

The evaluation of a pyroelectric detector with a carbon multi-walled nanotube coating in the infrared.

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Abstract. The performance of a pyroelectric detector with a carbon multi-walled nanotube coating was evaluated in the 0.9 μm to 14 μm wavelength range. The relative spectral responsivity of this detector was shown to be flat over most of the wavelength range examined and the spectral flatness was shown to be comparable to the best infrared black coatings currently available. The performance of the detector (in terms of NEP and D^*) was limited by the very thick (250 μm thick) LiNbO_3 pyroelectric crystal on which the coating was deposited. The responsivity of this detector was shown to be linear in the 0.06 mW to 2.8 mW radiant power range and its spatial uniformity was similar to other pyroelectric detectors utilising different types of black coatings. The carbon nanotube coatings were reported to be much more durable than other infrared black coatings commonly used to coat thermal detectors in the infrared, such as metal-blacks. This, in combination with its excellent spectral flatness demonstrated by this paper suggests that carbon nanotube coatings appears extremely promising for thermal detection applications in the infrared

Introduction

Coatings applied to thermal detectors must combine high absorptivity, to ensure that a large fraction of the incident radiation is absorbed, with low thermal mass to ensure that the resulting temperature increase is maximised for a certain level of incident radiant power [1]. These requirements are particularly important in the infrared where there is limited availability of black coatings whose characteristics match the conditions stated above. While the absorptivity of gold-black coatings in the infrared are very good [2, 3], their fibrous structure is very delicate leading to degradation in performance due to the collapse of this structure, particularly as a result of heating and physical contact. Lehman et. al. recognised that the characteristics of carbon nanotube coatings fulfill the main requirements of black coating for thermal detectors [4, 5]. The fabrication and evaluation of two pyroelectric detectors with two different types of carbon nanotube coatings was reported in the 600 nm to 1800 nm wavelength range [4, 5]. However, the main applications of thermal detectors are mainly in the infrared where the advantages of alternative (photon) detector technologies are not so overwhelming, allowing thermal detectors to compete for market share. The aim of this paper is to report the extension of the evaluation of a carbon Multi-Walled Nano Tube (MWNT) coated pyroelectric

detector in the infrared. The carbon nanotube coating which was grown by Hot Wire Chemical Vapour Deposition (HWCVD) was deposited on a 250 mm thick LiNO_3 crystal [5]. The active area of the detector was 3 mm in diameter. Full details of this pyroelectric detector and the characteristics of the carbon nanotube coating can be found elsewhere [5].

The performance of the MWNT pyroelectric detector was characterised using the NPL infrared detector characterisation facilities [6]. Full details of the NPL infrared spectral responsivity measurement facility can be found elsewhere [7]. For further information on the NPL spatial uniformity of response measurement facility and the NPL linearity of response measurement facility the reader is referred to references 6 and 8 respectively. The maximum level of spectral irradiance at which linearity measurements were made was restricted by the maximum spectral radiance available from the 2 mm wide element of the tungsten strip lamp. During the linearity characterisation, the unfiltered output of a tungsten strip lamp with a silica window was used. This was deemed acceptable because of the spectral flatness of the spectral responsivity of the carbon nanotube pyroelectric detector.

For all the radiometric evaluations described in this paper, the MWNT pyroelectric detector was used in combination with a trans-impedance amplifier operated at a fixed gain of 10^8 V A^{-1} . All measurements presented in this paper were performed at a 70 Hz modulation frequency.

Results

Figure 1 shows the relative spectral responsivity of the carbon nanotube pyroelectric detector in the 0.9 μm to 14 μm wavelength range, normalised at 1.6 μm . The error bars shown in Figure 1 represent the 1σ uncertainty of the measurements. The plot shows that the relative spectral responsivity was approximately flat in the 1.6 μm to 14.0 μm wavelength range. This, in turn, means that the absorptivity of the MWNT coating was also flat because that is the main parameter governing the relative spectral responsivity of thermal detectors [1]. For wavelengths below 1.6 μm the response of the detector decreased monotonically with wavelength down to 0.9 μm , the shortest wavelength studied. This behaviour confirms data previously reported by Lehman et al [5]. A similar behaviour has also been observed in some other good-quality metal-black coatings such as silver-black and

some gold-black coatings. No measurements were attempted for wavelengths longer than 14 μm because the Signal-to-Noise Ratio (SNR) of the measurements was extremely poor due to the poor Noise Equivalent Power (NEP) of the detector and the low radiant power coming through the double grating monochromator.

