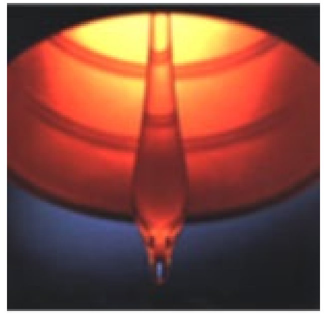


Berner Fachhochschule
Haute école spécialisée bernoise
Bern University of Applied Sciences

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

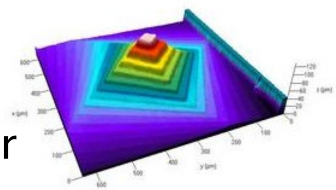
BFH-TI

Powder Process for Fabrication of Rare Earth-Doped Fibers for Lasers and Amplifiers
Valerio Romano, Sönke Pilz, Hossein Najafi

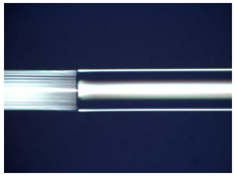
ALPS: Competences and Research Groups

Site Burgdorf:

- Laser Surface Engineering
B. Neuenschwander



- Applied Fiber Technologies
V. Romano



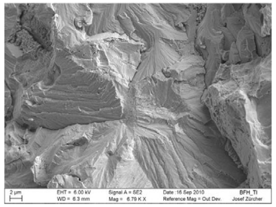
- Thin Films & Surfaces
S. Le Coultre

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

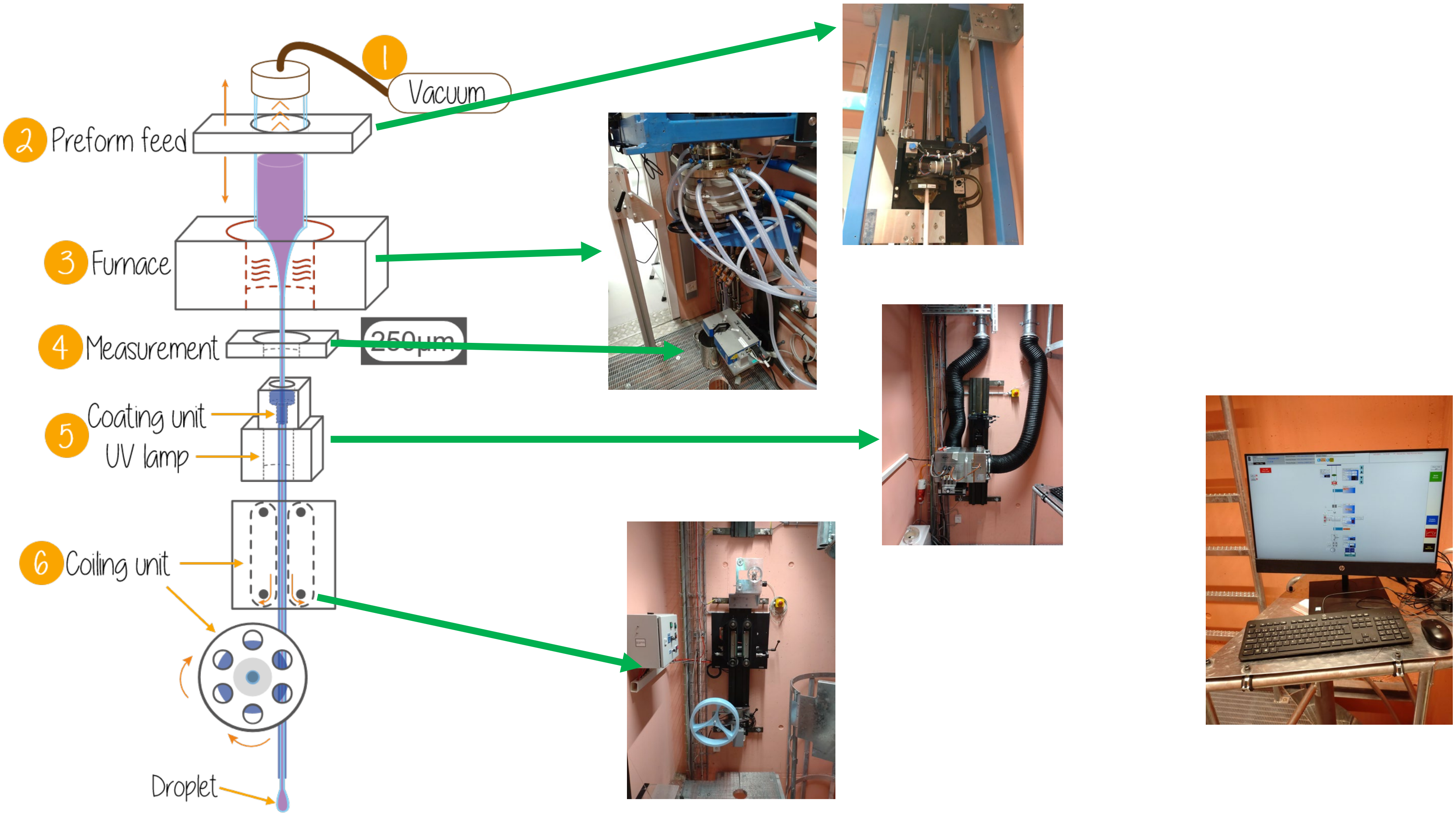


Content

- 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

Berner Fachhochschule
Haute école spécialisée bernoise
Bern University of Applied Sciences

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

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

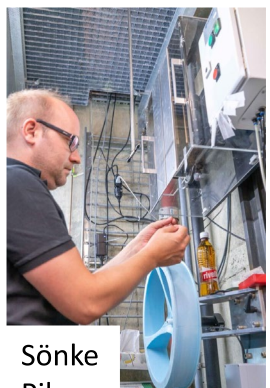
- Preforms and materials
  - Preparation of fiber materials
  - Assembling the Preform

