Aktivitäten des IAP im Bereich Fasern und Faserlaser

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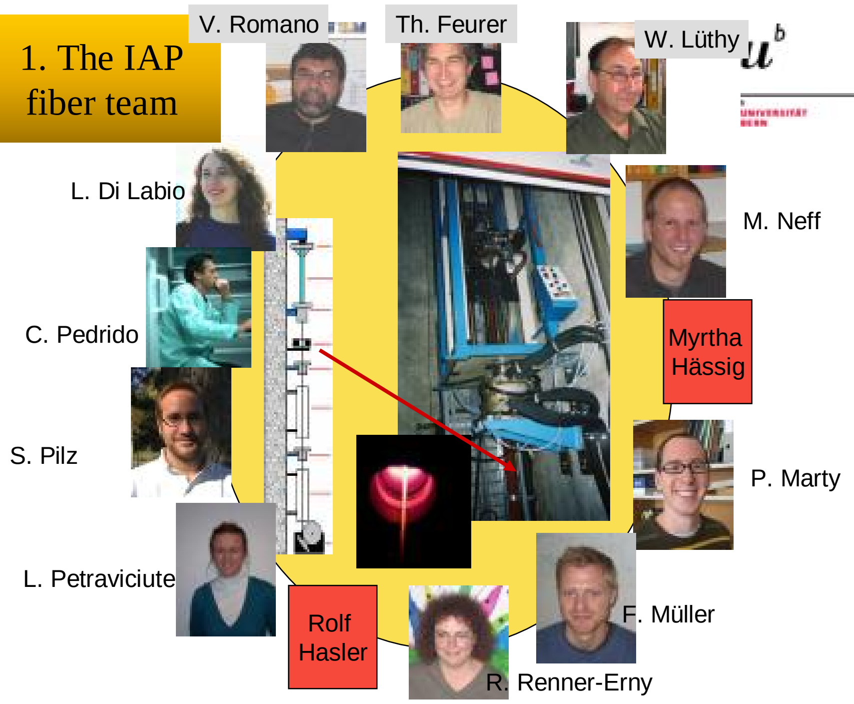
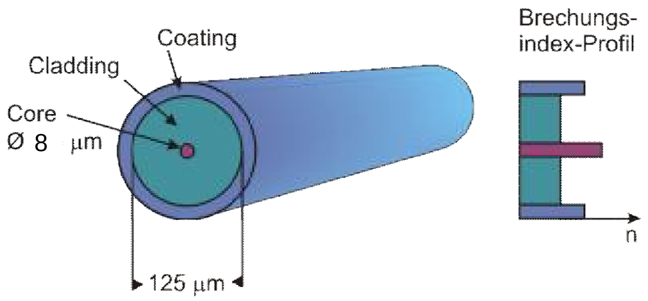
1. Das Team
2. Motivation: Grenzen der Standardfaser
3. „Rapid Fiber Prototyping“ und Beispiele

Zusammenarbeit mit der Industrie (KTI), SATW, SNSF, NCCR QP

1. The IAP fiber team



2.1 Standard-Faser



- Aktivieren des Cores durch eine seltene Erde (z. B. Er^{3+} od.YB^{3+}) - > Faserlaser
- Sehr gute Dämpfungswerte (ca. 0.2 dB / km)

2.2 Limits …

- Kleiner Kerndurchmesser:
  - Hohe Intensitäten;
  - Hohe Energieflussdichten;
  - Kleine extrahierbare Energie;
- Dispersion: gegeben v.a. durch das Material
- Limite für traditionelle SM Faser: 100 W (CW)
- Erhöhung des Coredurchmessers: Strahlung wird multimode (schlechter fokussierbar)

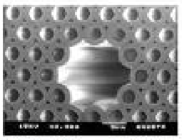
2.3 Damage Threshold of fused Silica for pulsed operation

Oberfläche → Energy Fluence; Bulk → Bulk damage

Pulse duration	Peak Power	Energy Fluence (MFD=60µm)	Bulk damage	Fiber mit 8µm core:
1ns	2.12 MW	97 J/cm^2	330 J/cm^2	**4.8mJ/Puls**
0.7ns	3.4MW	84 J/cm^2	273 J/cm^2	**4.2mJ/Puls**
0.48ns	4MW	68 J/cm^2	226 J/cm^2	**3.4mJ/Puls**
0.11ns	6MW	23 J/cm^2	108 J/cm^2	**1.1mJ/Puls**

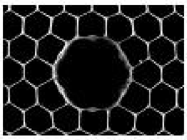
(W. Torruellas et al, Photonics West 2006)

2.4 Breaking the limits with new fiber concepts: a) photonic bandgap fibers



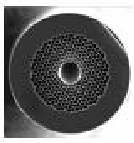
Knight et al, Science (1998)
Cregan et al, Science (1999)

Band-gap guidance in low-index region.



