Free-Space Sub-Terahertz Electro-Optic Detector

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The terahertz band covers the frequency from 0.1 to 1 THz, lying between the millimeter wave and the far infrared ranges. In recent years, the growth of research on terahertz communications has been increasing due to its benefits in increased capacity and less interference compared to its lower-frequency counterparts. Consequently, it has emerged as a prospective solution for enhancing the performance of wireless communication systems [1]. Among the systems, electro-optic modulators play an important role in manipulating and controlling terahertz waves for transmission and processing based on the electro-optic effect [2,3]. However, loss in terahertz transmission lines is one of the challenges in terahertz communications [1]. Therefore, we present the possibility of the electro-optic detector which is capable of receiving a weak signal at 140 GHz and modulating it onto a 1550 nm optical signal carrier.

Based on the electro-optic effect (Pockel effect) in certain materials, the refractive index can be altered when the external electric field is present in the material [2,3]. Therefore, light manipulation can be possible in such circumstances. As indicated in Eq. 1 [3] the change in the refractive index Δn_{eff} is mainly based on the strength of the external field, or terahertz waves in this case. Given a weak terahertz signal after traveling in the air, we use the concept of plasmonic within the interaction region, which can provide a strong enhancement on the incident field E_i. Thus, the field enhancement factor, FE, is significant.

$$\Delta n_{eff} = \frac{1}{2} n^2 r_{33} \Gamma n_g E_i \mathrm{FE} \tag{1}$$

Therefore, we introduce the electro-optic detector as in fig. 1 (a). The device comprises a terahertz bow-tie antenna, an optical silicon waveguide for 1550 nm, and an optical plasmonic waveguide. An electro-optic material fills the gap in the plasmonic waveguide and on top of the antenna structure. Utilizing the metal-insulator-metal (MIM) structure in the plasmonic waveguide to tightly confine both modes and provides field enhancement relying on the surface plasmon polaritons, hence there is a good interaction between the RF mode and the optical mode. Preliminary simulation results in fig.1 (b) indicate that the field enhancement in the plasmonic waveguide is as high as 36,000 and 8,000 at 140 GHz for the interaction area 12 µm long with 50 nm gap size and 50 µm long with 150 nm gap size respectively by use of a simple bow-tie antenna with a gain of 7.9 dBi.

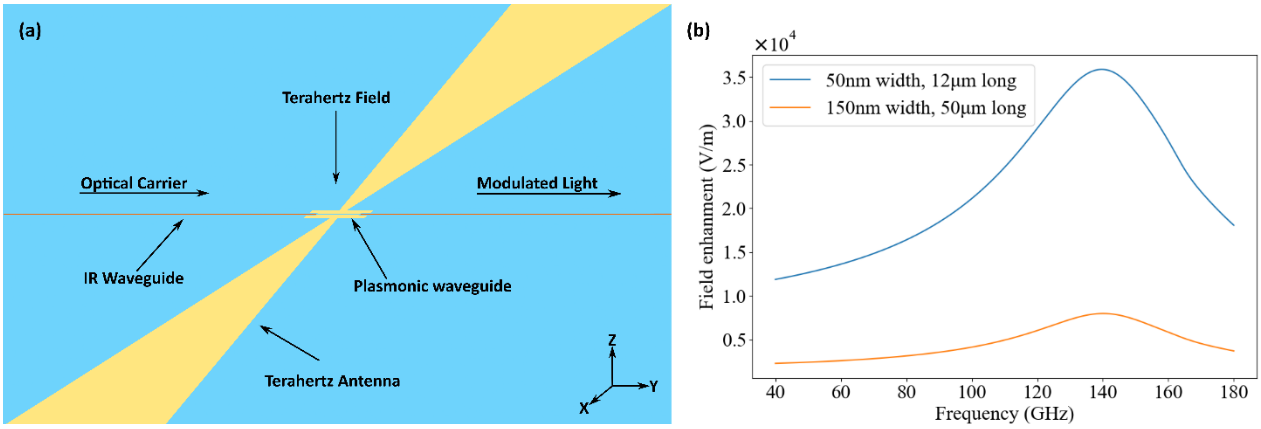

Fig. 1: (a) Structure of the electro-optic detector, comprising three parts: IR waveguide for the optical signal propagation, terahertz antenna for receiving free-space *x*-polarised 140GHz incident wave, and plasmonic waveguide for the interaction between the IR and RF signal. (b) Simulation result of the detector in two configurations.

[1] T. Nagatsuma, G. Ducournau, and C. C. Renaud, "Advances in terahertz communications accelerated by photonics," *Nature Photonics*, vol. 10, no. 6, pp. 371–379, May 2016, doi: https://doi.org/10.1038/nphoton.2016.65.

[2] A. Messner, D. Moor, D. Chelladurai, R. Svoboda, J. Smajić, and J. Leuthold, "Plasmonic, photonic, or hybrid? Reviewing waveguide geometries for electro-optic modulators," *APL photonics*, vol. 8, no. 10, Oct. 2023, doi: https://doi.org/10.1063/5.0159166.

[3] Y. Salamin *et al.*, "Direct Conversion of Free Space Millimeter Waves to Optical Domain by Plasmonic Modulator Antenna," *Nano Letters*, vol. 15, no. 12, pp. 8342–8346, Nov. 2015, doi: https://doi.org/10.1021/acs.nanolett.5b04025.