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

- Testing / characteri-sation
- Assembling fiber systems (e.g. Fiber lasers)

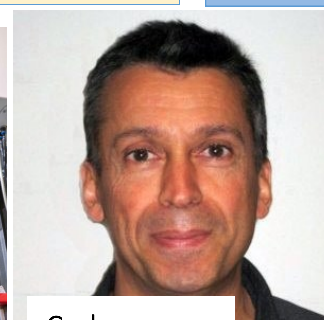
Valerio Romano, BFH / IAP

Thomas Feurer,IAP

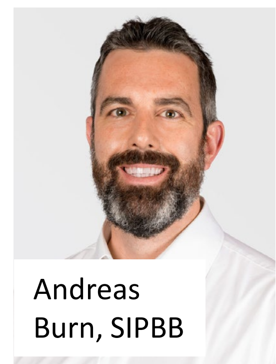


Sönke Pilz BFH

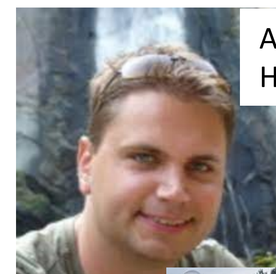
Sönke Pilz, BFH



Carlos Pedrido, BFH



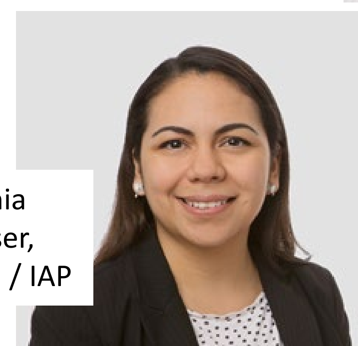
Andreas Burn, SIPBB



Alexander Heidt, IAP

Dirk Spangenberg, BFH / IAP

Manuel Ryser, IAP



Dunia Blaser, BFH / IAP

Pascal Hänzi, IAP

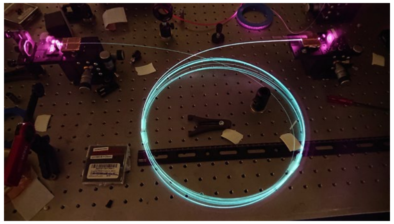
- The Drawing tower is only one part of the fiber production facility:

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

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

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

- Testing / characteri-sation
- Assembling fiber systems (e.g. Fiber lasers)

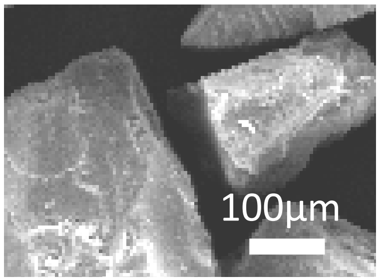


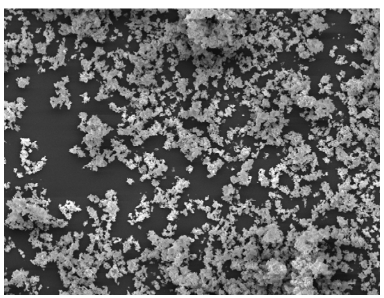
Will move to BFH campus

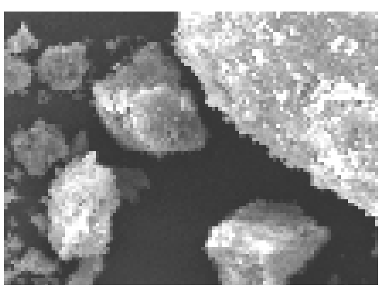
- Materials and preform production as well as fiber handling are in Burgdorf and Bern. They will be moved to the BFH campus as soon as it is finished.
- Additionally to the drawing tower locality at SIPBB each institution has several other labs and facilities related to fiber characterisation, system building (LASER systems) and application testing

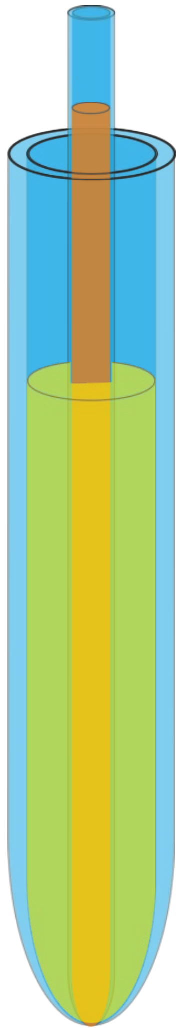
Propietary preform production technologies

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 od *doped/codoped* granulated silica

Sol-gel

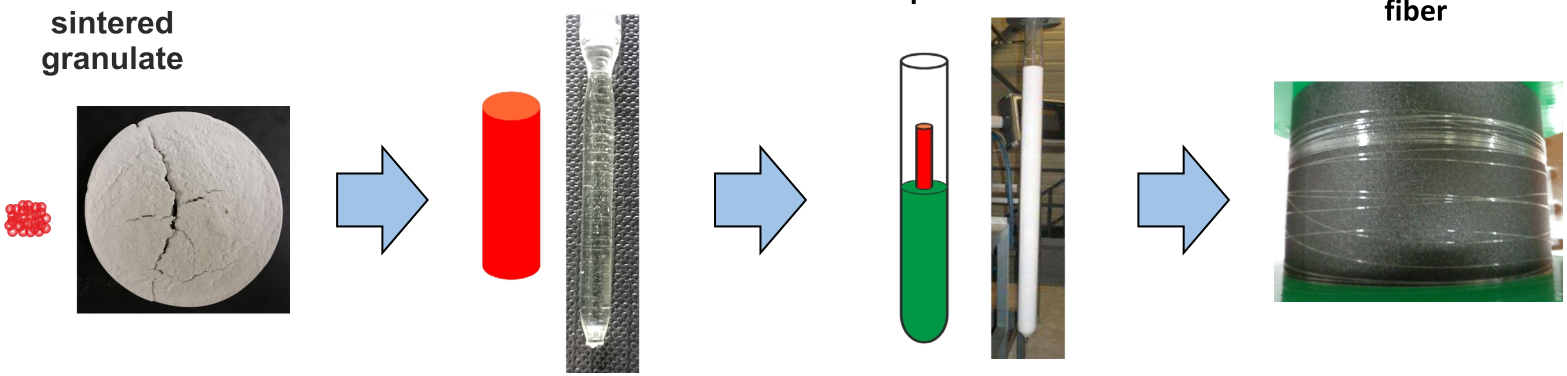
solution of precursors | **gel** | **powder**

grain size ~ nm - µm

every grain
homogeneously doped

Granulate-in-tube

sintered granulate | **vitrified glass core rod** | **granulate-in-tube preform** | **fiber**



