Novel perfect blackbody sheet having nano-precision surface microtextures for a planar standard radiator

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We present a novel perfect blackbody sheet from an elastomer. Nano-precision microtextures embossed on a PDMS sheet exhibit an extremely low reflectance of ≲0.001 (an absorptance of ≳0.999) over the entire thermal infrared wavelengths (typically 8 µm – 15 µm). In addition, this sheet maintains its high resilience to direct contact, tape-pulling, repeated bending, and scratching. Our tough planar blackbodies offer unprecedented applications including perfect standard radiators/absorbers, particularly with respect to thermal infrared detector/imager calibration.

INTRODUCTION

Low reflectance absorber materials have various applications including stray light suppression, light energy harvesting or management. Vertically aligned carbon nanotubes exhibit a very low reflectance of <0.001 [1–3]. Despite their excellent optical performance, they are too fragile to be used in an open environment.

We have developed a novel perfect blackbody sheet from polydimethylsiloxane (PDMS) having a microtextured surface, fabricated via high-energy heavy-ion manufacturing and replica molding [4]. The PDMS blackbody sheet exhibits an extremely low reflectance of ≲0.001 across the entire thermal infrared wavelengths (typically 8 µm – 15 µm). This blackbody sheet is highly durable for field use, whereas other porous nano-photonic absorbers are usually susceptible to mechanical contact.

This blackbody sheet is based on a micro-cavity strategy [4–6], in which incident light experiences multiple bounces, resulting in reduced reflectance. According to the finite differential time-domain (FDTD) simulation, the cavity aspect ratio (h/r, h: depth, r: radius) should be >3, and the cavity opening diameter should be on par with or greater than the longest wavelength of interest when targeting <0.001 total hemispherical reflectance [4–6]. We used the high-energy heavy-ion beam to fabricate such high-aspect-ratio micro-cavities on a substrate [4,5]. The microfabricated substrate can be used for replica molding, which more than compensates for the availability of a heavy ion beam facility. Therefore, we can scalably fabricate planar perfect blackbody replicas for the large-area application, including perfect standard radiators/absorbers, particularly with respect to thermal infrared detector/imager calibration.

EXPERIMENTS AND RESULTS

Fig. 1 shows the fabrication process of a perfect blackbody sheet from a microtextured elastomer. CR-39 plastic substrates were irradiated by swift heavy ion beam of Ne 200 MeV from a cyclotron accelerator of Takasaki Ion Accelerators for Advanced Radiation Application (TIARA) at ion exposure density of ~10^6 cm^{-2}. After that, the irradiated substrates were etched in 6.4 N NaOH solution at 70 °C for ~10 h to fabricate micro-cavities (etch pits) on their surface. Fig. 2 (left) shows the fabricated micro-cavity mold of a large area (80 mm × 100 mm). By using this CR-39 master mold, we replicated large-area microtextured sheets from PDMS with carbon black filler. The resultant sheet is shown in Fig. 2 (right). The mid-infrared (8 µm – 15 µm in wavelengths) hemispherical reflectance was extremely low (≲0.001), confirmed by FT-IR spectrometry with an integrating sphere (Fig. 3). Good reproducibility was confirmed as well.

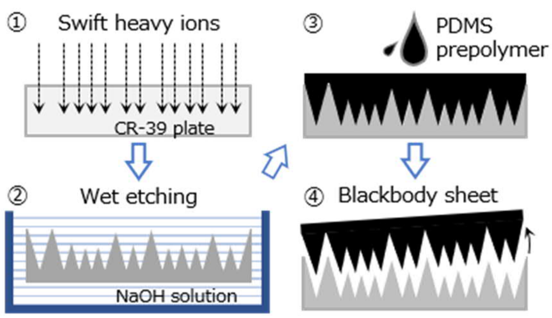

Figure 1. Fabrication process of a perfect blackbody sheet from a microtextured elastomer. ©AIST.

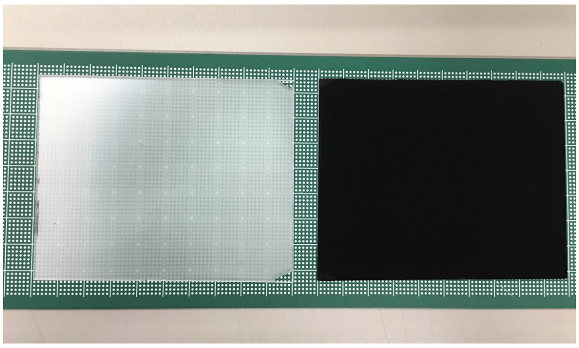

Figure 2 (left) Microtextured mold via swift heavy ion manufacturing, and (right) its replica from PDMS with carbon black filler.

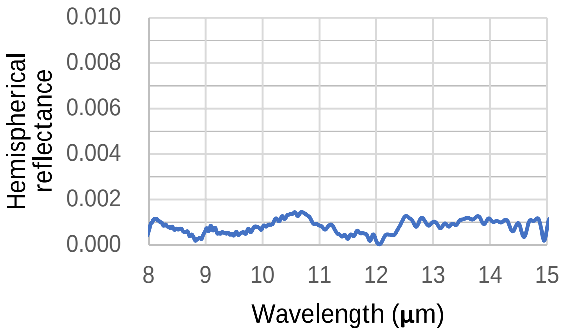

Figure 3 Spectral hemispherical reflectance of the PDMS blackbody sheet.

The appearance of the PDMS blackbody sheet seemed to be uniform over the entire area. The uniformity of the hemispherical reflectance is now under quantitative investigation.

Our PDMS blackbody sheets would serve as a planar standard radiator to calibrate thermography cameras. The advantage is that the emissivity correction can be extremely small ($\Delta\varepsilon/\varepsilon$ ~ 0.001), equivalent to the temperature uncertainty ΔT < 50 mK at room temperature (~23 °C). More practically, we can use the microtextured PDMS sheets as blackbody tapes, which would enable the accurate radiation thermometry of an arbitrary surface. It should be noted that the thermal conductivity of blackbody sheets is also a key issue for these precision applications.

SUMMARY

We have developed a novel perfect blackbody sheet from microtextured PDMS. They exhibit an extremely low reflectance of ≲0.001 across the entire thermal infrared wavelengths while maintaining their high durability and uniformity. Our novel blackbody sheets would be suitable for a planar standard radiator to calibrate a thermal infrared detector/imager.

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