Experimental Analysis of Thin Graphite Periodic Structures in the THz Band

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Abstract— The THz gap has attracted considerable interest in the last decade in a wide range of applications (from astronomy to biology) due to the low energy of the THz waves and their capability to provide chemical recognition and non-destructive inspection. To implement THz-based solutions, a wide range of components have been developed and efforts are being done to reduce the system cost through the use of cost effective materials.

This presentation analyzes the development of metal wire grids by using the conductive properties of graphite. The aim is drawing the wire grid using a simple graphite lead pencil on standard paper. This would reduce the cost of several wire grid base components, such as polarizers or filters.

An 8B pencil is used because of its high graphite contents. Parameters such as the pitch of the structure and its fill factor are set to study the behavior of the metal grid in a frequency range from 0.1 to 0.7 THz. An average pitch of 800 micrometers with a fill factor of 0.8 corresponds to an ER of 2 dB. The samples are analyzed using a fiber-based pulsed THz Time Domain Spectrometer in transmission mode. An ultrafast laser pulse impinges on a photoconductive antenna generating the THz beam that is detected by a similar switch. Preliminary experimental results show that the increase of the angle between the horizontally-polarized incoming electric field and the graphite periodic structure corresponds to a decrease of the THz absorption, hinting at a polarizer behavior.

1. INTRODUCTION

Technology developments along the last decades allow the use of almost the whole energy range of the electromagnetic spectrum. The different features of each frequency range provide valuable tools to investigate physical processes of different energy magnitudes. The THz range, that comprises frequencies from 100 GHz to 3 THz, is quite interesting because it allows the analysis of both the macro and the microscope world by using non-invasing techniques. Many efforts are being made to explain the interaction of THz waves with matter. Recent studies demonstrated the transparency of the THz to some common materials such as cotton, wool or leather but also wood and paper [1]. THz radiation is also used to investigate biological systems, for example to define a label-free sensing approach for the characterization of genetic material. Researchers demonstrated that is possible to identify the binding DNA state, by analyzing changes in its refractive index [2]. They are also usually employ in the analysis of chemical composition of medicines or unknown compounds [3, 4], that is quite useful both in the pharmaceutical industries and in terms of security issues.

Different methods for THz generation and detection have been developed, which allow THz time-domain spectroscopy (THz-TDs) and the THz frequency spectroscopy (FDS), THz imaging and THz ad-hoc devices [5].

Such a variety of application requires suitable and cost effective tools and the implementation of quasi-optical elements working in the THz frequency range plays an important role.

Retarders, polarizers, and phase shifters, for example, are mainly produced by using complicated and expensive techniques, such as photolithography (imprinting on a photoresist layer on an infrared transmitting layer) [6] or chemical evaporation of a metal on an appropriate substrate.

With the aim of reducing the cost of the THz systems [7], we try to identify a polarizing behavior of a metal wire grid based on the conductive properties of graphite and common paper.

2. EXPERIMENTAL PROCEDURE

Due to its high graphite content ([8, 9]), an 8B lead pencil was used to deposit a thin graphite layer on common printable paper. A periodic pattern was designed and printed on the sheet and then it was used as a guide to draw a periodic structure. The key parameters that has to be taken into account when planning a wire metal grid are the pitch (from center to center), the line width and the fill factor, that is the ratio between the wire and the pitch width. The polarizing effect takes

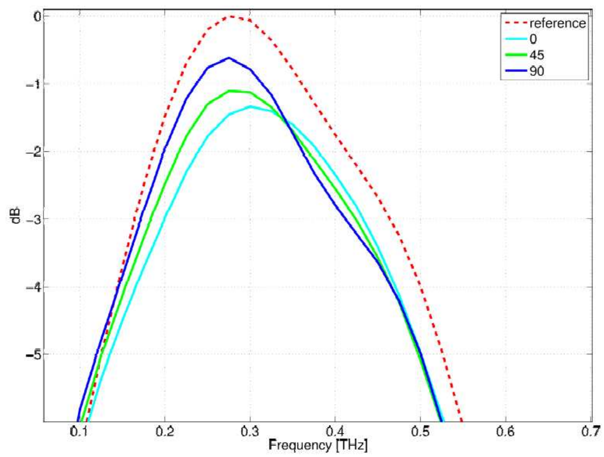

Figure 1: Frequency THz spectrum of the 0.800 mm pitch wire metal grid. The plot shows the THz power in the 0, 45, 90 degrees configuration. The dichroic effect is noticeable in the frequency range from 0.1 THz to 0.4 THz. The THz frequency amplitude decreases as the angle between the incoming THz beam and the direction of the grid decreases.