Smith et al., Nature (2003)

Loss ~ 13 dB/km
Air-filling fraction ~ 94%



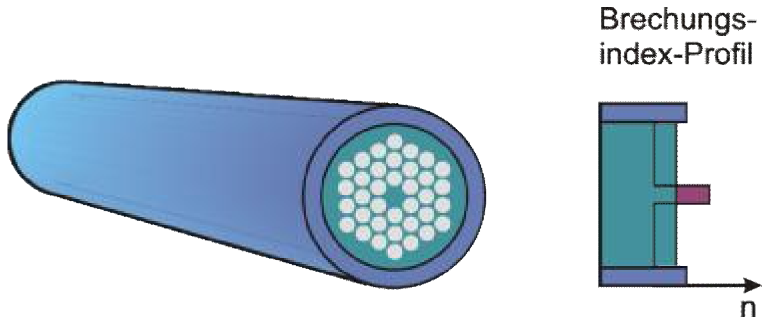
B. J. Mangan et al., OFC (2004)

Loss ~ 1.7 dB/km
multimode

- **Light is guided via diffraction rather than total internal reflection.**

2.5 New fiber concept: solid core PCF

- Cladding has lower index than core by air fraction
- Core size can be upscaled (almost) arbitrarily by appropriate choice of microstructure (allows single mode guidance for very large cores)

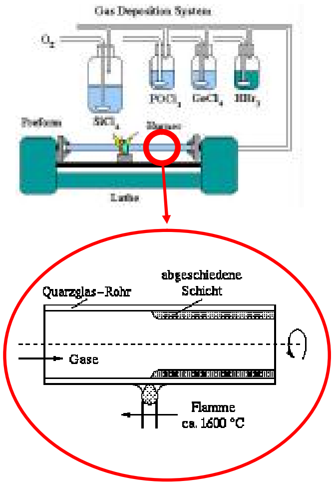


3. New production techniques

- -> Rapid Fiber Manufacturing
  - – Sol Gel
  - – Granulated silica method (patented by Silitec SA, Boudry)

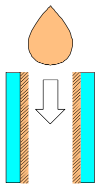
3.1 Production of Sol-Gel preforms

Standard technique:mCVD



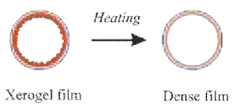
Sol-Gel technique at IAP:

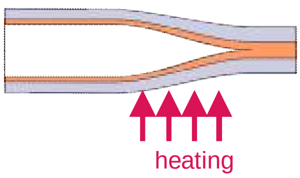
- TEOS $C_8H_{20}O_4Si$ → **source material**
- RE^{3+} Cl_3 → **active ion**
- Al Cl_3 → **prevents clustering**
- Ti Cl_3 → **control of refractive index**

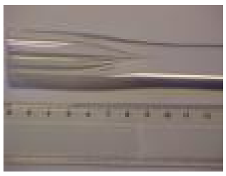


- → annealing 1000°C
- → collapse tube to rod
- → drawn to fibre

3.2 Tube coating and collapsing







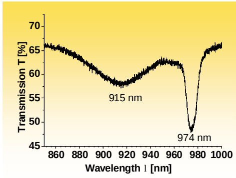
	1% Nd		5% Nd	
	τ_{slow} / ns	τ_{fast} / ns	τ_{slow} / ns	τ_{fast} / ns
2000°C	570	140	450	31
1000°C	370	46	300	22
900°C	360	36	200	8
800°C	220	44	160	14
700°C	150	34	85	15
600°C	-	-	28	4

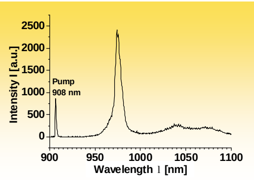
Table 1: Fluorescence lifetime

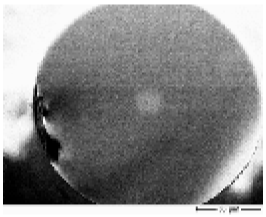
3.3 Yb^{3+}- doped Sol-Gel fiber

Ø Coating of tube with highly viscous sol (3 x 2.7 µm)
Ø Vitrification after each step
Ø Drawing at high temperature

