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This is the accepted version of a paper presented at *44th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz), Maison de la Chimie, Paris; France; 1-6 September 2019.*

Citation for the original published paper:

Smirnov, S., Morales, A., Okonkwo, C., Tafur Monroy, I., Lioubtchenko, D. et al. (2019)
Dielectric Rod Antenna Array for Photonic-Based Sub-Terahertz Beamforming
In: IEEE
<https://doi.org/10.1109/IRMMW-THz.2019.8874432>

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Dielectric Rod Antenna Array for Photonic-Based Sub-Terahertz Beamforming

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Abstract—This work presents a dielectric rod antenna array designed for a photonic-enabled beamforming system at sub-terahertz frequencies. The photonic chip generates an optical group delay, providing the beam-steering capability. The antenna array is fabricated from high-resistivity silicon by micro-machining. Simulation results demonstrate a directivity of 14.7 dBi and a beam steering range of 56 degrees at 85 GHz. The system is intended as a sub-THz transmitter for broadband wireless communications.

I. INTRODUCTION

MOBILE communication networks see a continuous increase in bandwidth requirements, which can be met by millimeter-wave and terahertz communications [1]. Their inherent limitation is the increasing free-space path loss and atmospheric absorption with the frequency. High-gain antennas are therefore required with capabilities of dynamically steering the radiated beam in space.

The proposed antenna array is designed for a photonic-based beamforming system [2]. The system is composed of a Si_3N_4 photonic chip, an array of low-temperature-grown (LTG) InGaAs photoconductive antennas (PCAs), and an array of Si rod antennas (see Fig. 1a). The input of the system is an optical signal with two carriers around 1550 nm, separated by the frequency of the desired sub-THz wave. The photonic chip, consisting of an optical true-time-delay network, splits the input in 4 signals with a tunable group delay between them [3]. The optical signals are focused on 4 PCAs with metalized bowtie antennas that generate the sub-THz waves. Finally, the dielectric rod array couples the sub-THz radiation into free space and focuses it into a narrow beam [4]. The phase shift between adjacent elements, defined by the true time delays, enables beam steering in the horizontal plane.

II. RESULTS AND DISCUSSION

Four rods are designed with a cross-section of 0.5 mm by 1 mm, optimized for the W-band (see Fig. 1b) [5]. The rod length of 10 mm is chosen as a compromise between directivity of the antenna and mechanical robustness. The spacing of 2 mm between the elements is selected as $\lambda/2$ at the operation frequency. A photonic-crystal-like structure connects the rods, without increasing the coupling between individual antennas. Sub-wavelength-sized cylindrical holes are used with a radius of 100 μm in a triangular lattice with a pitch of 300 μm .

The antenna array, combined with the PCAs on a 350 μm -thick InP substrate, was simulated with CST Microwave Studio 2019 at 85 GHz. The array exhibits a 14.7 dBi directivity in the main direction of radiation with a 3-dB width

Fig. 1. a) System diagram of the proposed beamforming transmitter. b) Schematic drawing of the silicon rod antenna array for focusing the sub-THz radiation. c) Simulated radiation pattern in the H -plane at 85 GHz for increasing phase shift between adjacent elements.

of 20.5 degrees. A beam steering range of 56 degrees is achieved in the horizontal plane for a phase shift $\Delta\Phi$ of 120 degrees between each element (see Fig. 1c).

The antenna array was fabricated from a 500 μm -thick 10 k Ω cm Si wafer with a single deep reactive ion etch (see Fig. 2). This standard process, optimized for silicon micro-machining, enables precise definition of small geometries and etching of high aspect ratio features. Fabricating the whole array as a single structure solves the problem of misalignment of individual antennas and has the potential of being extended to arrays with more elements. The advantages of the proposed solution, compared to traditional Si lenses, are the small size of the antennas enabling beam steering, and the possibility of

Fig. 2. Photograph of the fabricated antenna array.

high-volume manufacturing at a reduced cost. The whole system can be easily scaled up in frequency, allowing the design of high-bandwidth millimeter-wave and terahertz transmitter modules with beamforming capabilities.

ACKNOWLEDGEMENTS

This work was financially supported in part by the European Union's (EU) Horizon 2020 Innovative Training Network CELTA (grant No. 675683 of Call: H2020-MSCA-ITN-2015),

by the European Research Council (ERC) under the European Union's (EU) Horizon 2020 research and innovation programme (grant No. 616846), and by the Foundation for Polish Science through grants TEAM/2016-3/25 and MAB/2018/9 under the Center for Terahertz Research and Applications (CENTERA) project, carried out within the 'International Research Agendas' programme co-financed by the European Union under the European Regional Development Fund.

European
Commission

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