All-optical terahertz modulation with an epsilon near-zero material

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Abstract

We theoretically and experimentally study the THz electromagnetic properties of an undoped-InAs slab whose permittivity is optically modified by a photo-generation process. We show a high modulation of the THz transmission up to 90% from 0.75 to 10 THz at very low pump fluence in the continuous wave regime. We also demonstrate a high-speed transmission modulation rate up to 2 MHz range with a modulated pump.

1. Introduction

The development of the technology based on terahertz (THz) electromagnetic radiation is crucial for many application domains such as security, medicine, non-destructive inspection, astronomical instrumentation, spectroscopy, imaging and wireless communication. To respond to the demand for versatile THz components operating in the THz gap (0.1–10 THz), artificial structures such as metasurfaces have been recently investigated to dynamically control THz waves.

2. Discussion

We have theoretically and experimentally studied the THz electromagnetic properties of photo-generated carriers in an undoped-InAs slab. The modifications of the permittivity induced by an optical pump are calculated by solving the ambipolar rate equation for the photo-carriers. Photo-carrier diffusion plays a crucial role in the search of an optimal geometry [1-2].

To understand and to reveal the real impact of the photo-carrier diffusion in the InAs material, we have created a multiphysics code to calculate the electromagnetic properties of the InAs slab illuminated by a THz plane wave. We have analyzed the electromagnetic properties of the InAs slab as a function of the thickness "*h*", the pump fluence and the polarization (TE and TM) of the THz wave and demonstrated a high modulation of the THz radiations [2].

We have carried out the experimental demonstration by measuring the transmission of a THz-wave through a micrometric-thick slab of undoped-InAs using a continuous-wave (CW) and modulated by an IR laser of around 800nm wavelength. In the experimental set-up, the collimated THz wave radiates the InAs membrane located in the sample holder of the optic set-up, which in turns is traversed by the IR laser. The maximum power is 500 mW and the spot diameter is 2 mm when it is collimated. The rest of the optic set-up is composed of a FTIR spectrometer for frequencies from 1 to 10 THz.

These experimental results reveals that a modulation depth of 90% at 1 THz is obtained with a continuous laser at irradiation lower than 10 W.cm^{-2} for a 6 µm thick InAs slab, Fig. 1. This strong modulation is demonstrated to originate from the photogenetation of an epsilon-near-zero (ENZ) material that boosts the absorption of the THz wave within a sub-wavelength thick (λ/50) InAs slab. Since the IR pump intensity drives the ENZ frequency, the ENZ absorption effect provides an efficient way to modulate the THz signal over a broadband from 1 to 10 THz.

In addition, the experimental results performed in the dynamic regime reveals that a cut-off frequency of 3 dB attains 2 MHz, Fig. 2.

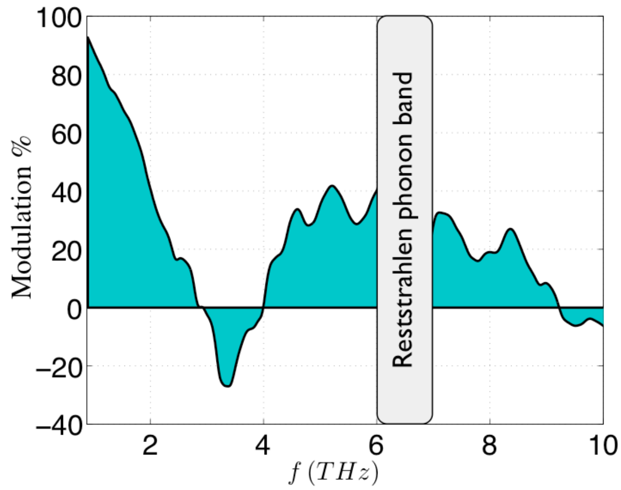

Figure 1: Modulation of an undoped 6 lm thick InAs slab irradiated with a pump irradiance of 8.1 W cm 2 at room temperature

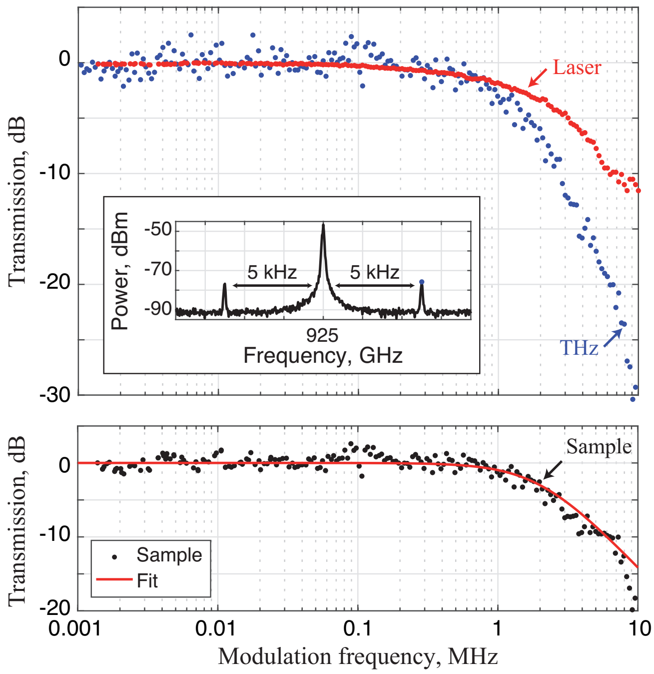

Figure 2: The transfer function of the InAs slab: the dots correspond to the experimental data and the solid line to their fit with a first-order low pass filter. The inset of the figure shows the THz spectrum measured using a 10 Hz resolution bandwidth for a laser amplitude modulation frequency 5 kHz.

3. Conclusions

We have demonstrated that the undoped-InAs is a promising semiconductor for the development of on-chip fast and efficiently THz components. A modulated pump at an irradiance of few W/cm^2 is enough to dynamically control the THz transmission over a frequency range from 1 THz to 10 THz and with a modulation rate up to 2 MHz range. These results open interesting routes for the design of advanced THz modulators.

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References

[1] E. Alvear-Cabezón, R. Smaali, E. Centeno and T. Taliercio,« Photogenerated metasurfaces at terahertz frequencies induced by a continuous-wave low pump », Phys. Rev. B **98**, 035305 (2018).

[2] E. Alvear-Cabezón, T . Taliercio, S. Blin, R. Smaali, F. Gonzalez-Posada, A. Baranov, R. Teissier, E. Centeno, « Epsilon near-zero all-optical terahertz modulator », Applied Physics Letters 117, 111101, 2020.

[3] E. Centeno, E. Alvear-Cabezón, R. Smaali, A. Moreau, « Inverse-designed terahertz modulators based on semiconductor multilayers», Semiconductor Science and Technology, accepted manuscript online 22 June 2021.