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Nano-structured top contact with low optical polarization dependence for THz generation using photodiodes

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Abstract—Uni-travelling carrier photodiode (UTC-PD) with different top optical and electrical accesses are proposed towards optical polarization sensitivity reduction. With the optimized structure, only 1 percent dependence in optical polarization is obtained while ensuring good RF access. Measurements up to 110 GHz are presented at -1V bias and 25.3 mW optical power.

I. INTRODUCTION

These last few years, many application in terahertz frequency band have been investigated covering imaging system, spectroscopy, non-destructive control system or high-data-rate communications for the most known. This region offers a very huge bandwidth which allows to increase actual data rate with simple modulation. Investigating high frequency generation is essential in the coming years for network adaptation to the growing needs of data rate. Lack of compact and reliable sources in terahertz region compatible with optical fiber networks limits the increase of data rate. The unitravelling carrier photodiode (UTC-PD) introduced by Ishibashi et al. [1] has shown good capabilities up to the THz range [2], [3]. UTC-PD uses photomixing, where spatial superposition of two continuous wave (CW) lasers produced THz frequency corresponding to the frequency difference between lasers, falling in the millimeter/THz range. In some applications, optical polarization can be modified during propagation in optical fiber or discrete devices, which generally affects the photomixing efficiency. Thus, impinging light wave needs to be polarized in a specific direction.

In this work, UTC-PD with different top optical and electrical accesses are investigated to minimize contact resistance and optical polarization dependence, using down to 6 μm diameter and square ($6\mu\text{m}\times 6\mu\text{m}$) photodiodes. Power photogenerated by UTC-PD for 25.3 mW optical power is measured in the small signal regime. Sensitivity, power and device linearity of the photomixing are considered for different filling factor of straight and zig-zag nanogrid. Fig. 1 b) and c) show Scanning Electron Microscope (SEM) image of square and zig-zag top contact topology for unitraveling carrier photodiode.

I TOP CONTACT TOPOLOGY

Top electrodes of the developed UTC-PD are made of a nanostructured metallic array. The grating geometrical parameters are the periodicity p , the filling factor a/p defined as the ratio between the metal width and the periodicity, and the thickness h , as shown in the Fig. 1 a). The periodicity p is equal to 1 μm , the thickness h is equal to 300 nm. We have studied different filling factors 0.3, 0.5 and 0.7 of straight nanogrid and 0.5 filling factor of zig-zag nanogrid. Fig. 1 b) and c) show Scanning Electron Microscope (SEM) image of square and zig-zag top contact topology for unitraveling carrier photodiode.

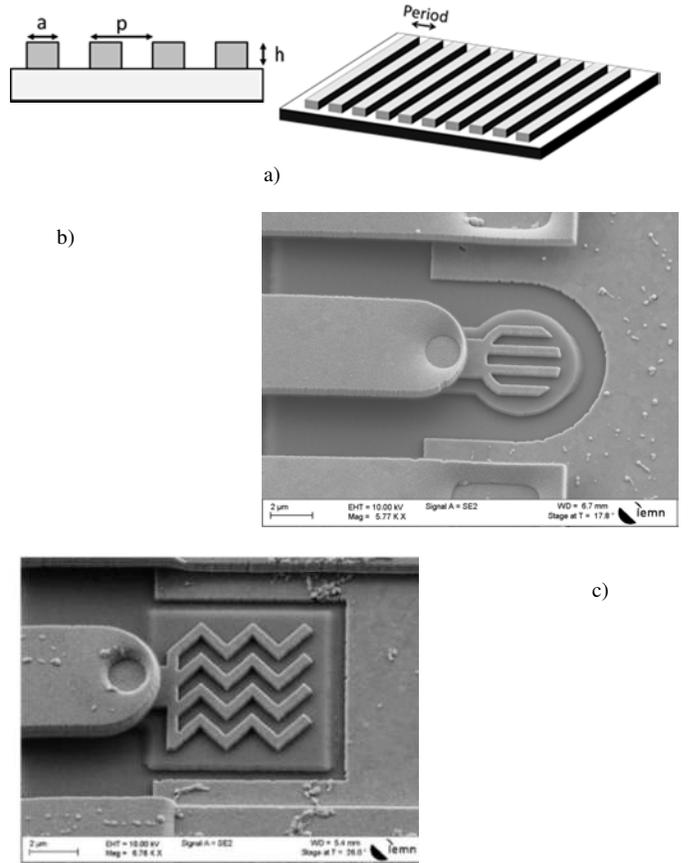


Fig. 1 Scanning Electron Microscope images of top contact. (a) subwavelength nanoaperture (square) (b) zig-zag top contact (c) Grid topology

II. RESULTS

Fig. 2 shows the experimental setup. To measure the DC and RF power generation, fabricated UTC-PD are connected with coplanar accesses probed using a Cascade Microtech coplanar Ground-Signal-Ground (GSG) probe matched to 50 ohm load with 125 μm contact separation. A bias-tee, connected at GSG probe output, enables the bias of the photodiode and the measurement of the DC current with a Keithley 2612A Source Measure Unit (SMU). Two continuous wave (CW) 1.55 μm tunable lasers produce optical beat note signal and optical polarization is controlled by manual fiber polarization controllers to check polarization dependence. Optical signal is applied to the photodiode by a microlensed fiber with minimum spot size of 3 μm . The optical power is controlled by a variable optical attenuator (VOA), the applied bias voltage is -1V for all photodiodes.

