Design and roll-to-roll nanofabrication of plasmonic solar light absorbers

M. Serra González, M. Keil, R. J. Taboryski
DTU Nanolab, Technical University of Denmark, Copenhagen, 2800 Kgs. Lyngby
msgo@dtu.dk

N. Okulova
Inmold A/S, Copenhagen, 2990 Nivå

In the recent years, the scientific community as well as the industry have pushed to find alternatives for more sustainable lifestyles. Leveraging renewable sources for diverse energy applications has been a central target of the latest research. A solution for water heating through solar energy is proposed in this work by means of absorption enhancement in a plasmonic metasurface fabricated by a roll-to-roll large scale method[1], Fig 1 a)-c).

For this purpose, a silicon master was fabricated containing a hexagonal arranged array of nanopillars using DUV lithography. A combination of novel resolution enhancement techniques -dipole illumination, triple cross-exposure and assist feature lines on the mask design[2]- allowed the DUV Stepper tool to improve the resolution from the manufacturer's specifications of 250 nm, down to 125 nm for a stable array and 80 nm for single pillars. Deep Reactive Ion Etching followed for the pattern transfer from the resist into the silicon wafer, achieving vertical sidewalls of 200 nm depth, enough for a stamp-like replication. Roll-to-roll processes were used both for the large-scale reproduction of the nanopattern and the aluminum metallization due to its low-cost and fast nature. In parallel, finite element simulations were conducted to obtain a theoretical and physical model that corroborates the fabricated structures, Fig 2.

The conducted optical measurements of the samples show that the better performing fabrication parameters are the arrays with 340 nm pitch exposed with 80 J/m^2 dose Fig 1 d). These plasmonic metasurfaces present a high absorption of 85% in the solar peak of irradiance, at 500 nm wavelength. A comparison of rectangular and hexagonal arranged nanopillars is investigated. Finally, the measurements and the simulated results are in good agreement, and they validate the larger absorbing band of the hexagonal plasmonic structures in the solar wavelength range.

---

[1]Murthy, S., Pranov, H., Feidenhans'l, N. A., Madsen, J. S., Hansen, P. E., Pedersen, H. C., & Taboryski, R. J. (2017). Plasmonic color metasurfaces fabricated by a high speed roll-to-roll method. Nanoscale, 9(37), 14280–14287. https://doi.org/10.1039/c7nr05498j

[2] Keil, M., Wetzel, A. E., Wu, K., Khomtchenko, E., Urbankova, J., Boisen, A., … Taboryski, R. J. (2021). Large plasmonic color metasurfaces fabricated by super resolution deep UV lithography. Nanoscale Advances, 3(8), 2236-2244. https://doi.org/10.1039/d0na00934b

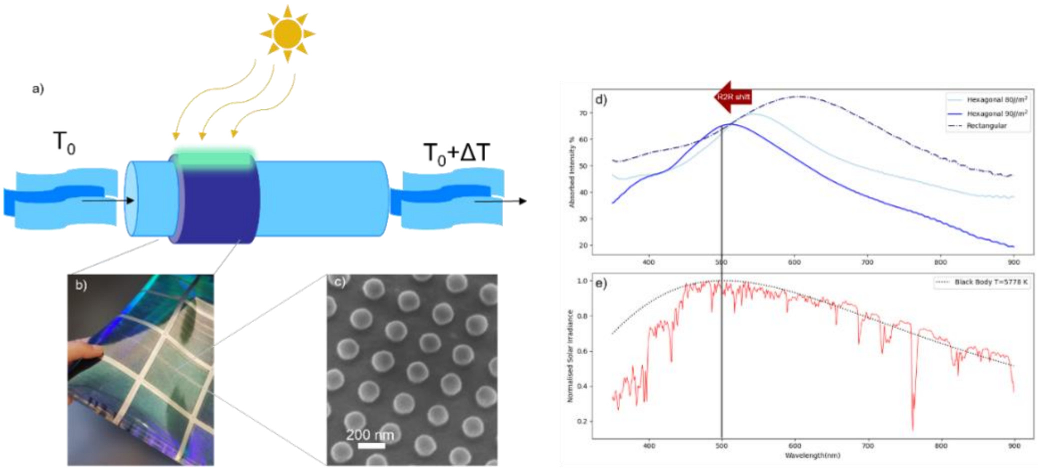

Figure 1 a) Sketch of the water pipe fabricated with the plasmonic metasurface material, shown in b). c) A SEM micrograph showing the nanostructured surface of the rectangular arranged array. d) Absorption of fabricated metasurfaces comparing hexagonal/rectangular array arrangement and lithographic dose (e-beam metallized). e) Solar irradiance spectrum peaking at the visible wavelength range, 500 nm. A 50 nm blueshift was observed when comparing R2R and e-beam metallization methods.

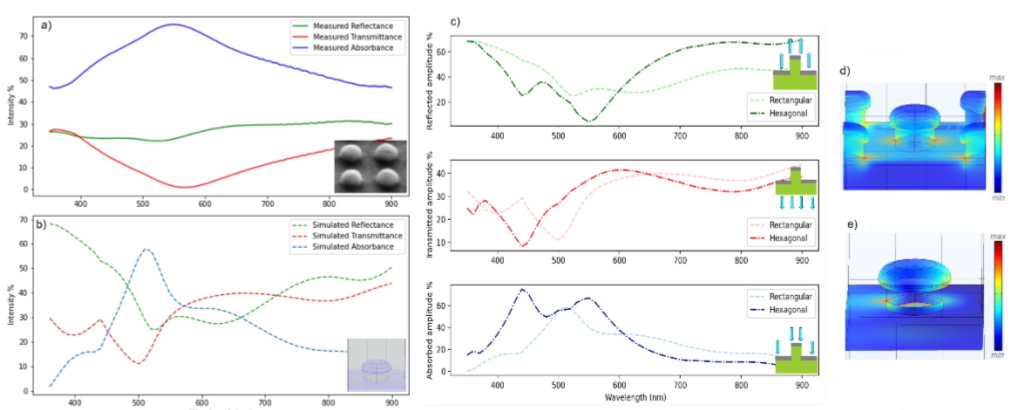

Figure 2 Comparison of the measured a) and simulated b) optical performance of the metasurface. C) Comparison of the nanopillar array geometry on the optical performance. Simulated hot-spots on the nanopillars for the hexagonal d) and rectangular e) geometries.