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Development of an highly distributed photoconductor for CW THz generation

F. Bavedila, V. Magnin, J. Harari, D. Yarekha, D. Troadec, S. Lepilliet, V. Avramovic, G. Ducournau, J-F. Lampin and E. Peytavit

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Abstract — In this communication, we propose a new architecture of photomixer in order to develop a wideband and powerful photomixing THz source. It is achieved by a velocity-matched distributed photoconductor (VMDP), in which the pump optical power is guided in a dielectric optical guide and slightly coupled to a low-temperature grown GaAs 1-mm-length photoconductor. We present the fabrication and the characterization of the dielectric optical guide and the THz waveguide which form the VMDP.

I. INTRODUCTION

One of the THz continuous-wave (CW) sources working at room temperature is based on the photodetection of the beating frequency generated by two spatially overlapped infrared lasers. It is the so called photomixing THz source[1][2]. This down converting between very high frequency (~300 THz) infrared lasers is intrinsically wideband and is potentially compact when semiconductor laser diodes and amplifiers are used but suffers from a lack of power, i.e., around 10 μ W at 1 THz. The output power is indeed limited by the trade-off between the small size of the photodetector used in order to minimize its electrical capacitance and the photocurrent needed in order to generate a high output power. Here, we propose a new architecture of photomixers in order to develop a wideband and powerful photomixing source. It is based on a highly distributed photoconductor (HDP) using a low-temperature-grown Gallium Arsenide (LT-GaAs) layer pumped by 780 nm lasers. The two main limitations of the distributed photoconductors, i.e., 1) the phase mismatch between the optical pump and the THz waves generated along the structure and 2) the propagation loss of the THz waveguide are overcome by using a dielectric optical guide slightly coupled to a membrane-supported coplanar waveguide. The conducting strips of the coplanar waveguide serve at the same time as photoconductor bias electrodes (see Fig. 1). Preliminary design has been presented previously[3]. Here we present the fabrication and the characterization of the membrane supported coplanar waveguide and of the dielectric optical waveguide consisting of a 200-nm thick Si_3N_4 layer and a 2- μ m-thick SiO_2 cladding layer.

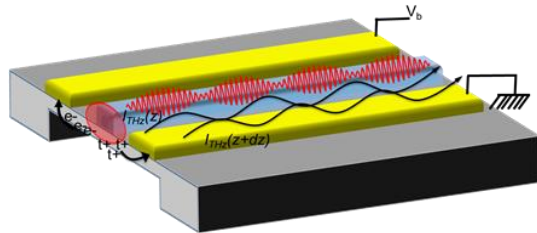


Fig. 1: Schematic of the proposed THz photomixer

II. FABRICATION

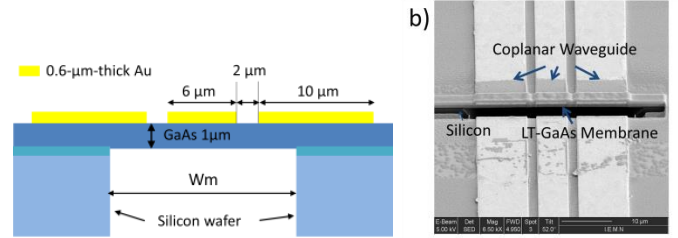


Fig. 2: (a) schematic view and (b) SEM view of FIB-cut of the membrane-supported coplanar waveguide

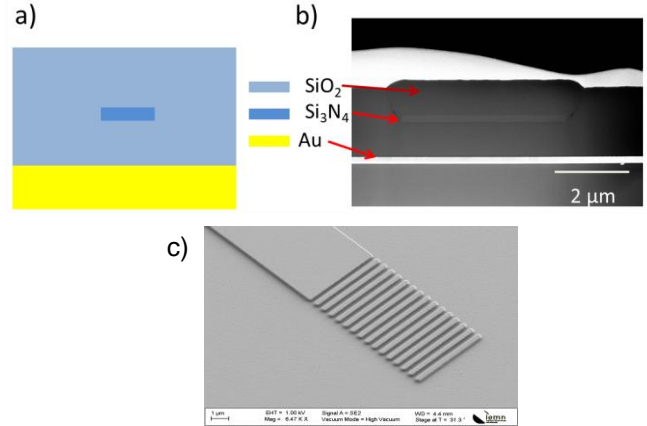


Fig. 3: (a) schematic view, (b) SEM view of FIB-cut of the dielectric optical waveguide and (c) SEM view of a grating coupler (period = 580 nm, duty cycle = 50 %)