- Lifetime 764 ± 4 µs (20 cm, 908 nm)
- Losses 0.28 dBm^{-1} @ 632.8 nm
- Losses 0.03 dBm^{-1} @ laser wavelength
- Numerical aperture: 0.099
- Diameter fiber 180 µm
- Diameter core 8.5 µm

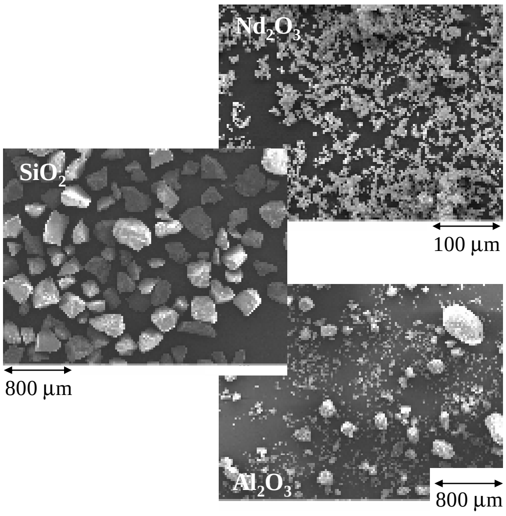


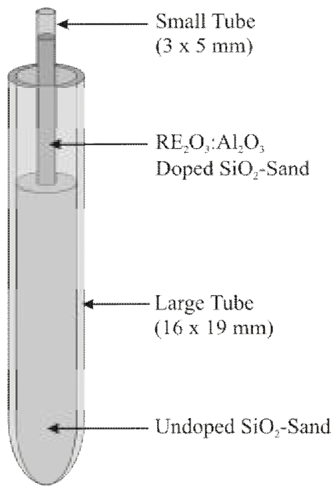




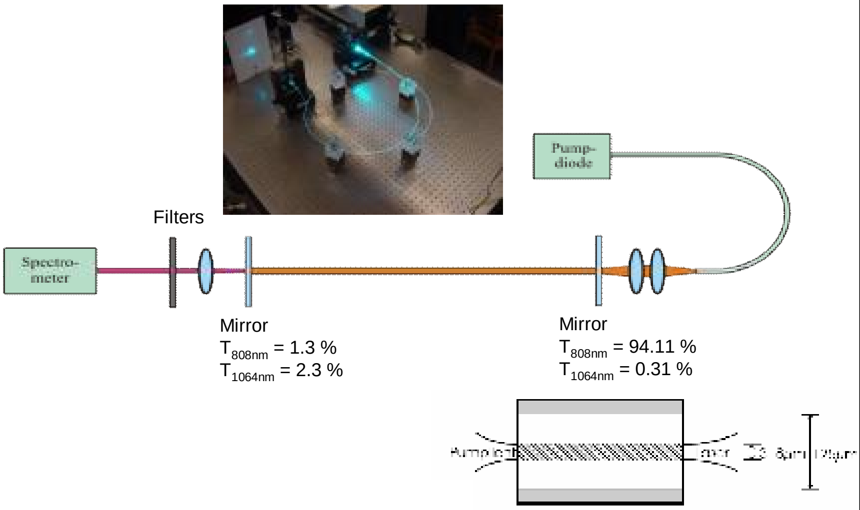
§ Laser emission at 1080 nm and 1088 nm
§ Fiber length 65 cm
§ 64 % slope eff.

3.4 Manufacturing of Granulated Silica Preforms

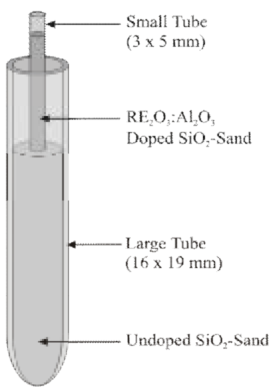


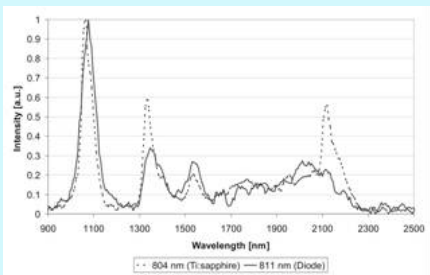


3.4 a) Fiber Laser set-up



3.5 Broadband light source



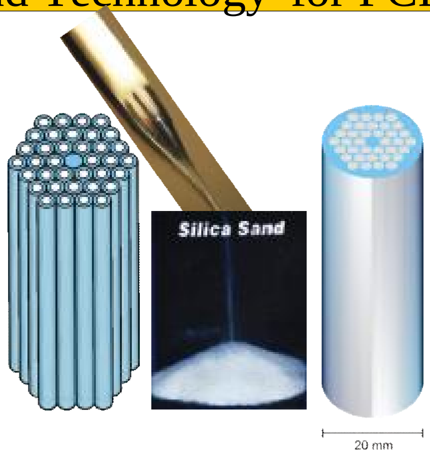


NIR fluorescence spectra of the single-core multiply doped fibre when pumped with the Ti:sapphire laser at 804 nm (dashed curve) and the single-mode single stripe laser diode at 811 nm (solid curve).

