Design of Near-Perfect Absorption with Random Particulate Materials

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Tailoring the spectral radiative properties of materials is essential for meeting modern challenges related to energy technologies. For instance, applications such as thermophotovoltaics, or energy-efficient gas sensing need to be supplemented by materials that exhibit spectral selectivity: a peak of absorptivity/emissivity around the semiconductor bandgap, or the resonant frequency of the molecule to be detected, respectively.

The prevailing approaches for the control of the radiative properties mainly rely on nanostructured materials such as photonics crystals, metasurfaces, stratified media, etc. Because of their ability to manage coherent wave phenomena through periodic patterns, these ordered materials have become a key component of modern thermo-optics.

On the other hand, though they are easier and less expensive to fabricate, disordered materials are infrequently contemplated as a competitive means to achieve spectral properties.

In this contribution, we realize the design of random particulate media that exhibit near perfect absorption at a prescribed frequency and no absorption elsewhere.

Our design is based on enlarging the scope of the critical coupling concept (usually associated with ordered materials supporting guided resonances) to suspensions of randomly distributed nanoparticles. The critical coupling is established between two types of particles, one of which is absorbing and one lossless. We will focus on systems of particles arranged in the shape of a thin layer. Statistical considerations, including ensemble average and fluctuation of the electromagnetic field, show that around 95% of the radiation incident on the layer is absorbed. The quantitative calculation of this absorptance has required specific numerical developments which, in addition, allowed us to observe that the incident radiation is not reflected by impedance mismatch, and propagates in phase opposition with the field scattered forward by the optimized systems of particles, resulting in almost vanishing reflectance and transmittance.