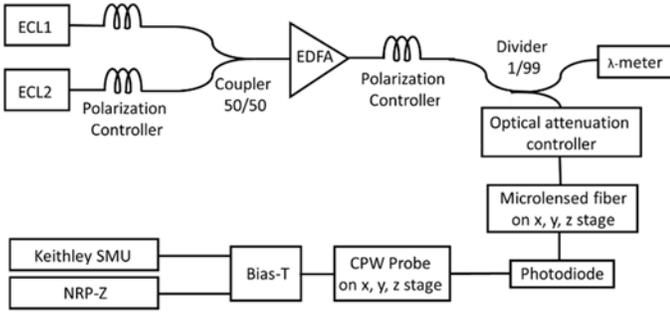


Fig. 2. Experimental setup : Extended Cavity Laser (ECL), Erbium Doped Fiber Amplifier (EDFA), Coplanar Waveguide (CPW), Source Measure Unit (SMU).

Output RF power at 100.2 GHz delivered by four different photodiodes with variation of top contact are compared (Fig.3). For 25.3 mW at the end of microlensed fiber, the measured RF power at UTC-PD (corrected from probe losses) with 0.7 filling factor is higher than other filling factor. It reaches 8.7 μ W for 0.7 filling factor whereas it is of 4.8 and 2.1 μ W respectively for 0.5 and 0.3 filling factor. The M parameter, representing the conversion efficiency, is the ratio between the RF power and the square of the optical power ($M = P_{RF} / P_{opt}^2$) [4]. This parameter is 0.014, 0.0075 and 0.0033 W^{-1} respectively for 0.7, 0.5 and 0.3 filling factor. This variation can be explained by a better photoresponse in A/W of the photodiode with 0.7/1 filling factor. The photoresponse of the photodiode with this top contact reaches 90 mA/W. The photoresponse of the zig-zag topology is 95 mA/W which is two times higher than nanogrid at the same filling factor. Output RF generated by the zig-zag contact photodiode reaches 10 μ W. The comparison between the straight and the zig-zag top contact shows better conversion for the zig-zag topology whatever the filling factor of straight topology. The linearity of photodiodes is important for multilevel modulation formats /high spectral efficiency communications. The RF power measurements of these four photodiodes with incident optical power show good linearity (Fig. 3), up to the available output optical power on the fiber amplifier used.

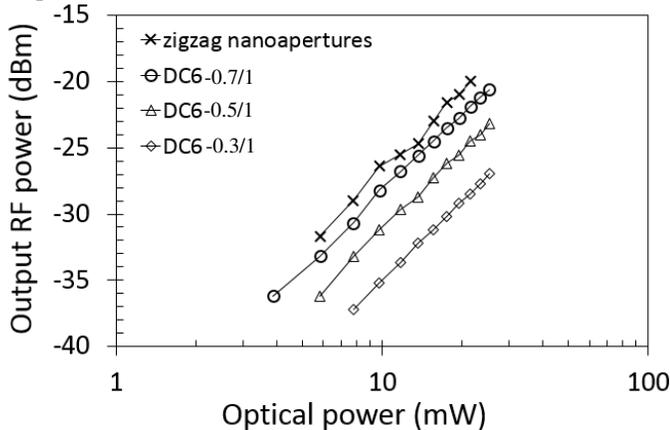


Fig. 3. Output RF power generated by zig-zag and straight subwavelength nanoaperture top contact of 6 μ m UTC-PD size for 0.3, 0.5 and 0.7/1 filling factor.

The performances measured in fig. 3 correspond to the best optical polarization applied on the photodiodes. Optoelectronic

photomixer with this dedicated top contact (nanogrid) suffers from optical polarization dependence. The two optical modes from incident optical wave (TE, TM) perceive different refractive index. For the nanogrid top contact with 0.7 of filling factor, the generated photocurrent measurement shows a dependence of 96.1 % to the optical polarization. Optical polarization dependence decrease at 80.5 % for 0.3 filling factor and the lower dependence is obtained for 0.5 filling factor with only 14%. However, the proposed zig-zag top contact makes it possible to reduce his dependence down to 1.1 %. This contact is thus better than nanogrid for communication due to enhanced robustness to optical polarization.

III. CONCLUSION

Preliminary study of top-contact variations towards mm-wave and THz generation with untravelling carrier photodiodes has been presented. Study of top contact shows that the topology and its filling factor influences the photoresponse and device RF capability. Ratio of optoelectronic conversion is measured and estimated by M parameter and best conversion efficiencies are obtained for 0.7/1 filling factor of nanogrid top contact of UTC-PD with 0.014 W^{-1} and zig-zag contact shows 0.016 W^{-1} . Optical polarization dependence on photogenerated photocurrent is lower for the 0.5/1 filling factor, which is interesting to decrease the device sensitivity to optical polarization. Last, the zig-zag structure is a solution to almost suppress this polarization sensitivity. Experimental study compares the nanogrid filling factor and zig zag top contact structure dependence on photogenerated power at 100 GHz. Photogenerated power, at this frequency, reaches -20 dBm with 1.8 mA photocurrent (25.3 mW optical power). Considering that these UTC-PD have been demonstrated to handle more than 8.5 mA [4], increasing the optical power could enhance the RF generated power can be > 200 μ W.

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