An oxide mixture of Nd^{3+}(0.1 at. %), Ho^{3+}(0.3 at. %), Er^{3+}(0.1 at. %), Tm^{3+}(0.3 at. %), Yb^{3+}(0.2 at. %), Al^{3+}(7 at. %), and silica is used to fabricate a single-core fibre

L. Di Labio, 2008

3.6 “Sand Technology”for PCF

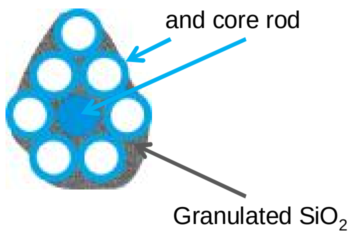


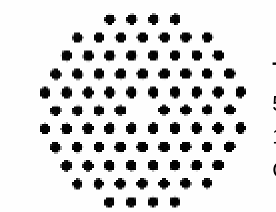
Depending on size, sand-based preforms are:
- **Vitrified and drawn directly in one step**
- **Vitrified and drawn in two steps**
- **First vitrified plus stretched and then drawn (two steps)**

3.7 Large core PCF

Microstructured fibers can take profit of the method:
stack and draw + filling interstitials with granulated silica

„Mixed technique“: capillaries from tubes, interstitials filled with granulated silica

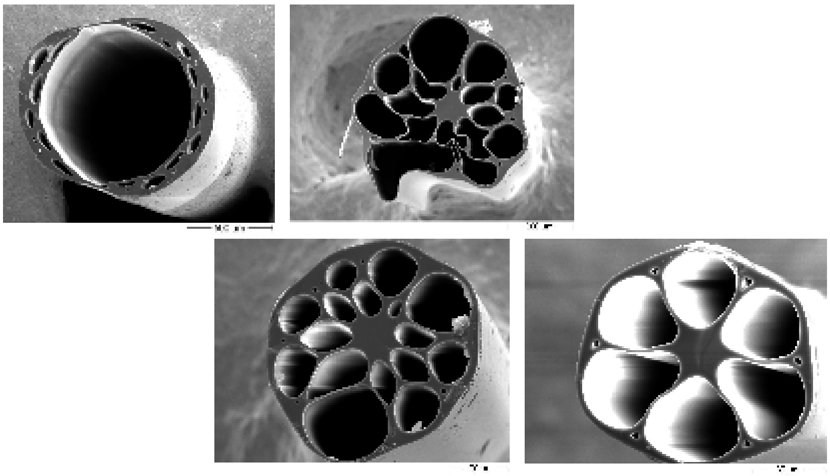




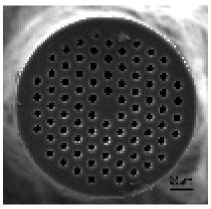
Theory:
5 „hexagonal“ rings
1 central „defect“
Core diameter: 23 um

3.8 From the preform to the fiber

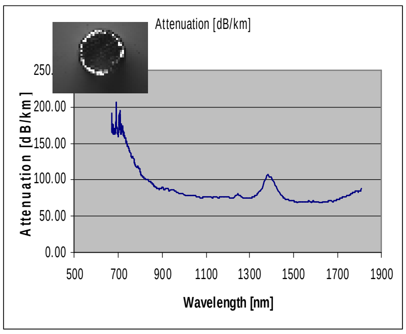
- First trials (2005 / 2006):