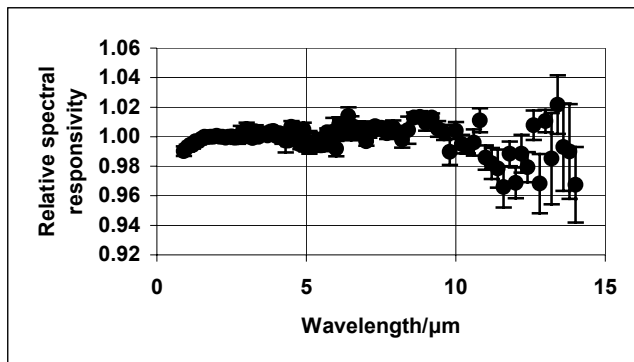


Figure 3: Relative spectral responsivity of the MWNT pyroelectric detector normalised at 1.6 μm . Error bars represent the 1σ uncertainty of the measurements.

The DC equivalent absolute spectral responsivity of the MWNT pyroelectric detector in combination with the trans-impedance amplifier with 10^8 V/A gain at 1.6 μm for a 70 Hz modulation frequency was measured by comparison with NPL standards to be 9.03 V W^{-1} . The Noise Power Spectral Density (NPSD) of the detector/amplifier combination at 70 Hz was measured to be $1.46 \mu\text{V Hz}^{-1/2}$. Ignoring the noise contribution due to the transimpedance amplifier (the noise was dominated by the pyroelectric detector), the specific detectivity (D^*) of the carbon nanotube pyroelectric detector at 1.6 μm at 70 Hz was estimated to be $1.82 \times 10^6 \text{ cm Hz}^{1/2} \text{ W}^{-1}$. This is a relatively poor value compared to gold-black-coated LiTO_3 pyroelectric detectors which have typically two orders of magnitude higher D^* values. The low D^* value of the MWNT pyroelectric detector was not unexpected because this detector was based on a 250 μm thick LiNbO_3 crystal. The thicker crystal (typically a factor of 5 times thicker than LiTO_3 pyroelectric detectors studied previously) in combination with the poorer pyroelectric characteristics of the LiNbO_3 crystal can account for most of the observed difference. Furthermore, the coating deposition required the LiNbO_3 crystal to be heated to temperatures in excess of 300 $^\circ\text{C}$ [5], which may also have led to a deterioration of the its pyroelectric properties.

Theory predicts that the absorbance of MWNT coatings will depend on the fill factor and will exhibit some dependency on wavelength. The results of this study show that the relative spectral responsivity of the MWNT coated pyroelectric detector and therefore the absorbance of the MWNT coating does not exhibit any wavelength dependency in the 1.6 μm to 14 μm wavelength range. This observation can only be explained by the carbon nanotubes being long and crooked as well as being poorly aligned. This is supported by the shape of the nanotubes recorded by SEM and shown in Figure 2.

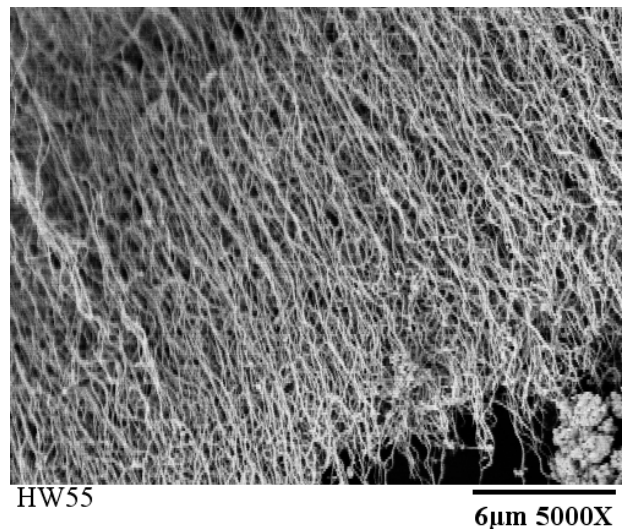


Figure 2. Scanning electron microscope image of the MWNT coating

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