Terahertz Investigation of X-Ray Anti-Imaging Coatings: Spectroscopic Characterization and Imaging

Nathan M. Burford[1], Brennen Freiburger[1,2], and Magda El-Shenawee[3]
[1]University of Arkansas Microelectronics-Photonics Program, Fayetteville, AR, 72701 USA
[2]Space Photonics Inc., Fayetteville, AR, 72701 USA
[3]University of Arkansas Electrical Engineering Department, Fayetteville, AR, 72701 USA

***Abstract*— An investigation of the terahertz properties of x-ray blocking and scattering (XBS) coating materials is performed. Spectral characterizations of the XBS materials reveal much stronger absorption coefficients as compared to the control coatings, as well as significant change in the refractive index. To examine the effectiveness of the coating material, pulsed THz reflection images of coated electronic microchip circuits are obtained. The microchips are covered with XBS coatings of varying thickness. The results demonstrate that this coating can successfully block the incident THz signal between 0.08 and 4 THz if the coating is sufficiently thick. This allowed for the proper thickness of the coating to be determined such that potential intellectual property contained in the microchip design could be protected from THz imaging.**

I. INTRODUCTION

PULSED THz time-domain spectroscopy (THz-TDS) offers a potential for many applications in nondestructive evaluation of electronics, biomedical imaging, material characterization and national security. Similar to microwaves and x-rays, THz radiation can penetrate into many materials, to depths of several millimeters in some cases. For imaging purposes, THz offers the advantage of higher spatial resolution than microwave imaging. Also, unlike x-rays, THz photon energies are lower than material ionization energies, which make them truly nondestructive in nature. In addition to imaging, material characterization using THz-TDS is an attractive potential application, as many materials have strong spectral characteristics in the THz band, allowing them to be identified [1].

In the microelectronics industry, protection of intellectual property is of great importance, particularly for smaller hi-tech startup companies [2]. In this work, THz-TDS is performed on XBS materials (x-ray blocking and scattering), which are designed and used as a coating to prevent x-ray imaging of electronic devices containing valuable intellectual property. A commercially available THz-TDS and imaging system with a pulse bandwidth of 0.08 to 4 THz. THz spectral characterization allowed frequency dependent electrical properties of the materials to be extracted while a reflection imaging module was utilized to investigate imaging potential of microelectronic devices with coatings of varying thickness.

II. RESULTS

THz-TDS of XBS coating materials and reflection imaging of microchip circuits covered by an XBS material layer is performed using a commercially available THz spectroscopy and imaging system. The XBS materials under investigation are compounds consisting of an epoxy base with a proprietary concentration of additives, the active materials contributing to the XBS behavior. In this work, the epoxy used is Epo-Tek EP30AN-1, although different epoxies can be used for different applications. Three samples are considered here; two XBS compounds with different additive types/concentrations and one control sample consisting of the epoxy base with an aluminum nitride particle additive.