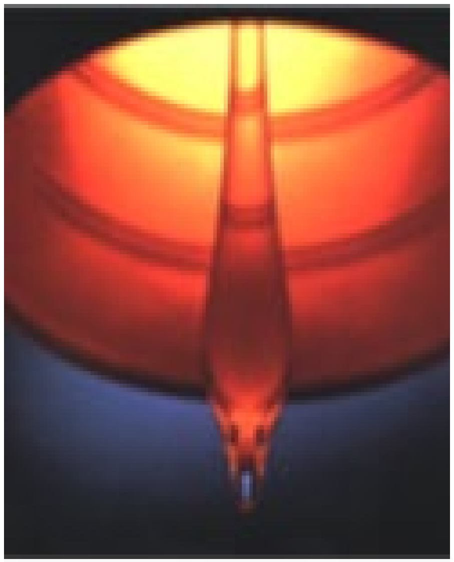
sintering & milling
removal of OH-groups
grain size ~ 100 µm

laser-based
travelling small-zone
vitrification for
loss reduction

cladding drawn
directly from
granulate

Thermal quenching in a drawing tower...

...allows to mix materials with different thermophysical properties



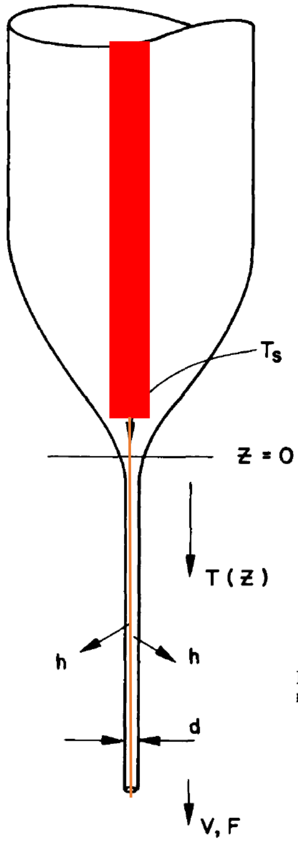


Fig. 1. Schematic of necked-down region in fiber drawing process.

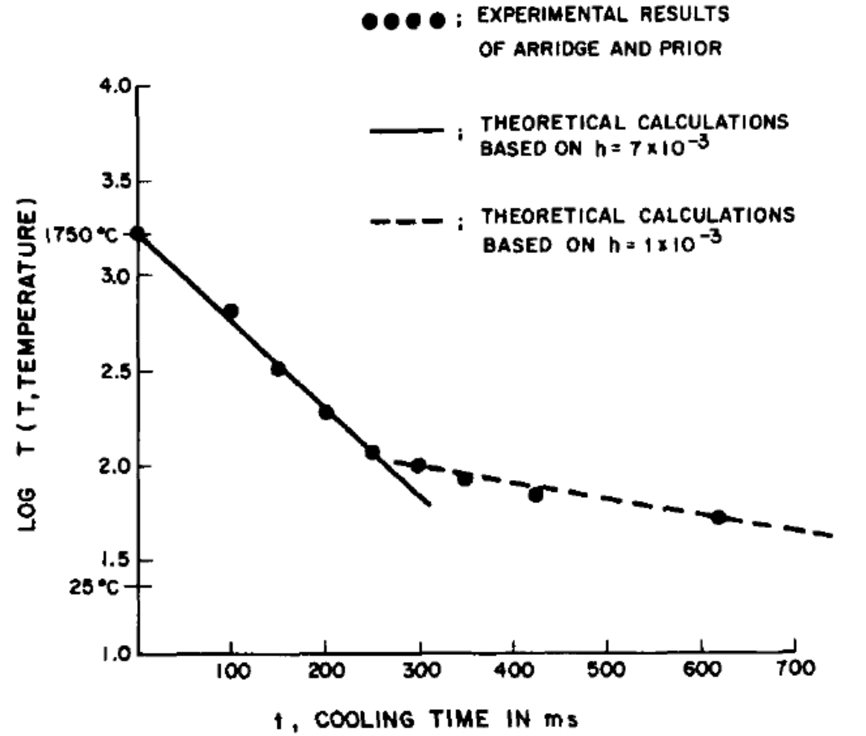


Fig. 2. Comparison of calculated and experimental cooling rates.

Paek, U. C., and C. R. Kurkjian. "Calculation of cooling rate and induced stresses in drawing of optical fibers." Journal of the American Ceramic Society 58.7-8 (1975): 330-335.