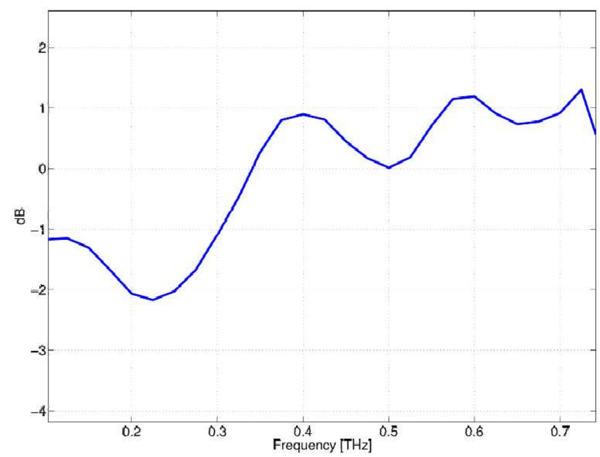

Figure 2: ER of the metal wire grid based on graphite as a function of frequency.

place as long as the pitch is a fraction of the incoming THz wavelength [10]. Otherwise, the periodic structure exhibit a diffraction effect. The sample area is $35 \times 35\,\mathrm{mm}^2$ with a pitch of a 0.8 mm and a wire width of 0.6 mm, that lead to a fill factor of about 0.8. As the graphite deposition was hand made, it wasn't possible to ensure the deposited graphite amount, but the integrity and precision of the designed wires was checked by scanning them with an optical microscope.

To characterize the performance of the graphite-based polarizers, a transmission fiber THz-TDS setup was used. A femtosecond pulsed laser at 1550 nm provides 100 fs excitation pulses, at 100 MHz repetition rate. The pulse is split into two branches: the sampling one that impinges on a photoconductive switch that generates the THz beam, and the probe one that is used to sample the THz waveform in the photoconductive antenna that detects the THz beam. An optical delay line is used to scan the THz wave and lock-in detection is employed to improve the dynamic range of the measurement [11].

The metal wire grid was stuck with tape on an adjustable holder and placed in the optical path in the collimation area [12]. All the measurements were performed at normal incidence, while the angle θ between the incoming THz beam and the direction of the grid was changed by rotating the holder.

In Figure 1 the frequency THz spectrum is displayed. Each line is calculated by considering the blank paper sheet as reference. It can be noticed that to a decrease of the angle θ corresponds a decrease in the amplitude of the detected photocurrent signal. In particular, when the direction of the wire metal grid is perpendicular to the polarization of the incoming THz beam ($\theta = 90°$) a maximum of transmission is detected, while a minimum corresponds to the parallel direction ($\theta = 0°$). These results agree with the dichroism effect of selective absorption, that assets that only the components of the electric field parallel to the grid transmission axis pass the polarizer.

To evaluate the polarizing features of the graphite-based wire metal grid, its Extinction Ratio (ER) is calculated as a function of the frequency (Figure 2).

The achieved ER of 2 dB supports the idea that the wire metal grid based on graphite could be work as a polarizer.

3. CONCLUSION

A metal wire grid polarizer drawn using ordinary lead pencil based on graphite on common blank sheet paper has been experimentally demonstrated. Due to the conductive properties of the graphite, the wire grid shows a polarizing behavior based on the dichroism effect. The low-cost and the availability of the employed materials make this solution attractive in terms of cost reduction. Further studies have to be performed to achieve a better ER and to emphasize the polarizing behavior of the wire metal grid. Methods to improve their durability and robustness are, among others, issues that play a key role in the development of a THz polarizer.

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