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Millimeter Wave Beam Steering Based on Optically Controlled Carbon Nanotube Layers

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Abstract—In this paper, the dielectric constant changing of thin carbon nanotube layers under light illumination was used for phase shifter development in dielectric rod waveguides. This designed phase shifter was introduced to the dielectric rod waveguide dual-antenna array. The measurements of the beam steering at 90 GHz of the dielectric rod antenna array, covered with carbon nanotubes, were carried out.

I. INTRODUCTION

DIELECTRIC rod waveguides (DRWs) are the prospective platform for millimeter wave and terahertz active and passive devices. [1,2] The DRW has low propagation losses and no cut-off frequency compared to the standard metal waveguide technology. Moreover, the DRW is an open, not metal-shielded waveguide system that allows affecting it with external electro-magnetic fields including light. Therefore, by covering a wall of the DRW with a variable impedance layer, the propagation constant can be dynamically tuned. [3]

Carbon based nanomaterials were intensively studied at low THz frequencies. In [4], it was shown that the single-walled carbon nanotube (SWCNT) layers can have low insertion losses in the frequency range above 120 GHz (see Fig.2). Carbon based nanomaterials were also successfully used as MEMS/NEMS varactor membranes. [5] They showed higher tenability, lower actuation voltage, simplicity of fabrication, and 100% tunability. SWCNTs can also be simply deposited inside metallic waveguides for fabricating terahertz absorbers. It was shown that after chemical treatment they can be better performing than standard commercial ones. [6]

Carbon nanomaterials are extensively studied for ability to tune their properties. The use of SWCNT layers for optically-controlled phase shifters was proposed in [7] and successfully employed in [8]. The simplicity of the SWCNTs integration is relevant for large surface area devices, e.g. for the fabrication of reflector surface coating, sensor matrices, and antennas. SWCNT components can also be integrated with DRW antenna elements for millimeter wave and THz beam steering applications. [9]

In this work, the optically controlled phase shifting in the DRW, loaded with a thin SWCNT layer, was experimentally studied and applied for beam steering in a dual-antenna array at 90 GHz.

II. RESULTS

Optically controlled phase shifters were fabricated based on DRWs, covered with thin carbon nanotube layers (see Fig. 2). The devices were measured in the W-band with a Rohde & Schwarz ZVA24 Vector Network Analyzer with frequency extension head modules. The devices showed a phase shift of 15° with an insertion loss below 0.1 dB in the frequency band of 75-110 GHz. [7]

An array of two DRW antennas was fabricated as shown in Fig. 4a. The antennas were fed by standard rectangular WR-10 waveguides through a power divider block. One of the antennas was covered with a thin carbon nanotube layer with a transparency of 80-95%. The CNTs were illuminated by a tungsten halogen lamp with the main radiation spectrum at 550–680 nm with a light intensity of 23 mW/cm^2 . The radiation patterns were measured with a Rohde & Schwarz ZVA24 Vector Network Analyzer. The measurement results with and without light illumination of the SWCNTs are illustrated in Fig. 4b. From the radiation patterns, one can note the change of the beam direction due to the phase shifting in the DRW.

Fig. 1. S-parameter measurements of DRW, loaded with SWCNT layer [4].

Fig. 2. Typical SEM and TEM images of the SWCNT layer. [8]

Fig. 3. Terahertz phase shifter design based on SWCNT-loaded DRW. a) Schematic drawing of the measurement setup. b) Measured phase shift in the 75–500 GHz frequency range. [8]

Fig. 4. a) Fabricated DRW antenna array. b) Radiation pattern measurements at 90 GHz without and with illumination of the SWCNT-loaded DRW.

III. CONCLUSIONS

The phase shifting effect in the DRW loaded with SWCNT layer under light illumination was applied experimentally for beam steering in a dual-antenna array at 90 GHz. The ultra-wide band optically-controlled SWCNT-based phase shifter was found fitting for beam steering applications with suitable phase shift and insertion loss level.

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