Broadband THz Modulators Based on Multilayer Graphene on PVC

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Abstract— **In this study we present the direct terahertz time-domain spectroscopic measurement of CVD-grown multilayer graphene (MLG) on PVC substrate with an electrically tunable Fermi level. In a configuration consisting MLG and injected organic dopant, the transmitted intensity loss of terahertz radiation was observed with an applied voltage between 0 and 3.5 V.We showed that MLG on PVC devices provided approximately 100 % modulation between 0.2 and 1.5 THz at preferentially low operation voltage of ca. 3V. The observed modulation bandwidth in terahertz frequencies appears to be instrument limited.**

I. Introduction

THz modulators are structures capable of actively controlling the amplitude (or phase) of the transmitted (or reflected) THz waves.[1] Different types of THz modulators have been intensely investigated such as semiconductor hetero-structures containing a two dimensional electron gas (2DEG)[2], metal–oxide–semiconductor technology [3] and metamaterial-based modulators [4]. A room temperature 2DEG modulator was demonstrated by Kleine et al. Although RT operation is practical, poor modulation depths of 3%–4% have been reported due to the usage of metal gates. Gao et al. reported 50% amplitude modulation with gated single-layer graphene using metallic ring apertures. This spatial light modulator can operate with low bias voltage at room temperature but it has a narrow bandwidth. Recent metamaterial based modulators can also have around 50% modulation. However, their narrowband operational range and polarization-dependent response may limit their future applications. Single layer graphene offers very low insertion loss (0.2 -0.5dB). Kakenov et al. presented an ionic liquid based THz intensity modulator.[5] Modulator structure consisted of two graphene coated quartz wafers with a spacer in between which is filled with ionic liquid. Due to efficient mutual gating of graphene electrodes and ionic liquid more than 50 % modulation depth was obtained.

We experimentally demonstrate an excellent performance on THz modulation based on MLG/ionic liquid structures on Polyvinyl chloride (PVC) substrate. The modulation covers a broadband frequency range from 0.2 to 1.5 THz with the modulation depth of up to 99% with application of very low voltage of 3 V. This high modulation depth stems from the strong gating effect of ionic liquid. To our knowledge, this is one of the highest modulation depths from graphene based THz modulators with such a broad THz range.

II. Results

In Figure 1 THz transmission of modulator device is given in a range from 0.2 to 1.5 THz at representative voltages. The observed modulation with the set voltage appears to be independent of the THz frequency and only instrument limited. Up to ~2 V less than 20 % modulation is observed. A modulation between 40 and 60% at ca 2.5V can be achieved.

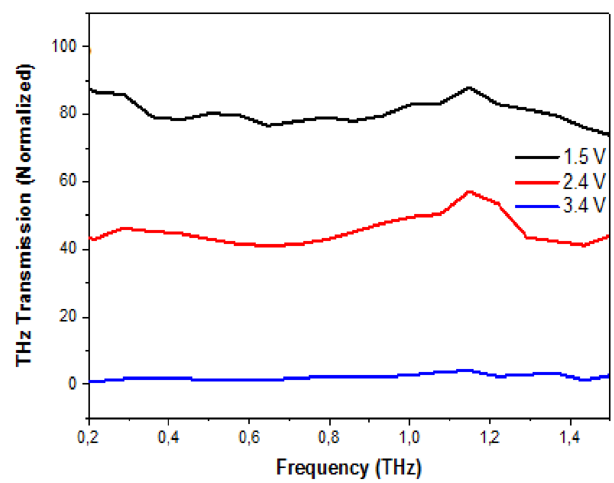

Figure 1. Normalized frequency transmission of the THz signals of MLG l grown on PVC at 1.5V, 2.4V and 3.4V applied voltages. The layer thickness is, 19.2 nm.

A complete modulation has been achieved with modulator devices at voltages beyond 3V. As clearly seen from the data presented in the figure, the modulation depth is significantly improved compared to single and multilayer devices.

III. Summary

In conclusion, we fabricated THz modulators using CVD-grown graphene layers doped with ionic liquid electrolyte and investigated THz transmission by THz time-domain spectroscopy. High modulation depth over such a broad spectrum and a simple device structure brings significant importance toward application of this type of device in THz and related technologies.

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