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Processing and characterization of photonic crystals on flexible substrates for light absorption enhancement in solar cells

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Motivation

- High pressure to innovate because of need for renewable energy sources
- Thin film solar cells have some advantages but also drawbacks:

Saving costs | Saving material | Less efficiency

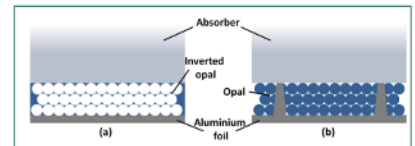
- Photon management can unwind the drawback in light absorption of thin films [1]

- **Scattering structures:** max. path length enhancement for silicon ≈ 50 [2]
- **Resonant structures:** max. path length enhancement for silicon ≈ 2980 [2]
- 3D photonic crystals such as artificial opals combine scattering and resonant properties which can be easily tuned.

Backside foil

- Realization of resonant optical path enhancement by fabrication of artificial opals on a flexible aluminum substrate as a backside structure for solar cells.
- Advantages of such a photonic crystal backside foil: [3,4]

- Easy integration into existing solar cell concepts because of separated production.
- Aluminum substrate acts as a backside mirror and can serve as an extensive back side contact.
- An additional PET-layer at the backside provides flexibility, electrical isolation and protection against environmental influences.

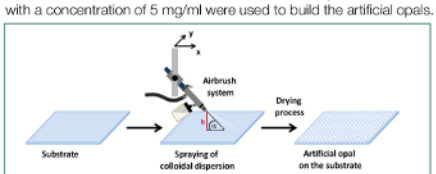


3D photonic crystal implemented as a backside foil to a solar cell taken from [3]

Production of artificial opals on flexible substrates

Processing technique: Spray coating

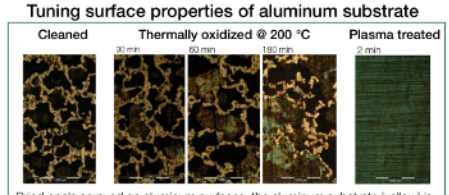
- PMMA-colloids with a diameter of 600 nm in an aqueous solvent with a concentration of 5 mg/ml were used to build the artificial opals.



Schematic illustration of production of the artificial photonic crystals taken from [3]

- Spray coating is an adequate technique for the production of large opaline structures. It is cheap, fast, and scalable and therefore suitable for industrial application.

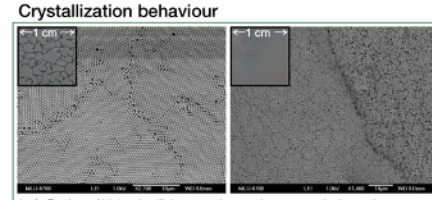
Tuning surface properties of aluminum substrate



Dried opals sprayed on aluminum surfaces: the aluminum substrate (yellow) is covered with amorphous (dark) an crystalline (green) areas of colloids

- Short oxygen plasma treatment (6 sec to 2 min; 300 W power) leads to suitable surface properties caused by removal of hydrophobic contamination and the forming of an hydrophilic aluminum oxide layer [5]; thermal oxidation has low influence on surface properties.

Crystallization behaviour

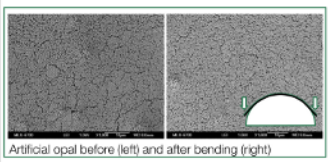


Left: Region of high cristallinity on an incomplete covered, cleaned aluminum substrate (inset). Right: Completely covered plasma treated substrate (inset) with regions of high and low cristallinity

- With spray coating large area photonic crystals can be produced.
- The quality of the crystal even on completely covered substrates is not homogeneous.

Mechanical stability

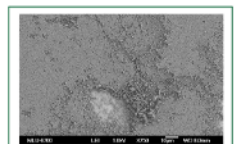
- Bending of the substrate within a radius of 15 mm has no apparent influence on the opal.



Artificial opal before (left) and after bending (right)

- Adhesive force between the colloids and the aluminum substrate is sufficiently high to create a stable and flexible photonic crystal.

- Squeezing the opaline structure to a polymer substrate leads to peeling off the colloids.

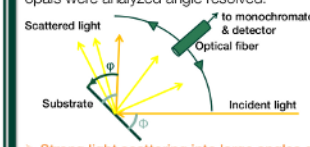


Peeled-off opals after squeezing

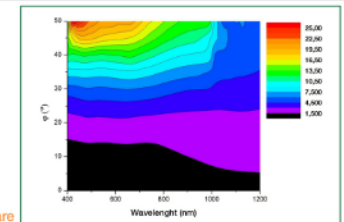
- To establish a roll-to-roll production technique further preparation of the opaline structures is needed.

Optical characterization

- The reflection properties of the artificial opals were analyzed angle resolved:



- Strong light scattering into large angles of deflection φ.
- Optical properties improved compared to bare aluminum substrate.
- Optical path length enhancement expected when applied to thin film solar cell.



Angle-resolved reflection of artificial opal normalized to aluminum substrate; angle of incidence Φ= 55 °

Conclusion & Outlook

- An adequate surface preparation was found which enables the production of large area photonic crystals by spray coating.
- The artificial opals show partly high crystallinity, yet regions with low degree of crystallinity are still considerable.
- Further investigation of wide-angular diffraction has to be done in order to improve optical properties.
- To produce a conductive photonic crystal the opaline structure will be inverted by atomic layer deposition of Al:ZnO.
- Electrical characterization and cell integration of the photonic crystal backside foil is planned.

References & Acknowledgements

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This work has been carried out by the Infravolt- and Struktursolar-Consortia. Financial support by the German Federal Ministry of Education and Research (BMBF) within theses projects is gratefully acknowledged.

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung