Automated spray coating process for the fabrication of large-area opaline structures on textured substrates

Daniela Schneevoigt[1], Frederik Bub[1], Alexander N. Sprafke[1] and Ralf B. Wehrspohn[1,2]

[1]Institute of Physics, Martin-Luther-University Halle-Wittenberg, Germany
[2]Fraunhofer Institute for Mechanics of Materials IWM, Halle, Germany

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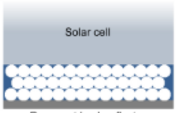
Universität Halle-Wittenberg

Motivation

3D Photonic crystal [1,2] as back reflector for thin film solar cells

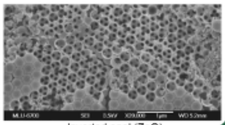


Resonant back reflector with 3D PhC

3D Photonic crystal (PhC) at the rear side of the absorber: Combines reflective and diffractive features

→ Elongation of light path [3,4,5]
→ Higher material efficiency

Material system: Opaline structures (e.g. inverted opals)


Inverted opal (ZnO)

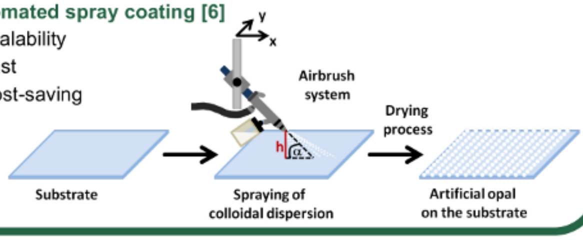
Fabrication technique for integration of 3D PhC in solar cell production process: **Spray coating**

Spray coating of artificial opals

Up to now: Dip coating, knife coating or spin coating (small-scale and time-consuming)

Now: Automated spray coating [6]

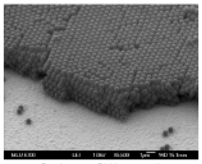
- Scalability
- Fast
- Cost-saving

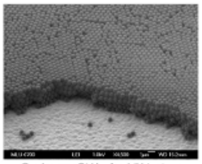


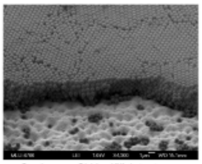
Opaline structures on textured substrates

Substrates: **µc-Si:H** (ca. 1000nm) on smooth and textured **TCO** (Al:ZnO)
→ by FZ Jülich

Process parameters:
- Size of PMMA colloids: **601 nm**
- Solid content of colloidal dispersion: **5% w/v**
- Dispersion agent: **30% 2-propanol + 70% water**
- Number of monolayers: **1-10**


Opal on µc-Si:H - smooth


Opal on µc-Si:H - AsahiU texture


Opal on µc-Si:H - Jülich texture

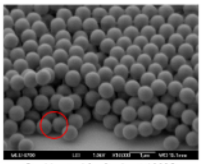
Crystallization of high-quality extensive opals on different µc-Si surface textures via spray coating successful

Inversion of the opals

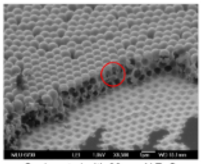
1. Step: Heating of the opals

Heating slightly below the glass temperature of PMMA: : **2 min at 100°C**

→ Bond bridges between individual spheres increase stability of the opal


Opal heated for 2 min at 100°C

2. Step: Coating with Al:ZnO


Opal coated with 80 nm Al:ZnO

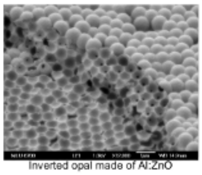
Conformal coating via Atomic Layer Deposition (ALD): **80 nm Al:ZnO**

→ Good infiltration of Al:ZnO into opal structure
→ Bond bridges between spheres lead to openings in Al:ZnO layer

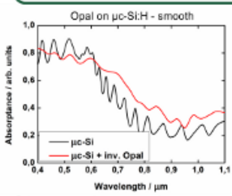
3. Step: Removal of the opal template

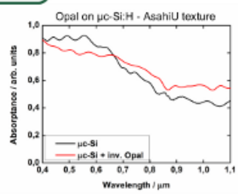
Calcination of the PMMA for **6h at 450°C** in ambient atmosphere

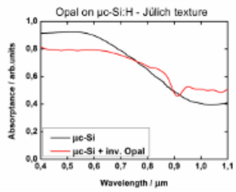
→ Complete removal of the opal template


Inverted opal made of Al:ZnO

Analysis of optical properties

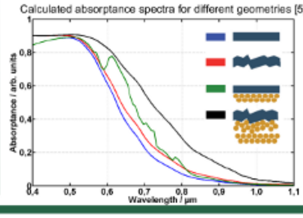






Observations:
- **Inverted opal increases absorptance for long wavelengths**
- **But:** Decrease in absorptance for short wavelengths
- **Overall change in absorptance from 400 - 1100 nm:** +16% for smooth µc-Si texture, +4% for AsahiU texture and -2% for Jülich texture
- **For wavelengths >900 nm:** Strong contribution of absorptance in Al:ZnO front contact

Calculated absorptance spectra for different geometries [5]



Comparison to theory:
- Enhancement of absorption for long wavelengths expected ✓
- No change of absorptance for short wavelengths expected ✗

→ Needs to be investigated

Conclusion & Outlook

Successful fabrication of large-area opaline structures on smooth and textured µc-Si:H substrates by an automated spray coating process

- Inverted opal on all textures increases absorptance for long wavelengths
- Enhancement of entire absorptance for smooth µc-Si and for AsahiU texture

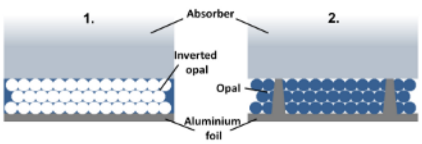
→ Optical characteristics promising for application in light management for solar cells

Next steps:
- Deposition of metallic back contact
- Electro-optical characterization

Concept

Implementing the structure as a backside foil for solar cells

Possible layouts:
1. PhC made of el. conductive material
→ large-scale backside contact
2. PhC made of el. isolating material
→ localized el. contacts by laser-firing the aluminium foil



Independent fabrication of foil cuts down damaging impacts on the absorber material

Patent DE102011112696 (A1)

References & Acknowledgements

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[6] A. N. Sprafke, D. Schneevoigt, S. Seidel, S. L. Schweizer, R. B. Wehrspohn, "Automated spray coating process for the fabrication of large-area artificial opals on textured substrates," Optics Express 21 (S3), 528-538 (2013).

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