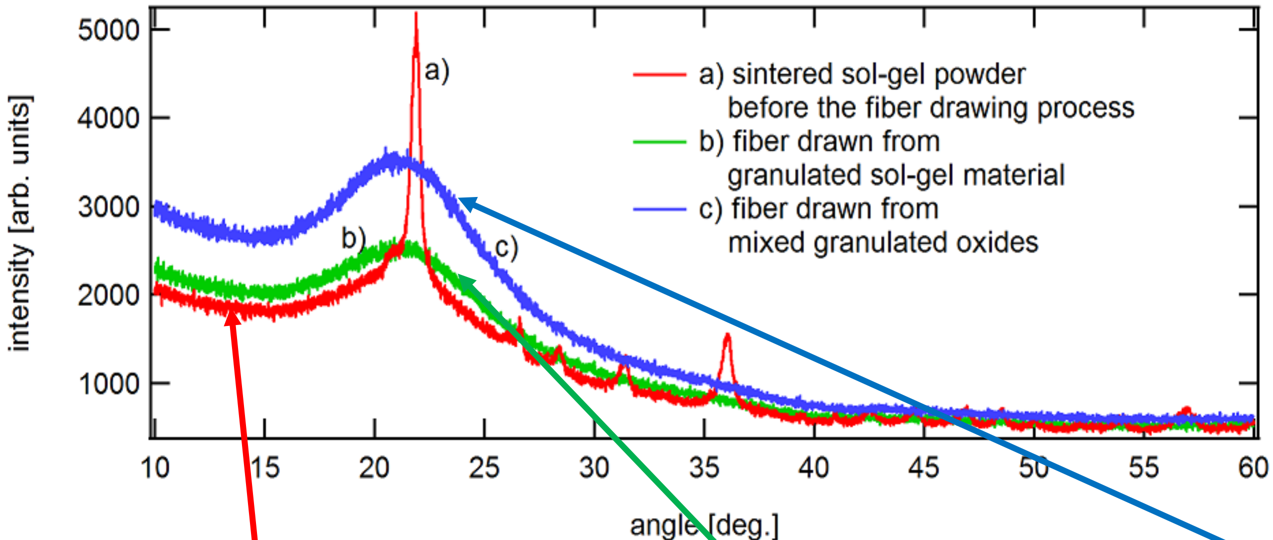
Cooling rates:

75’000 K/s in the first 10 ms;

5’500 K/s in the first 300ms;

Consequence of thermal quenching in fiber

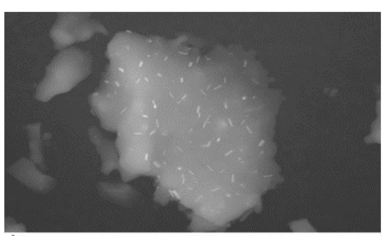
Test for Crystalline Silica : X-Ray Diffraction Measurement



Quenching the Sol-Gel material after heating at 1600

Crystalline material was amorphized after fiber drawing process

Crystalline

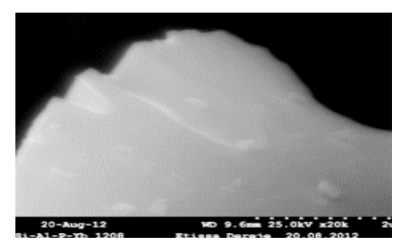


Before Drawing

Amorphous

Fiber from Sol-Gel Granulate

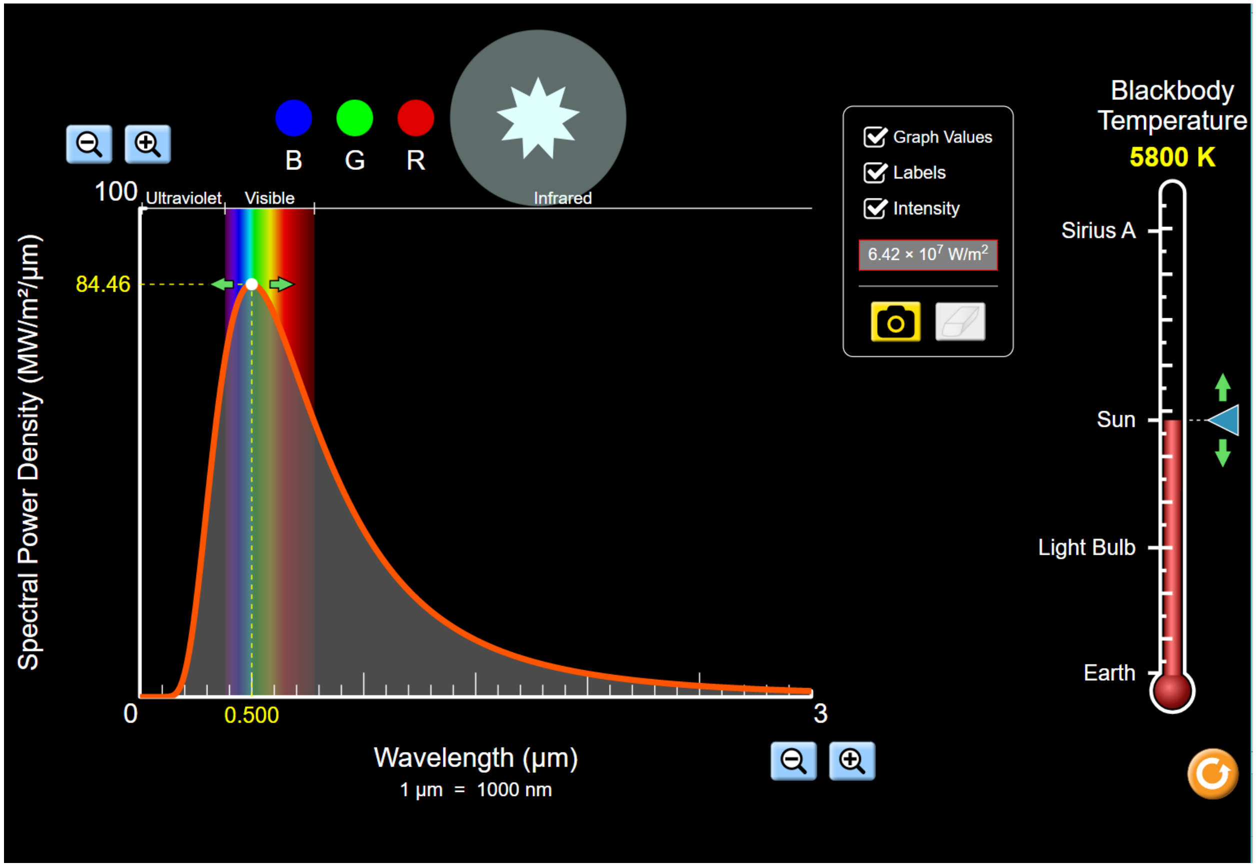
Amorphous



Fiber Directly from Granulates

Example of a fiber application: photovoltaic wavelength converter

- Preamble: two words about «solar» photovoltaics

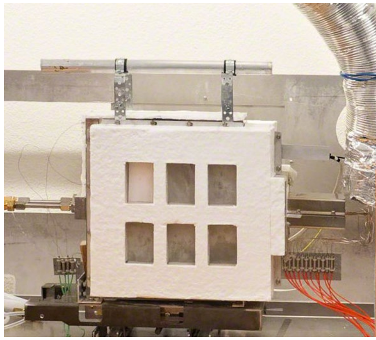


On the earth:

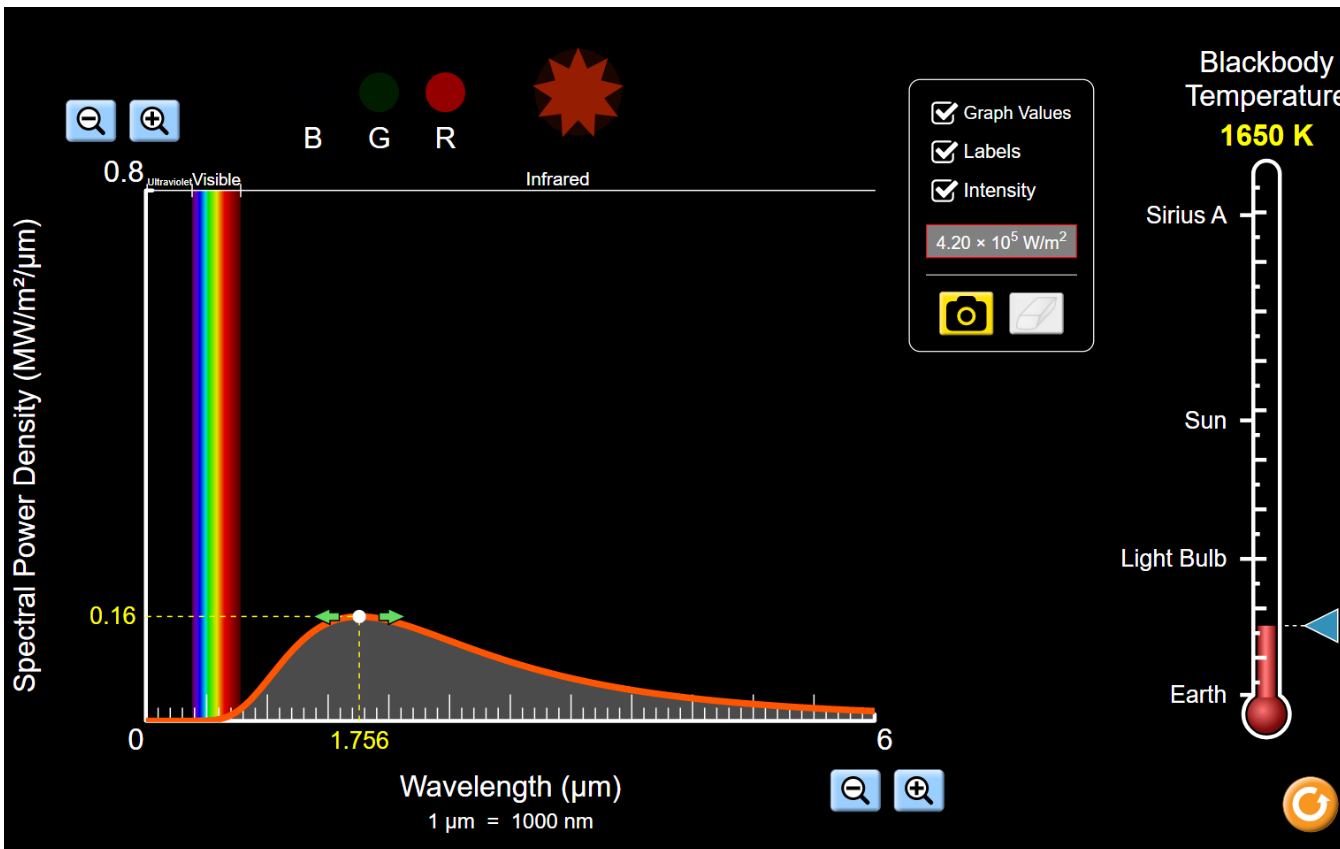
- 1kW / m2
- Silicon photovoltaics (covers UV – 1.1 μm wavelength)
- Open challenge: using a bigger part of the spectrum more efficiently

- 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 1.6mu – 2mu
- 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)

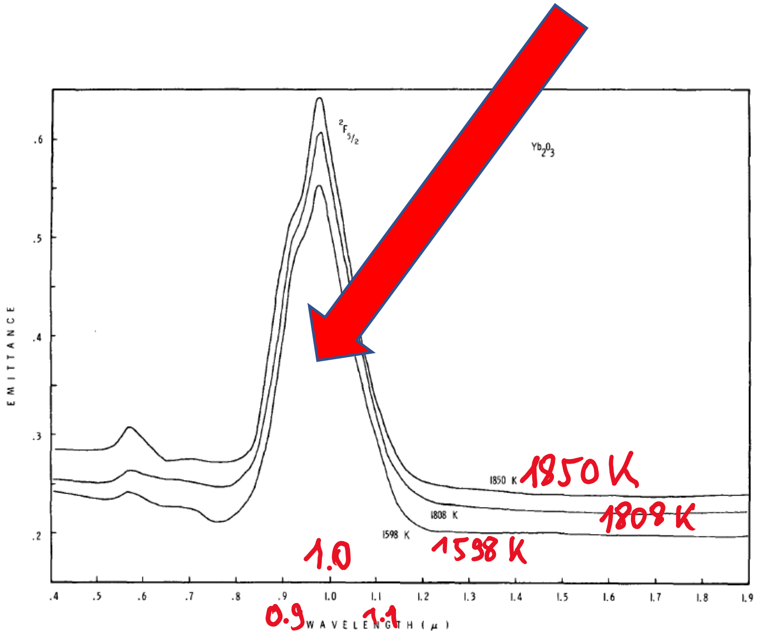
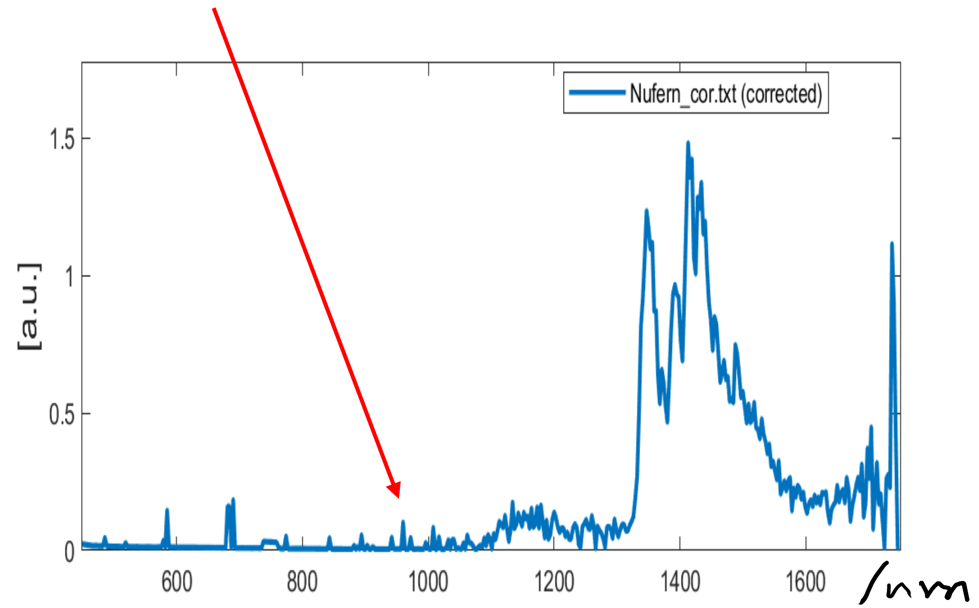


FIG. 6. Spectral emittance of Yb_2O_3 over the spectral range of 0.40–1.90 μ.

Spectral emittance of Yb_2O_3 over the spectral range of 0.40 μm – 1.9 μm

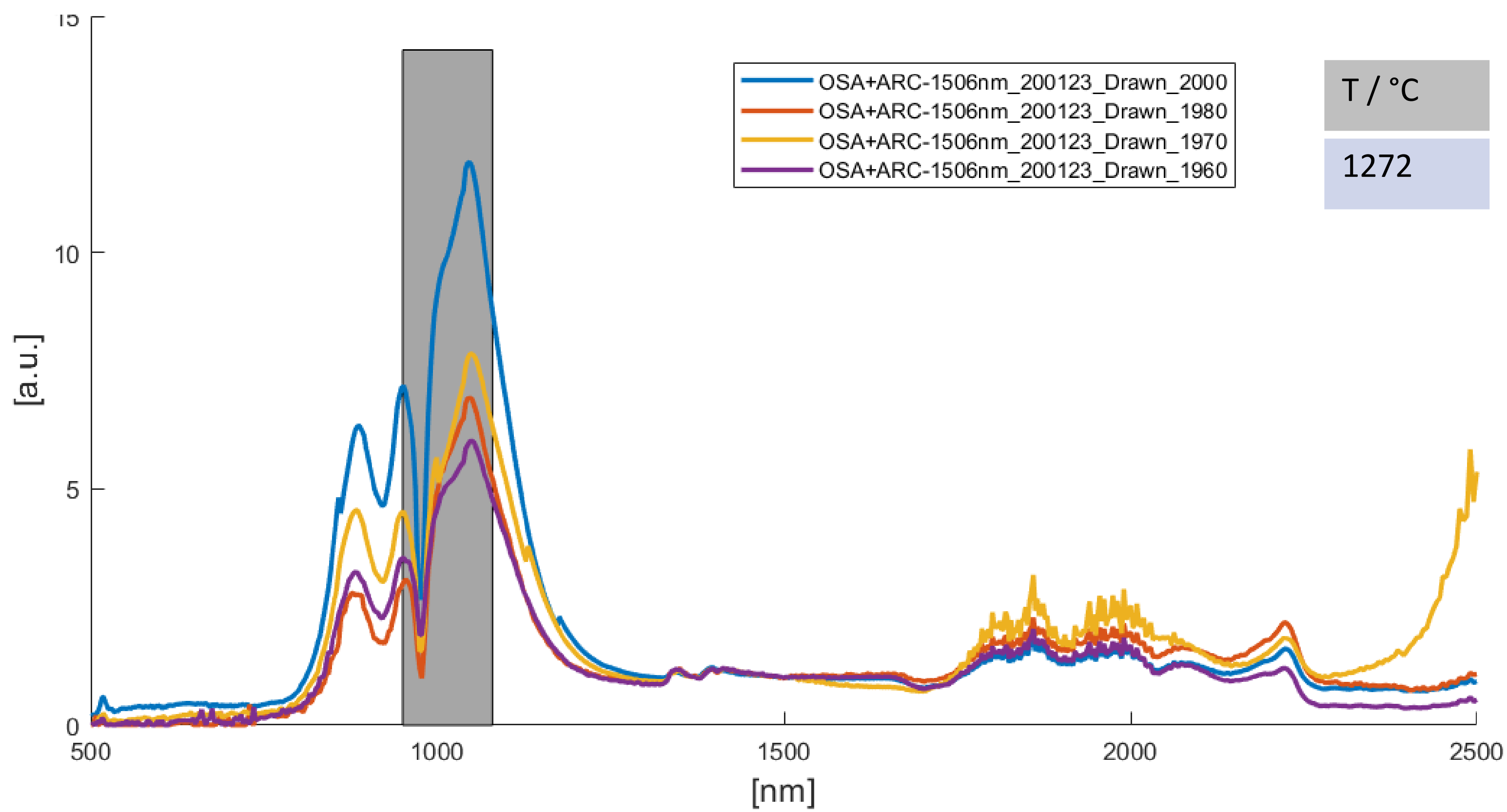
Guazzoni, G. E. (1972). High-Temperature Spectral Emittance of Oxides of Erbium, Samarium, Neodymium and Ytterbium. Applied Spectroscopy, 26(1), 60–65.



