted from the structures as free space wave again.

III. Results

A lateral resolution in the order of tens of microns is achievable using commercially available drilling and milling bits down to 25 µm in diameter. However, system vibrations limit the feature size, introducing roughness to the side walls, as shown in figure 2. These defects, which would normally affect the optical performance of the components, are less apparent on the moulded structure in figure 2(b), where we see a smooth structure with a Root Mean Square roughness on the surface of less than 3.5 µm (i.e. around 1 % of the wavelength for 1 THz) and suitable for optical components. The SU8 templates have an even lower surface roughness, as it is expected from a photoresist based fabrication method.

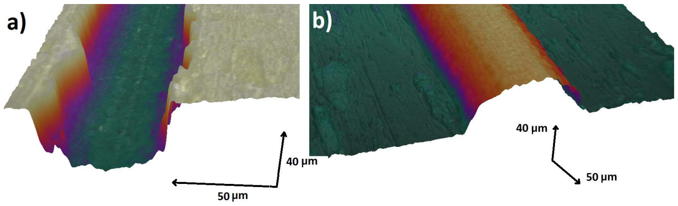

Fig. 2. Optical profiler images of a mould milled in PVC (a) and a PDMS groove structure after moulding (b). The roughness of the sidewalls of the mould is not visible on the moulded structures; it appears that this kind of defect is not transferred during the moulding process.

To structures were optimized using a commercial FDTD simulator (Lumerical) The grooves were designed for slow-light operation in the 0.75 to 1.1 THz region, to be within the measurement range of the Agilent Vector Network Analyzer. Simulations show a sawtooth like frequency spectrum over the broader frequency range of the THz time domain spectrometer (~0.1-3.5 THz), corresponding to the multiple band gaps appearing in the dispersion curve for such structures, as shown in [2] (if the dispersion curve is extended to higher frequencies) (fig 3).

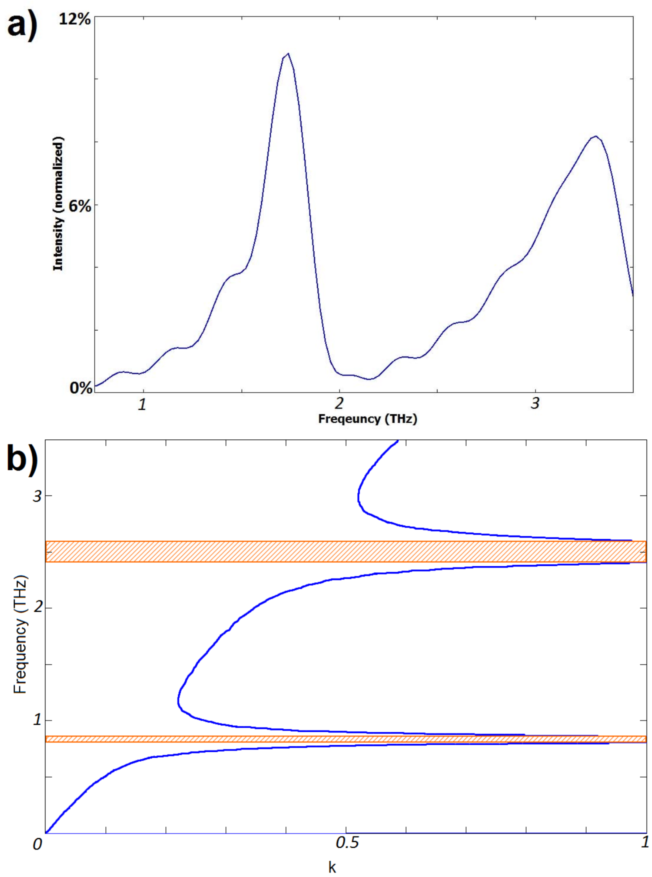

Fig. 3. Transmission spectrum (from FDTD) of a 1D groove structure and the calculated dispersion curve for the same structure (b). The band gaps are marked (orange). The dimensions of the structures are: groove height: 90 µm; groove width: 20 µm, pitch: 50 µm.

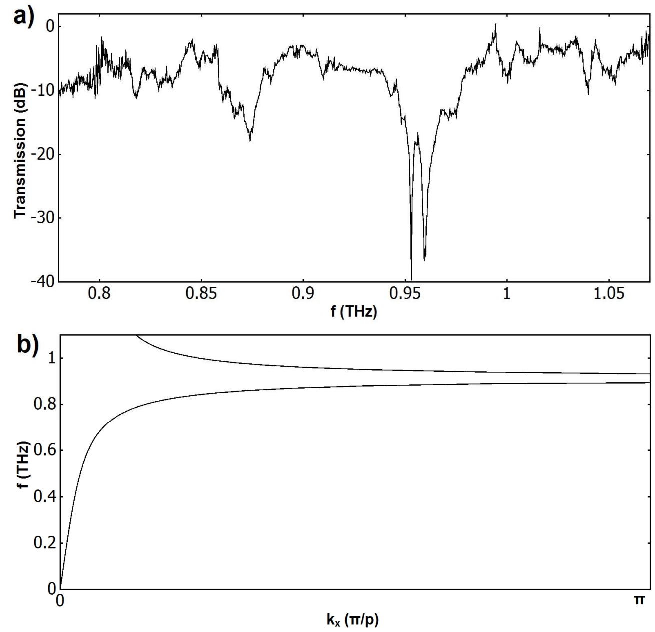

Fig. 4. (a) Measured transmission spectrum of a 1D groove structure. A large drop in transmission can be seen around 0.96 THz. This matches well with the theoretically predicted band gap as visible in the dispersion curve in (b). The dimensions of the structures are: groove height: 82 µm; groove width: 32 µm, pitch: 20 µm.

The measured samples show a sharp dip in transmission at approximately the same frequency as the photonic band gap was predicted by the dispersion curve (figure 4). However, the attenuation around 0.87 THz is not predicted by the theory, and may be caused by defects or deviations between single grooves. Overall, it can be stated that the device is functional around the area of the most significant feature, which is the band gap.

IV. Summary

An inexpensive method to produce spoof surface plasmon polariton structures has been presented. The structured surface quality and limits of the method are discussed. A THz Vector Network Analyzer is used in a double knife-edge scattering experiment to characterize the structures and the results are compared with the theoretical predictions.

V. Acknowledgements

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References

[1]. N. Yu and F. Capasso, “Designer spoof surface plasmon structures collimate terahertz laser beams”, N*at. Mat.,* vol. 9, pp. 730-735, March, 2010.
[2]. Q. Gan and F.J. Bartoli, “Ultrawide-Bandwidth Slow-Light System Based on THz”, *Phys. Rev. Lett.*, vol. 100, June, 2008.