In Fig. 2 are shown a schematic view and a SEM image of the membrane-supported coplanar waveguide. It has been fabricated thanks to the transfer of a 1- μ m-thick LT-GaAs layer from a GaAs substrate to a silicon substrate by using a benzocyclobutene (BCB) polymer bonding layer followed by a deep reactive ion etching (DRIE) of the silicon. By using this process, we achieved the fabrication of membrane of length reaching several millimeters whereas their width (W_m) was 35 μ m and 55 μ m. Such low transverse dimensions are mandatory to obtain thermal properties of the device compatible with the heat flux which will be generated in the device in operation. In Fig. 3 are shown a schematic view and a SEM image of an optical waveguide consisting of a 200-nm-thick Si_3N_4 layer and a 2- μ m-thick SiO_2 cladding layer deposited at 300 $^{\circ}\text{C}$ by plasma enhanced chemical vapor deposition (PECVD) technique. A grating coupler used to couple the light coming from an optical SM fiber into the waveguide is also shown.

III. CHARACTERIZATION

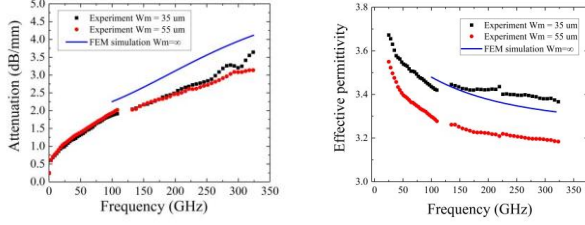


Fig. 4: a) Attenuation coefficient and b) Effective permittivity versus frequency of the membrane-supported THz waveguide

On-wafer measurements have been performed in the 0.5-110-GHz, 140-220-GHz and 220-325 GHz frequency bands by means of vector network analyzers (VNA), coplanar probes and Line-Reflect-Reflect-Match calibration kit. We present in Fig 4 the experimental attenuation coefficients and effective permittivities of the membrane supported coplanar waveguide described in Fig. 2. It can be noticed a good agreement with the results obtained by FEM simulation in which the membrane dimensions are assumed to be infinite. The 35 μm -width membrane show similar attenuation coefficient as the 55 μm -width, around 3 dB/ mm at 300 GHz. The propagation losses are dominated by the ohmic losses ($\propto(\text{frequency})^{1/2}$) and it is then possible to predict that the propagation losses will reach around 5.5 dB/mm at 1 THz which enable the fabrication of distributed photodetector of length reaching 500 μm with negligible effects of the propagation losses on the output powers generated by the photomixer. Regarding the phase velocity of the THz wave, it can be noticed a slightly higher effective permittivity which can be seen as the effect of the silicon wall which are closer from the waveguide when the membrane -width is smaller.

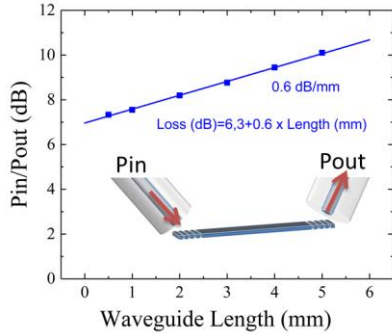


Fig. 5: Coupling and propagation losses measurement of the dielectric optical waveguide at $\lambda=780$ nm

We show in Fig. 5 the experimental results obtained on 5- μm -width optical guide fabricated on a gold metallic layer serving as back reflector for the grating coupler (as shown in Fig. 3). The characterization of the structure are achieved by injecting an optical power (P_{in}) coming from a cleaved en facet of a SM optical fiber (@780 nm) by means of a first grating coupler and to measure the optical power (P_{out}) which has been outcoupled, after propagation in the waveguide, into a second identical SM optical fiber. By using different waveguide lengths, it is possible to extract the coupling loss of the grating coupler and the waveguide propagation losses. After optimization of the deposition parameters and the

grating parameters, we obtain coupling losses as low as 3.15 dB and waveguide losses as low as 0.6 dB/mm, which are state of the art results for optical wave guide fabricated at low temperature (300 °C), compatible with III-V materials and noble metals.

In conclusion, the performances of the THz and optical waveguides presented in this communication are compatible with the development of a travelling wave photomixer of length between 500 μm and 1 mm allowing for the use of watt-level optical pump powers.

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