NON-DESTRUCTIVE EVALUATION OF DEFECTS IN COMPOSITE BI-MATERIAL STRUCTURES AND ESTIMATION OF FRACTURE FRONT USING DATA DRIVEN TERAHERTZ TIME DOMAIN ANALYSIS

Sushrut Karmarkar[1]*, Andreas Jung[2], Vikas Tomar[1]

[1]School of Aeronautics & Astronautics, Purdue University, USA,
[2]Department of Physics and Astronomy, Purdue University, USA
** Presenting Author email: skarmar@purdue.edu*

Abstract

The high luminosity Large Hadron Collider (HL-LHC) will collide particles at unprecedented rates to search for new physics and make high precision measurements to challenge the standard model with emerging technologies that pose high demands for the materials of charged particle tracking detector support structures. Tracking detectors at current (and future) colliders are encounter high-radiation environment where polymeric and carbon fiber composite materials are used in the mechanical support structures of the detectors. The accumulated radiation dose for these materials and thermal loads lead to defects like voids and cracks due to de-gassing and thermal cycling. Terahertz time domain spectroscopy is used to map these strains in a bi-material strip and trace the locations of fractures in a thermal interface material (TIM) layer or an adhesive layer. Statistical data driven terahertz scan image processing analysis is used for predicting the fracture propogation behavior to validate the cohesive FEA model for the fracture observed.

1. Introduction

Terahertz time domain spectroscopy (THz-TDS) is a powerful technique for material characterization and is gaining significant traction in the non-destructive evaluation of material properties as well as detection of internal fractures and defects. The THz-TDS measures the changes in the phase and amplitude of an electromagnetic pulse in the terahertz band to quantify small variations in the materials dielectric strength. THz region encompasses the far infrared region between 0.1 and 10 THz, hence achieving better resolution than other microwave methods, which together with its ability to pass through most dielectric materials makes for a new non-destructive strain analysis approach with high potential in remote sensing applications. Correlation of the optical properties, namely the phase delay of the received terahertz wave to the strain state of a single material has been validated in works published by Luis Baudes et al [1]. The use of strontium titanate (STO) doped passive composite sensor has been expanded to implement void and fracture mapping in thermal interface layers. The applications of this technique to the current effort for the composite support structure design, manufacturing and validation of the Compact Muon Solenoid (CMS) High Luminosity Phase Upgrade for LHC-CERN is shown. The silicon sensor and modules are mounted on a carbon composite backing that with a thermal interface material. The cross section of a typical sensor module is shown in figure 1(a). In order to quantify the thermal and mechanical strain non-destructively for a cross section of the silicon detector, a terahertz time domain spectroscopy was identified as a potential non-contact spectroscopy technique since the THz spectral signatures are unique, and THz spectroscopy gives information that cannot be obtained from other spectral domains. This is the case of transparent polymers made of low-weight molecules. X-rays are unable to “see” or interact with the lightest atoms, typically lighter than oxygen. If the polymers are transparent in the visible part of the spectrum, imaging is unable to distinguish them. Moreover, some polymeric molecules are IR-inactive due to their symmetry, and thus IR spectroscopy cannot identify them.[2] This also leads to novel applications of THz-TDS in a host material that is opaque to the visible light for applications of imaging defects. This is also important in the CMS detector as studies have shown that the thermal interface material is susceptible to cracking under gamma radiation environments. Identifying such cracks in the detector architecture is essential to estimate the performance of a silicon detector. The figure 1(b) shows the cracks in the thermal interface layer and figures 1(c) and 1(d) show the schematics of the THz-TDS setup and preliminary results to identify the crack fronts.

2. Results

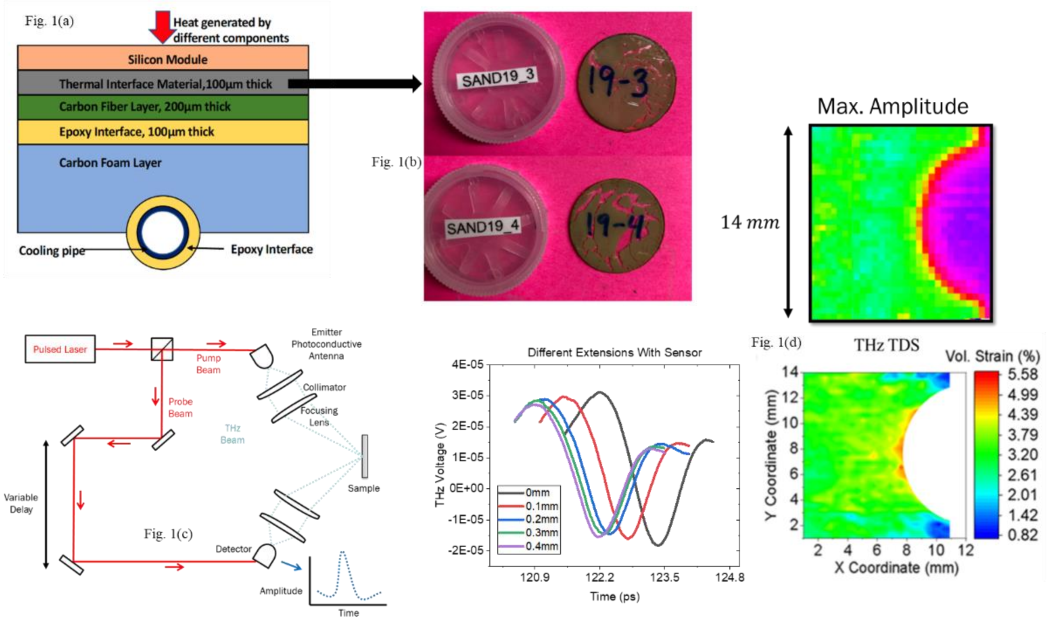

Fig.1(a) The cross-section of a dector support structure used in the Inner Tracker region of the CMS detector shows the thermal interface layer that has to with stand a cumulative dose of ~ 1.5 GRad closest to the interaction point which leads to de-gassing and cracking as seen in the fig. 1(b). The THz-TDS set up (fig. 1(c)) enables us to map these cracks non-destructively which is done by analysing the change in time of arrival of a dielectrostrictive material like a STO dopant in the thermal interface layer (TIM).[3] Such a signal is then mapped using data driven image analysis models to obtain a strain field and then translate the same to fracture front images as seen in fig 1(d).

THz-TDS scans show that the mapping of internal defects like voids / cracks are dependent on the complex refractive index definition in the THz-TDS analysis. This enables us to capture with higher sensitivity the crack front present in the TIM. Data analysis driven image processing models help analyze the strain/stress concentration regions at the crack front. Implementation of cohesive failure models in the TIM material system and providing simulation results to map the crack propogation techniques is explored and shows promising results.

3. Conclusions

Dielectrostrictive passive sensors like STO-TIM composite enable crack/void imaging using THz TDS by sensing the change ToA of a THz pulse transmitted through the sensor, localized variations in strain can be analyzed with FFT and complex valued refractive index to strain field correlations. Experimental results combined with data driven model were used for mapping the strains and fractures in the visibly opaque regions of the composite stack used in the sensor.

References

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