Broadband perfect absorbers based on copper nanoparticles thin films

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Nowadays, we have learned how sunlight can be absorbed in a low-cost, high-efficiency way by using solar thermal collectors (STCs). Due to the global energy crisis, STC studies intensified for a few years. STCs have been used in many applications, like agriculture [1], electricity generation [2], and many more [3]. However, it remains a prime challenge to improve the performance of the absorber part of the STC by examining different types and optimizing the material used.

In this study, which combines experimental theoretical, and numerical research, we investigate nanoparticle-based multilayer thin-film broadband perfect absorbers. Copper is used as the main nanoparticle material due to its low-cost and much higher abundance than the previously used noble metals eg. gold and silver. Also, few studies imply that copper nanoparticles could absorb more sunlight than alternative metals. The broadband perfect absorber consists of a thin film comprising copper nanoparticles randomly arranged in space and at a sufficiently high density. The thin film containing the nanoparticles is placed above a metallic ground plate separated by a thin dielectric spacer.

The entire device is simulated using a multiscale-modeling approach that starts by considering an individual nanoparticle, studies the response of clusters made from many randomly placed nanoparticles, and explores reflection and transmission from a periodic arrangement of such larger clusters in the entire layer stack. The approach is efficient and predictive, so parameters characterizing optimal samples while considering experimental constraints could be identified. Parameters for optimal samples are passed on to the experimental steps for fabricating dedicated samples. In this case, final devices are fabricated using the magnetron co-sputtering method. Various techniques are used for comprehensive structural and optical characterizations. Finally, we explore the devices concerning their integration into an STC. Selected results are shown in Fig. 1.

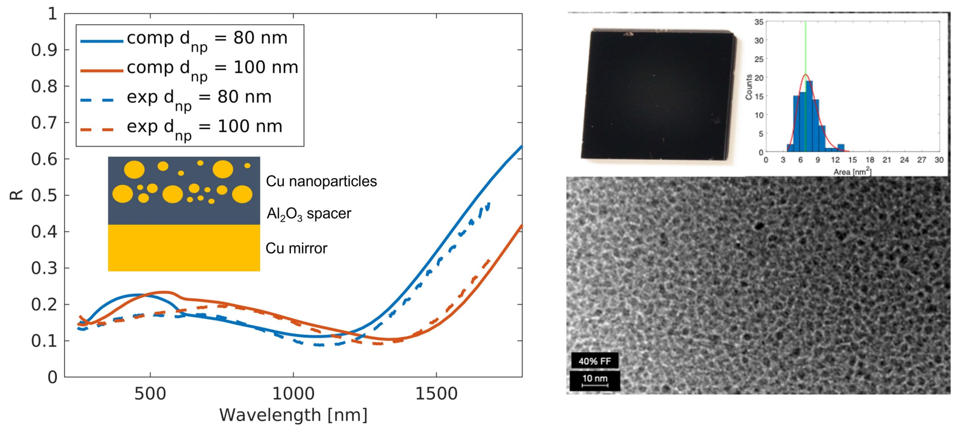

Fig. 1: (left) Reflectance curves of selected broadband absorbers comprising copper nanoparticles in multiple films with a gradient filling factor. The solid line represents the simulation results, and the dashed line those from experiments. d_{np} is the total thickness of a layer with nanoparticles. The sketch of the thin film layers is shown in the inset. (right) TEM micrograph of fabricated films with copper nanoparticles with 40% filling factor. The top insets depict the top-view of a fabricated sample and the measured size distribution of the nanoparticles as considered also in simulations.

Our sample can absorb almost 90% of light ranging from ultraviolet (UV) to near-infrared (NIR) spectrum. We compare the absorptance curve of the simulated and fabricated samples, illuminated with unpolarized light. It can be confirmed that the simulation compares well with the experiment's results. Also, we learn that light absorption on the thin film can be made stronger when considering nanoparticles with increasing gradient filling factor.

Example References

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