Microstructured ytterbium-doped multicomponent optical fibers as wavelength converters for photovoltaics

Dr. Valerio Romano Professer for photonics
Applied Fiber Technology Lab AFT, Pestalozzistrasse 20, Burgdorf
Institute ALPS
BFH-TI
ALPS: Competences and Research Groups

Site Burgdorf:

- Laser Surface Engineering
  B. Neuenschwander

- Applied Fiber Technologies
  V. Romano

- Thin Films & Surfaces
  S. Le Coultre

Site Biel:

- Materials Technologies & Heat Treatment
  S. Kleiner

- Material Analysis & Plasma Treatment
  M. Baak, Th. Nelis

- Common Service Lab for Material and Surface Analysis
  J. Zürcher
• Some words about our BFH-UniBE-SIPBB joint fiber production facility
• Sol-Gel granulated silica method
• Ytterbium-doped materials for wavelength conversion
• Guiding clad and guiding core multicomponent, multicore high temperature fibers and intermediate results
Bernese Optical Fiber Production Facility: Drawing Tower

• Was installed at the University of Bern, IAP, ExWi building until summer 2021
• Has been now moved to Biel into the localities of the SIPBB (Innovation Park Biel Bienne)
• It is jointly run by BFH – IAP - SIPBB
Bernese Optical Fiber Production Facility

• The Drawing tower is only one part of the fiber production facility:

- **Fiber design**
  - Ideation of new fibers for novel applications
  - Mathematical modelling

- **Preforms and materials**
  - Preparation of fiber materials
  - Assembling the Preform

- **Fiber drawing**
  - Adapting drawing parameters to materials
  - Handling preforms and fibers

- **Testing / characterisation**

- **Assembling fiber systems (e.g. Fiber lasers)**

Valerio Romano, BFH / IAP

Thomas Feurer, IAP

Sönke Pilz, BFH

Carlos Pedrido, BFH

Andreas Burn, SIPBB

Sönke Pilz, BFH

Dirk Spangenberg, BFH / IAP

Manuel Ryser, IAP

Dunia Blaser, BFH / IAP

Pascal Hänzi, IAP

Alexander Heidt, IAP
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- Materials and preform production as well as fiber handling are in Burgdorf and Bern. They will be moved to the BFH campus as soon as it is finished.

- Additionally to the drawing tower locality at SIPBB each institution has several other labs and facilities related to fiber characterisation, system building (LASER systems) and application testing.
Proprietary preform production technologies

Granulate-in-tube method
Drawing fibers from sand -> evacuating while drawing avoids bubbles

- arbitrary geometries and compositions
- rapid prototyping
- very cost-effective

- high scattering losses (~ 1 dB/m)
- inhomogeneous doping distribution
Improvement: Sol-gel based granulated silica method

Production of doped/codoped granulated silica

**Sol-gel**

solution of precursors → gel → powder

- every grain homogeneously doped
- grain size ~ nm - μm

**Granulate-in-tube**

sintered granulate → vitrified glass core rod → granulate-in-tube preform → fiber

- sintering & milling removal of OH-groups
- grain size ~ 100 μm
- laser-based travelling small-zone vitrification for loss reduction
- cladding drawn directly from granulate

Cooling rates:
75’000 K/s in the first 10 ms;
5’500 K/s in the first 300 ms;
Consequence of thermal quenching in fiber

Test for Crystalline Silica: X-Ray Diffraction Measurement

- a) sintered sol-gel powder before the fiber drawing process
- b) fiber drawn from granulated sol-gel material
- c) fiber drawn from mixed granulated oxides

Quenching the Sol-Gel material after heating at 1600

Crystalline material was amorphized after fiber drawing process

Crystalline

Before Drawing

Amorphous

Fiber from Sol-Gel Granulate

Amorphous

Fiber Directly from Granulates
Example of a fiber application: photovoltaic wavelength converter

- Preamble: two words about «solar» photovoltaics

On the earth:
- 1kW / m²
- Silicon photovoltaics (covers UV – 1.1 μm wavelength)
- Open challenge: using a bigger part of the spectrum more efficiently
- otherwise this technology is mature and is widely and very successfully used
...what if light comes from a burner at lower temperature?