Spectral emittance of SiO_2 with a very small amount of Yb_2O_3 <0.3 at.% over the spectral range of 0.5 μm – 1.75 μm

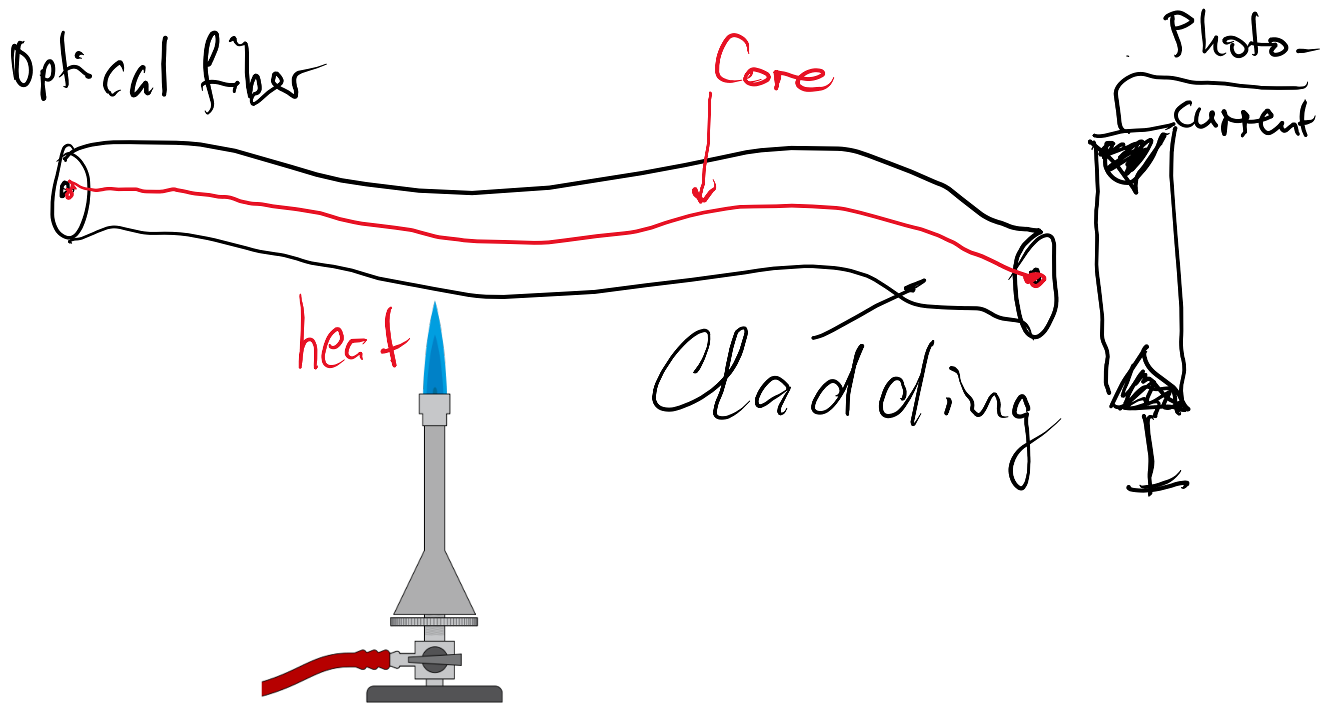
Materials for core and cladding

- High alumina and Ytterbium content materials have been developped that can be used as core or cladding material in optical fibers



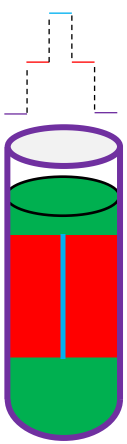
Putting Ytterbium ions into a fiber

- 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 (SiO_2 up to 1200°C); high Aluminum oxide content fibers should allow higher temperatures (> 1500°C?)



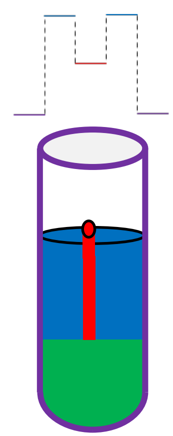
Guiding clad / guiding core fibers

- 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



	active or passive	composition
	Active	Yb/Si = 3/97at.%
	Passive	Sapphire
	Passive	Si = 100at.%
	Passive	Si = 100at.%