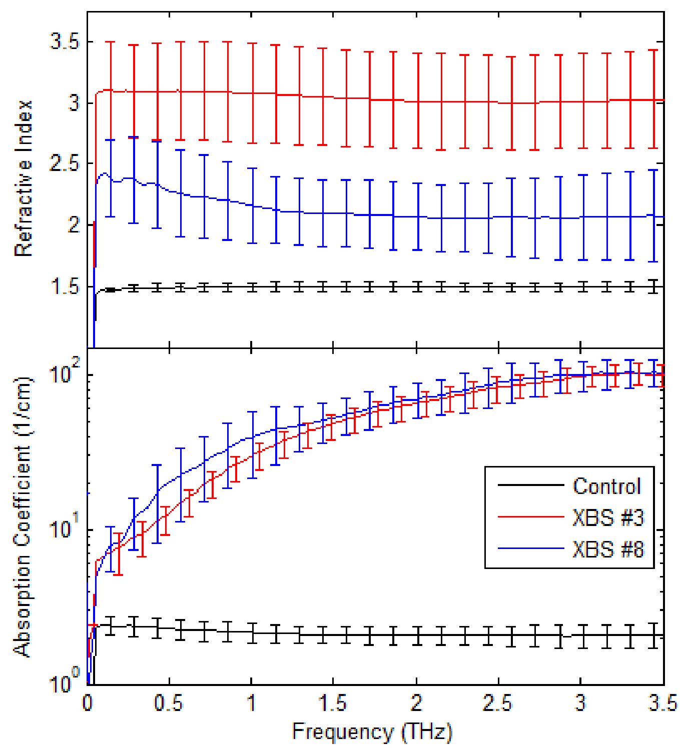

Fig. 1. Refractive index (top) and absorption coefficient (bottom) THz spectroscopy results for the three different coatings. Error bars illustrate standard deviations in the 8 separate measurements taken on each sample.

The preliminary THz spectroscopy results for the two XBS and one control materials are illustrated in Fig. 1. The samples are deposited on a 1 mm thick polystyrene slide, with the thickness of the sample being approximately 0.8 mm. The magnitude and phase of the transmitted THz pulse is measured and from this information the refractive index and absorption coefficient can be calculated. For each sample the measurements are repeated across 8 different physical locations, with Fig. 1 illustrating the average and standard deviation of these measurements.

The spectroscopy results illustrate how the additives significantly alter the THz properties of the coatings. The refractive indices of each are fairly constant across the entire frequency range at values of approximately 1.5, 3 and 2.1 for the control, XBS #3 and XBS #8 coatings, respectively. The measured refractive index and low absorption coefficient of the control sample is consistent with the reported values of

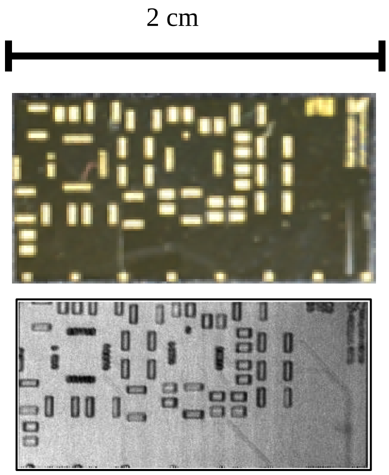

Fig. 2. Photograph of microchip without XBS coating (top) and frequency domain THz image of the same chip without XBS coating, taken at 3 THz and 50 µm pixel size.

Epo-Tek epoxy in the infrared range. For both XBS coatings, increased refractive index, absorption coefficient and standard deviation in the measurements are noted. This arises from the nanoparticle additives that contribute to absorption and scattering of the transmitted THz pulse, while the increased standard deviation is due to potential non-uniform distribution of the additives.

Reflection imaging of chips coated in the control and XBS material revealed that the ability of the coatings to prevent THz imaging depends strongly on the coating thickness. Fig. 2 shows both a photograph and THz reflection image of an uncoated microchip, taken from the Fourier Transform of the time-domain signal at 3 THz. Similar microchips were coated in the control and XBS coatings in thicknesses varying from 345 µm to several millimeters.

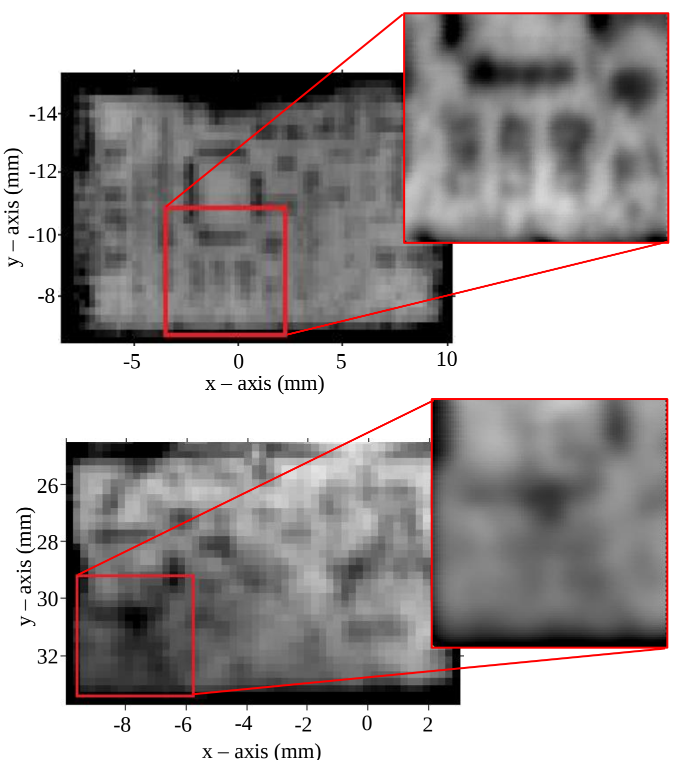

Fig. 3. THz time-domain image of microchip with 345 µm (top) and 1500 µm (bottom) of the control coating with 250 µm pixel size. Inset illustrates a reduced section of the sample with a 50 µm pixel size.

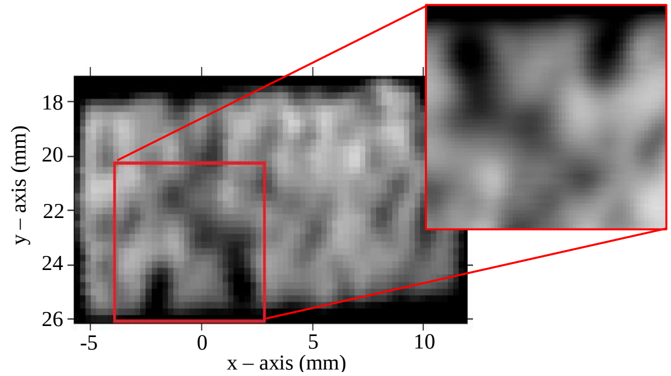

Fig. 4. THz time-domain image of microchip with 650 µm of the XBS #3 coating with 250 µm pixel size. Inset illustrates a reduced section of the sample with a 50 µm pixel size.

Fig. 3 illustrates THz reflection images of microchips with 345 µm (top) and 1500 µm (bottom) thick coatings of the control material. These images are taken from the maximum peak size in the reflected time-domain signal at each pixel. In the 345 µm sample it is observed in the higher resolution 50 µm pixel size image that most of the same features can be resolved that are seen in the uncoated sample. When the coating is increased to 1500 µm, only the larger features are observed and many of the smaller details are lost. This is due to the non-negligible absorption in the coating. Similar observations were made with the XBS coatings. Fig. 4 illustrates the THz reflection imaging results of the microchip with 650 µm of XBS coating material. Although some detail in the chip layout can be seen, it is noted that the additives in this coating greatly reduce the clarity of the image as compared to the control.

III. Summary

In this work THz time-domain spectroscopy and imaging has been utilized to study XBS coatings designed to prevent x-ray imaging of electronic devices. This has allowed for the refractive index and absorption coefficient of the coatings to be acquired across a range of 0.08 to 3.5 THz. Reflection imaging of microchips with varying coating thickness has demonstrated that the ability to successfully prevent THz imaging depends strongly on the thickness of the coating layer. Future work will be performed to apply various image processing methods to improve the clarity of the THz time-domain images. This will allow for the true limitations of the ability of these coatings to prevent THz imaging to be fully understood.

References

[1]. W, L Chan, J Deibel, and D, M Mittleman, "Imaging with Terahertz Radiation," Rep. Prog. Phys., vol. 70, pp. 1325-1379, 2007.

[2]. C Neubauer, "Intelligent X-Ray Inspection for Quality Control of Solder Joints ," IEEE Trans. Compon. Packag. Manuf. Technol. C, vol. 20, no. 2, pp. 111-120, 1997.