- e.g. synthetic methanol burner (CO2-neutral)
- Typical burning temperature around 1450°C

Challenges:
- emission maximum 1.6µm – 2µm
- direct silicon photovoltaics not possible
- InAs or InGaAs possible but not ideal (costs, ruggedness)
Wavelength conversion by Ytterbium doping

- Approach to use silicon photovoltaics with radiation from Burners at temperatures around 1200°C – 1500°C: Rare Earth doped materials.
- Good candidate: Ytterbium (Yb$^{3+}$ ions in glasses, crystals and ceramics)


**Spectral emittance of Yb$_2$O$_3$ over the spectral range of 0.40 μm – 1.9 μm**

**Spectral emittance of SiO$_2$ with a very small amount of Yb$_2$O$_3$ <0.3 at.% over the spectral range of 0.5 μm – 1.75 μm**
• High alumina and Ytterbium content materials have been developed that can be used as core or cladding material in optical fibers.
Putting Ytterbium ions into a fiber

• We exploit our preform production capabilities and want to put Yb-ions into a short optical fiber

• Why fiber:
  • integration into a waveguide allows to transport produced radiation to PV converter
  • Optical fibers can withstand high temperatures (SiO2 up to 1200°C); high Aluminum oxide content fibers should allow higher temperatures (> 1500°C?)
• Putting Ytterbium into a fiber is a good idea

• It is necessary to separate the radiation production region from the radiation transport region inside the fiber as Ytterbium reabsorbs its own emission

• We have designed two families of fibers: guiding clad and guiding core fibers

• The guiding region of the fiber consists of Aluminum-doped fused silica to have a higher index.

• The rest of the fiber consists of Yb-doped material

Guiding core design

<table>
<thead>
<tr>
<th>active or passive</th>
<th>composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active</td>
<td>Yb/Si = 3/97at.%</td>
</tr>
<tr>
<td>Passive</td>
<td>Sapphire</td>
</tr>
<tr>
<td>Passive</td>
<td>Si = 100at.%</td>
</tr>
<tr>
<td>Passive</td>
<td>Si = 100at.%</td>
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</table>

Guiding clad design

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<tbody>
<tr>
<td>Active</td>
<td>Yb/Al/Si = 3/6/91at.%</td>
</tr>
<tr>
<td>Passive</td>
<td>Al/Si = 28/72at.%</td>
</tr>
<tr>
<td>Passive</td>
<td>Si = 100at.%</td>
</tr>
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Result at 1060°C and 1272°C

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<th>Temperature</th>
<th>Output power per side</th>
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<tr>
<td>1060 °C</td>
<td>31.7 μW</td>
</tr>
<tr>
<td>1272 °C</td>
<td>0.445 mW</td>
</tr>
</tbody>
</table>

Expected per 10 cm fiber length and for both sides:
1060°C: 33 x 2 x 0.032mW = 2.1mW
1272°C: 33 x 2 x 0.445mW = 30 mW

For an array of 10’000 fibers of 10cm length each:
1060°C: 21 W
1272°C: 300W

Challenges:
Implement the scaling!
Go to higher temperatures!
Increase the number of cores!
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Conclusions and outlook

• A rough overview has been given about the production of high Alumina high temperature microstructured fibers.
• Scaling to high powers by combination of short pieces in an array seems possible
• Multicore high alumina fibers can be drawn
• The challenge of using our fibers in continuous way at > 1400°C will give us much interesting work in the near future
Thank you

• Thank you for your attention.

• Thanks to these organisations and companies for support:

PHOTONICS
NTN INNOVATION BOOSTER

• Thanks to these people and companies for their precious and tireless work: