Micro-structured Silicon Spectral Emissivity at Intermediate Temperatures from 100°C to 350°C

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Abstract— This work presents a detailed experimental investigation of the spectral and temperature dependence of emissivity in microstructured highly doped silicon, commonly referred to as Black Silicon (BSi). Leveraging the Cryo-DRIE process, we fabricated nanostructured BSi with a typical feature height of 5 µm on a highly doped Si substrate ($0.001\,\Omega\cdot\text{cm}$). Direct emissivity measurements were performed over the mid-infrared spectral range (2.5–20 µm) and across a temperature range from 100°C to 350°C using a custom-built setup, which was cross-validated using a vertically aligned carbon nanotube (VACNT) blackbody reference. Flat highly doped Si samples of identical resistivity were used as a reference.

Our results confirm that BSi exhibits near-unity emissivity up to 10 µm, even at elevated temperatures, due to strong light-trapping, multiple scattering effects, and possible coupling with surface plasmon polaritons (SPPs). While flat Si also shows increasing emissivity with temperature, its values remain significantly below those of BSi. For instance, the total hemispherical emissivity of BSi increases from ~ 0.95 at 150°C to ~ 0.98 at 350°C, compared to ~ 0.73 to ~ 0.85 for flat Si. Interestingly, a plateau in total emissivity emerges at high temperatures for both flat and structured Si, suggesting a convergence mechanism potentially linked to doping-induced changes in carrier concentration and optical absorption.

Monte Carlo simulations were performed to assess the uncertainty in emissivity values, incorporating spectral signal fluctuations, reflectivity, and temperature uncertainties. The results were compared with room-temperature absorptivity data obtained by Fourier Transform Infrared spectrometer (FTIR), as well as with reference values from the literature.

This study provides the first direct temperature-resolved emissivity data for BSi, demonstrating its thermal stability and high performance under operational conditions relevant to infrared emitters, thermophotovoltaic systems, and radiative heat management technologies. These findings lay the groundwork for the design of next-generation thermal metamaterials with tailored radiative properties.

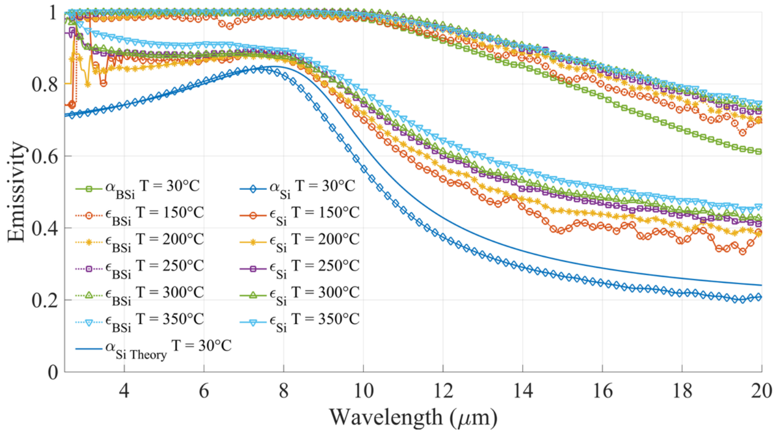

Figure 1: Spectral emissivities measured for both BSi and flat Si at different temperatures and compared to the corresponding indirect values of their spectral absorptivity. The solid blue line represents the theoretical simulation of the spectral absorptivity of silicon with a resistivity of $0.001\,\Omega\cdot\text{cm}$.