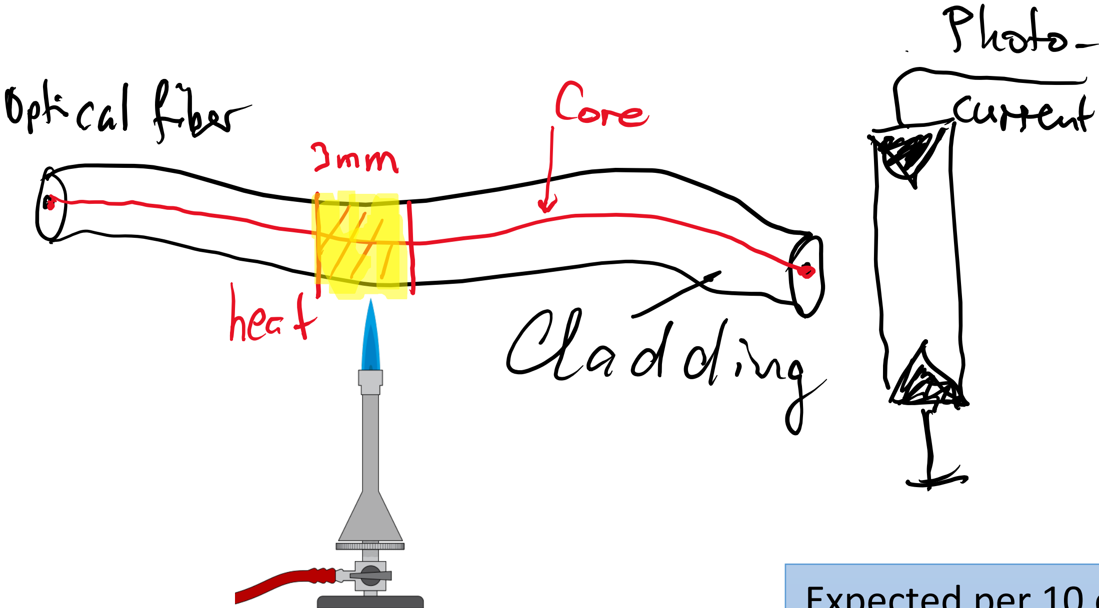
Guiding core design



	active or passive	composition
	Active	Yb/Al/Si = 3/6/91at.%
	Passive	Al/Si = 28/72at.%
	Passive	Si = 100at.%
	Passive	Si = 100at.%

Guiding clad design

Result at 1060°C and 1272°C



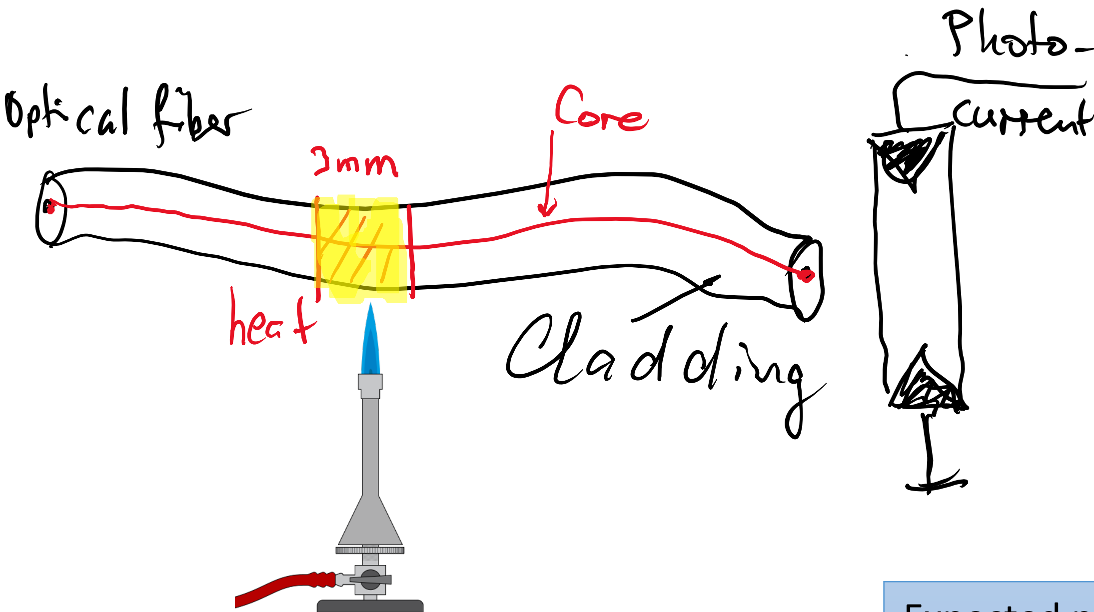
Temperature	Output power per side
1060 °C	$31.7\ \mu W$
1272 °C	$0.445\ mW$

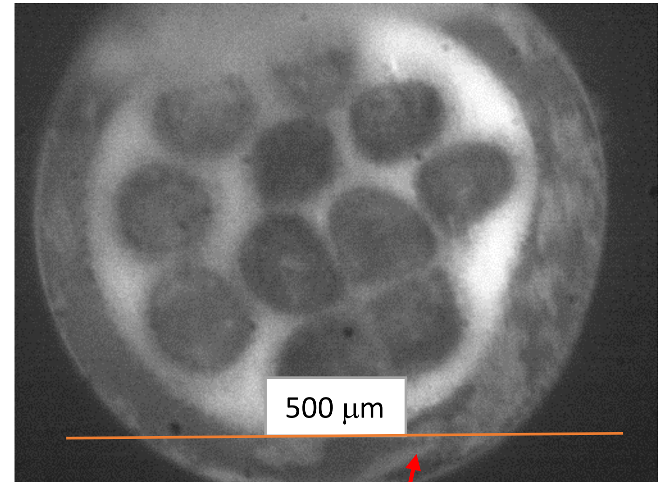
Expected per 10 cm fiber length and for both sides:
1060°C: 33 x 2 x 0.032mW = 2.1mW
1272°C: 33 x 2 x 0.445mW = 30 mW

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!

Result at 1060°C and 1272°C





Temperature	Output power per side
1060 °C	$31.7\ \mu W$
1272 °C	$0.445\ mW$

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!

Conclusions and outlook

Berner Fachhochschule
Haute école spécialisée bernoise
Bern University of Applied Sciences

- 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

Berner Fachhochschule
Haute école spécialisée bernoise
Bern University of Applied Sciences

- Thank you for your attention.
- Thanks to these organisations and companies for support:

PHOTONICS NTN INNOVATION BOOSTER

SWISS PHOTONICS

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Innosuisse – Schweizerische Agentur für Innovationsförderung

econimo DRIVE

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