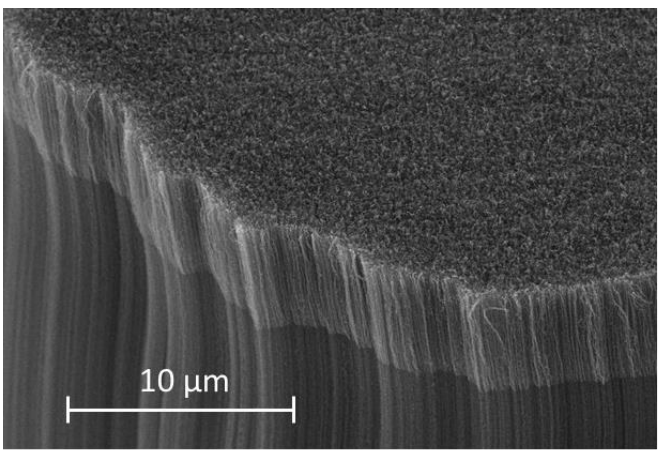
# Carbon Nanotube-Based Coatings Provide Extremely-High Surface Emissivity for Improved Radiometric Calibration and Stray Light Control

## OVERVIEW

Santa Barbara Infrared (SBIR) and Surrey NanoSystems (SNS) have partnered to produce a line of extended-area blackbody sources with exceptionally-high emissivity and radiometric accuracy. The emitter plates in these sources feature a carbon nanotube (CNT) based coating with remarkable light-trapping properties. This ultra-black coating was developed by SNS to satisfy a broad range of applications requiring surfaces with extremely low reflectance. The resulting blackbody sources provide more accurate infrared (IR) radiometric calibration than previously achievable by drastically reducing errors due to reflected IR light from the surrounding environment. SBIR and SNS are also offering the coating for applications to reduce stray light in optical and IR imaging systems.

## LOW REFLECTANCE COATINGS

**Vantablack**®: SNS has recently developed two types of CNT-based coatings. The Vertically-Aligned Nanotube Array (VANTA) or Vantablack® coating consists of a forest-like structure of aligned, equally-spaced, high-aspect-ratio carbon nanotubes. The spacing of the tubes is such that virtually all of the light arriving at the surface enters the spaces between the tubes and is absorbed after multiple reflections between neighboring tubes. The scanning electron microscope (SEM) photos in Figure 1 (left) show the vertically-aligned nature of the coating at magnification. Vantablack® nanotubes are grown in a chemical vapor deposition (CVD) reactor. The coating can be grown on complex 3-D shapes, with optimization of the CVD plasma distribution for best results.



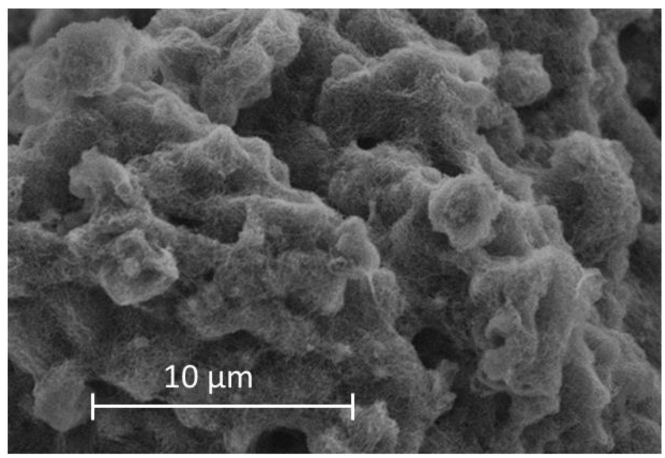




**Figure 1. SEM image of Vantablack® coating at magnifications of 2500x (left) and Vantablack-S at 2750x (right). Compare the precise organization of the vertically-aligned Vantablack® nanotubes (~30 µm tall) to the random orientation of the Vantablack-S tubes.**

**Vantablack-S:** SNS has also developed a black coating compatible with aerosol application which has performance approaching that of the CVD-grown Vantablack®. Vantablack-S is a versatile coating based upon similar CNT technology. The proprietary material and application process results in a coating with enhanced absorption properties and a passive surface that repels water and other contaminants. Figure 1 (right) shows a ~15,000x SEM image of a Vantablack-S coated sample that reveals its random nanotube orientation and "forest canopy-like" surface structure. Vantablack-S has extremely low reflectance in the visible spectrum (less than 0.2% at 700nm), and provides state-of-the art performance out through the SWIR, MWIR and LWIR spectral ranges. The coating has been shown to have good resistance to water adsorption, thermal shock, mechanical shock and vibration. The aerosol application of the Vantablack-S coating provides a significant cost reduction compared to the CVD-grown version, and also allows much larger and more complex samples to be processed. Also, a lower process temperature allows application to a wider variety of materials, including many polymers.

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## ENHANCED IR RADIOMETRIC CALIBRATION ACCURACY AND STRAY LIGHT CONTROL

Both types of carbon nanotube coatings are very broadband absorbers and have excellent optical properties from the near-IR out to wavelengths beyond 15 µm. Figure 2 compares the spectral emissivity of Vantablack-S to a commonly-used, high-emissivity coating. This high absorbance makes SBIR's extended-area blackbody sources with Vantablack-S coated emitter surfaces ideal for high-accuracy for radiometric calibration in both the MWIR and LWIR spectral regions.

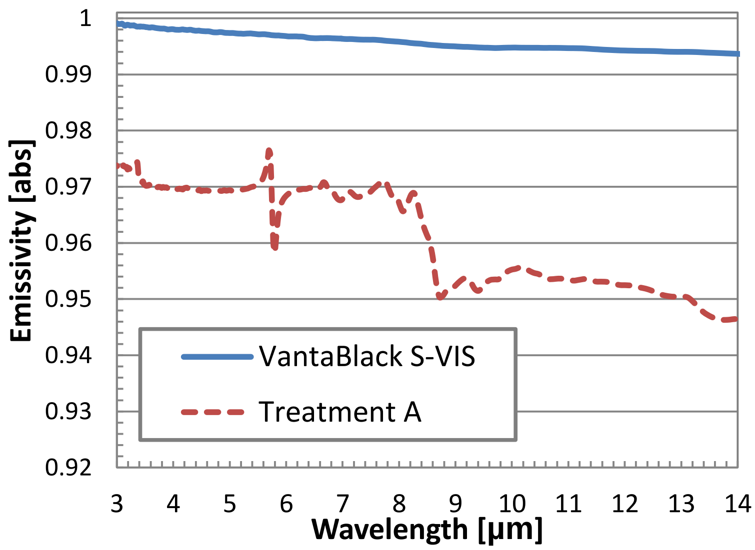


**Figure 2. IR spectral emissivity (3-14 µm) of Vantablack-S compared to Treatment A, a paint commonly used for extended-area blackbody emitter plates.**

Precision-controlled "blackbody" emitters are commonly used as calibration sources for IR sensors. A metal source plate is coated with a high-emissivity black paint to make it as close to an ideal radiator as possible, and then controlled to a known temperature. Current paints commonly in use have IR emissivity values in the neighborhood of ~97% (MWIR) and ~95% (LWIR). The total radiance from the surface of such a blackbody plate includes both emitted radiation and radiation that is reflected from the surrounding environment. The total radiance of the surface can be written as:

$$L_{Total} = L\left(T_{plate}\right) * \epsilon_{surf} + E_{env} * (1 - \epsilon_{surf})$$

where $L_{total}$ is the total radiance leaving the surface, $L(T_{plate})$ is the radiance of an ideal blackbody at temperature $T_{plate}$, $\epsilon_{surf}$ is the emissivity of the surface coating, and $E_{env}$ is the irradiance from the environment that is striking the blackbody surface. The temperature of the plate and the emissivity of the surface are usually well known, with temperature measurement accuracy ~10 mK and emissivity accuracy to ~0.25%. However, the irradiance of the environment onto the blackbody surface is typically not well known, and this contribution can be a major driver of the absolute radiometric error in a calibration system. Consider a blackbody at 20°C in a 23°C environment. The apparent radiometric temperature of a blackbody surface painted with Treatment A from Figure 2 in the MWIR region (97% emissivity), would be 20.094°C. The apparent temperature of a blackbody coated with Vantablack-S (MWIR emissivity > 99.7%), would be 20.009°C, leading to an order-of-magnitude lower radiometric error due to surface reflection.

The low reflectance of the CNT-based coatings also makes them ideal for reducing stray light in both visible and infrared optical systems. The wider range of use and easier application of the Vantablack-S coating makes it particularly attractive for use in these systems. The coatings are also applicable to situations where particle contamination is a concern. The Vantablack® coating has recently been through partial space qualification, including shock, vibration, thermal cycling and outgassing, and exhibited no particle fallout (PFO) and no significant mass loss. Preliminary testing on the Vantablack-S coating supports similar performance.

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