

# Carbon nanotubes based coatings for laser power and energy measurements using thermal detectors

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**Abstract:** We describe the spectral responsivity, spatial uniformity, and other properties of thermal-detector coatings based on carbon nanotubes. Such coatings may form the basis of the next generation of standards for laser power and energy metrology.

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The primary standards for all of our laser power and energy measurements (and hence measurement traceability for such measurements in the United States) are based on thermal detectors. Thermal detectors for high accuracy laser measurements have broad and uniform spectral responsivity as well as relative variations in spatial uniformity less than 1 %. In principle, the response as a function of wavelength (the spectral responsivity) of thermal detectors depends on the variation of reflectance of the detector coating as a function of wavelength. We have evaluated a bulk form of single-wall carbon nanotubes (SWNTs) as a thermal detector coating.

During the last 50 to 100 years, thermal coatings have been developed from carbon-based paints, diffuse metals (for example, gold black), and oxidized metals. Gold-black coatings are capable of very low reflectance, ranging from the wavelengths of 0.2  $\mu\text{m}$  to beyond 50  $\mu\text{m}$ . However, such coatings are vulnerable to damage at moderate power density and from physical contact, in addition to aging and hardening.<sup>1</sup>

Carbon nanotubes are known to be lightweight inert materials with high thermal conductivities<sup>2</sup> and experimental evidence indicates that carbon-nanotube-based coatings may be superior to present alternatives. We have undertaken the evaluation of carbon nanotube coatings by building several pyroelectric detectors, each having a different absorber, and measuring the spectral responsivity, spatial uniformity, and damage resistance. The detectors were 1 cm in diameter and were constructed from 60  $\mu\text{m}$  thick  $\text{LiTaO}_3$ , with chromium-gold electrodes. The first detector was coated with gold-black, and provides a reference as being the state of the art for such a device. The other detectors were evaluated having bare-metal electrodes, or with various layers of purified laser-generated SWNTs.

Several features of the SWNT coatings are apparent from our measurements. The absorption efficiency of both SWNT coatings is greater than that to be expected for the bare (uncoated) detector. Furthermore, the detector's response (and hence the absorption SWNT coatings) shown in Fig. 2 varies less than 5 % as a function of wavelength from 600 nm to 1550 nm. We are encouraged simply because the nanotube-based coatings do not compromise the detector performance. But we are especially encouraged because the SWNT-coated detectors are somewhat spectrally uniform, and we expect that when we achieve an optimized SWNT coating, the detector responsivity will surpass the performance of the gold-black coated detector.<sup>3</sup>

Our future goals for this work include hot wire chemical-vapor-deposition (HWCVD)-controlled growth of oriented MWNTS directly onto a detector substrate.<sup>4</sup> In addition, we will incorporate other elements to pure carbon nanotubes to modify the detector behavior. Gold or other reflective metals might enhance the spectral uniformity at longer wavelengths. Diamond may be incorporated to enhance the material properties, such as increased thermal conductivity and damage resistance.<sup>5</sup> With this capability we intend to create the basis of the next generation of our laser calorimeters, radiometers, thermopiles, and pyroelectric detectors.

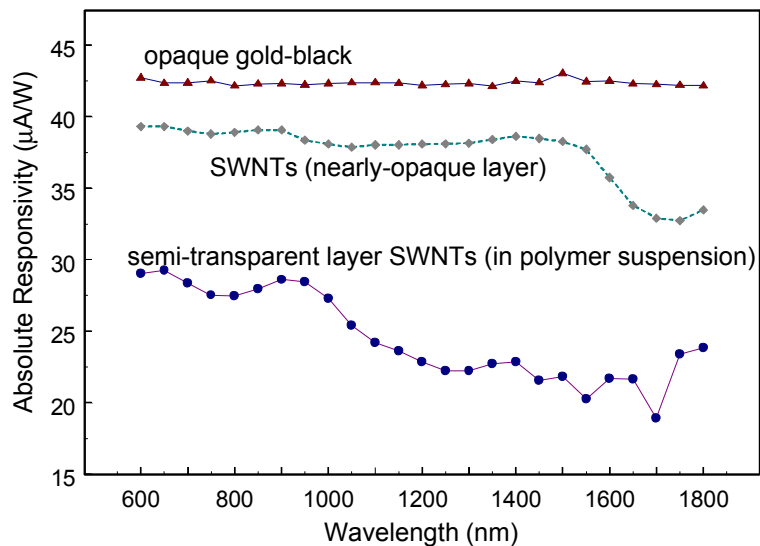


Figure 1. The plot depicts the spectral responsivity of four pyroelectric detectors. The detectors are nearly identical with the exception of the thermal coating. For this measurement, the relative expanded uncertainty is 1.24 %, where the level of confidence is approximately 95 %.

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