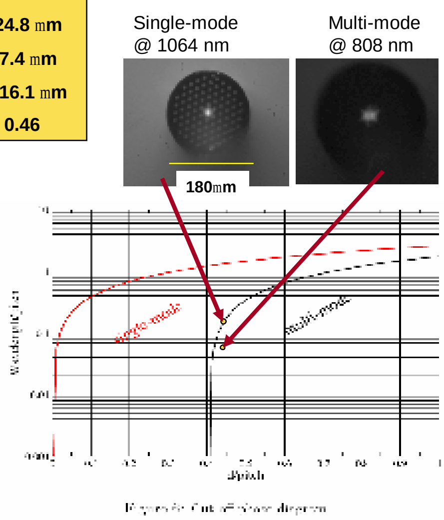


3.9 Success at last: Large core PCF



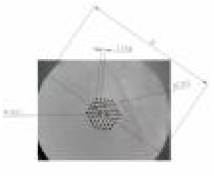
Fiber diameter:	**180mm**
Core diameter (d):	**24.8 mm**
Hole diameter:	**7.4 mm**
Pitch:	**16.1 mm**
d/pitch:	**0.46**

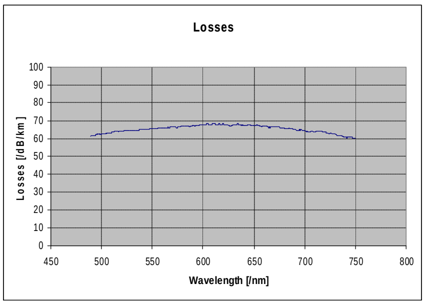


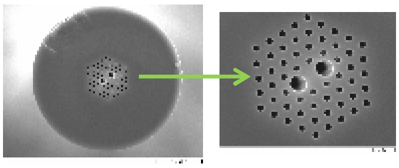


3.10 Polarization maintaining PCF

- § Fiber diam.: 125.0 mm
- § Core: ~4 mm x 6 mm
- § Hole diameter: 1.5 mm







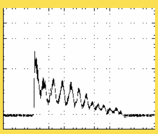
- Flat spectrum in vis.
- Polarization maintaining
- (almost) single mode in complete range

3.11 Next steps: MOPA with large core fibers

- All fiber MOPA (Master Oscillator / Power Amplifier)

MO (Master Oscillator) → PA (Power Amplifier)

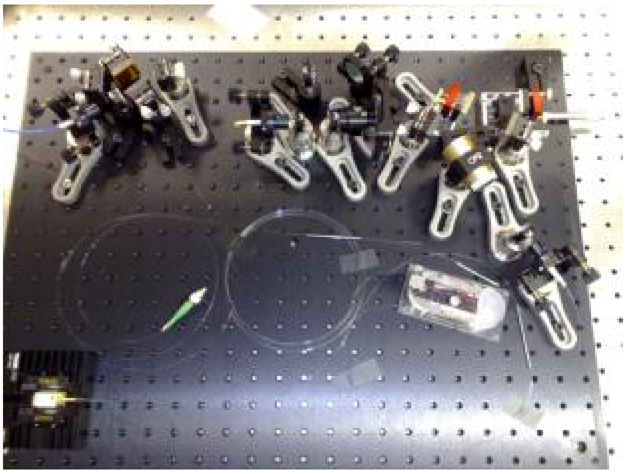
Temporal pulse shaping adapted to application is done here at low power and based on reliable and well known technology



High peak power (>kW) is generated in the amplifier based on Rare Earth doped Photonic Crystal Fiber Technology.

One high power design will try to cover as many pulse length and repetition rate regimes as possible.

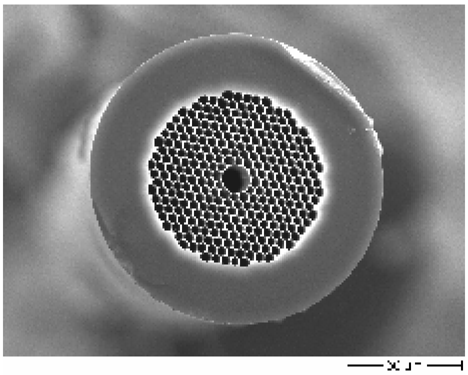
3.12 Femtosecond Yb^{3+} Fiber laser



- **< 100 fs**
- **50 MHz**
- **Verst: 23dB**
- **0.5 W**

IAP 2007, F. Müller

3.13 Wellenlängennormale



Struktur einer Hollow Core Photonic Crystal Fiber (HCPCF).

Realisation von Wellenlängennormalen mittels Gas gefüllten Hollow Core Photonic Crystal Fiber(HCPCF).

Anwendungsgebiete:

-Metrologie

-Telekommunikation

P. Marty, 2008

Conclusions

- Team: 13 people involved at IAP (growing)
- Rapid Fiber Prototyping for implementation of new fiber concepts
- Several PCFs have already been drawn

- Next steps:
  - applications
  - Hollow core fibers (Photonic Bandgap Fibers)