High-efficiency broadband THz wave modulator based on phthalocyanine-compound organic/silicon films

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***Abstract*—We report a high efficiency, broadband terahertz (THz) modulator following a study of phthalocyanine-compound organic films irradiated with an external excitation laser. Both transmission and reflection modulations of each organic/silicon bilayers were measured using THz time-domain and continuous-wave systems. For very low intensities, the experimental results show that AlClPc/Si can achieve a high modulation factor for transmission and reflection, indicating that AlClPc/Si has a superior modulation efficiency compared with the other films (CuPc and SnCl2Pc). In contrast, the strong attenuation of the transmitted and reflected THz waves revealed that a nonlinear absorption process takes place at the organic/silicon interface.**

I. INTRODUCTION

Terahertz (THz) functional devices for THz spectroscopy, imaging and communication have been extensively investigated. Very recently both Hyung Keun Yoo and Tatsunosuke Matsui have demonstrated that organic copper phthalocyanine (CuPc) thin films deposited on a Si wafer can significantly reduce the transmittance of THz pulse energy in a wide range of frequency when an external laser irradiates [1-3]. Those works shows CuPc is an interesting material for THz modulator. However, we thought not only CuPc but also other phthalocyanine compounds has a huge potential as materials in THz modulator and should be need deeply explored. Moreover, alter external laser wavelength to make further efforts for reduce the laser power requirement which also can reach the highest modulation efficiency is will be study too.

In this paper, we present three phthalocyanine compounds (AlClPc, CuPc and $SnCl_2Pc$) as THz wave amplitude modulators. Using thermal evaporation we deposited 200-nm thick films on a 2-mm thick Si wafers. We will demonstrate that more than 99% modulation efficiency (ME) is obtained from AlClPc/Si and CuPc /Si films, and also a 96.3% ME from $SnCl_2Pc$/Si. Such high ME value was achieved with a very low laser power excitation, which is very significant. Mechanism of the high and broadband THz frequencies modulation phenomenon was investigated by calculating the carrier density.

II. RESULTS

We used 2 mm-thick, high resistive Si films as substrates. Using thermal evaporation we deposited 200-nm thick film on the substrate, and without using thermally annealed. A 450nm CW semiconductor laser was used as the optical modulating source. Both transmission and reflection modulations of each organic/silicon bilayers were measured by using THz time-domain and continuous-wave systems. The experimental result (Figure 1) shows that THz wave amplitude modulation efficiency of the three films quickly increased by increasing external laser power. The result presents that AlClPc/Si and CuPc/Si films can achieve more than 99% modulation efficiency, and the SnCl2Pc/Si is 96.3%. Moreover, these modulation effects can be achieved by a relatively lower modulating laser power. For the AlClPc/Si film with the highest modulation efficiency, the external laser power is 94.3mW, the corresponding intensity is 1.57x102mW/cm2.

By using the dielectric parameters at 0.59 THz, we obtained the plasma frequency and then extracted the carrier density, which is 1.78x1019number/cm3 for AlClPc/Si, 2.84x1018 number/cm3 for CuPc/Si, and 7.59x1017 number/cm3 for SnCl2Pc/Si. The results show the strong attenuation of the transmitted and reflected THz waves revealed that a nonlinear absorption process takes place at the organic/silicon interface, and also explains why the AlClPc/Si films has better modulation efficiency than the others.

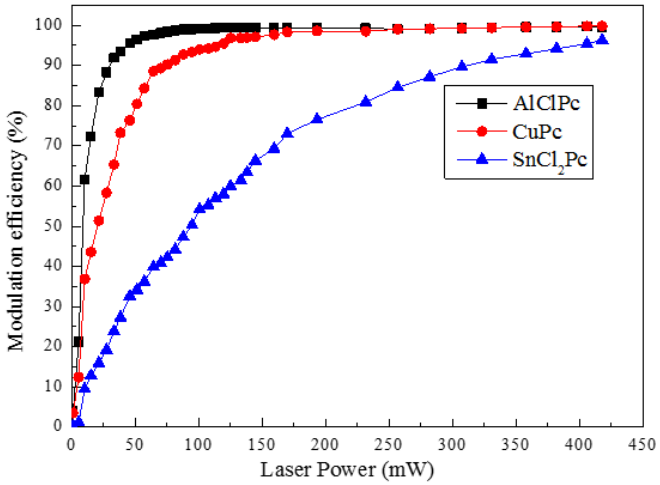

Fig. 1. The modulation efficiency (ME) of three phthalocyanine compounds, and the external laser output power changed from 0 to 420mW.

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