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Fluoride Glasses and Fiber for Mid-IR Applications

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Philadelphia Sept 2014

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Outline

- Introduction
- Fluoride Glass
- Fluoride fiber
- Fiber Handling
- Reliability
- Fiber Lasers
- Planar Waveguide
- Conclusion

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Introduction

- Fluoride glasses have been discovered in 1975 at Rennes Univ.
- Very unique and outstanding optical properties
- Experienced extraordinary development
  - ✓ Ultra-low theoretical loss 0.001 dB/km
- 25 years of development
  - ✓ Ultra-low loss goal was not reached
  - ✓ Made the technology ready for short and medium length applications

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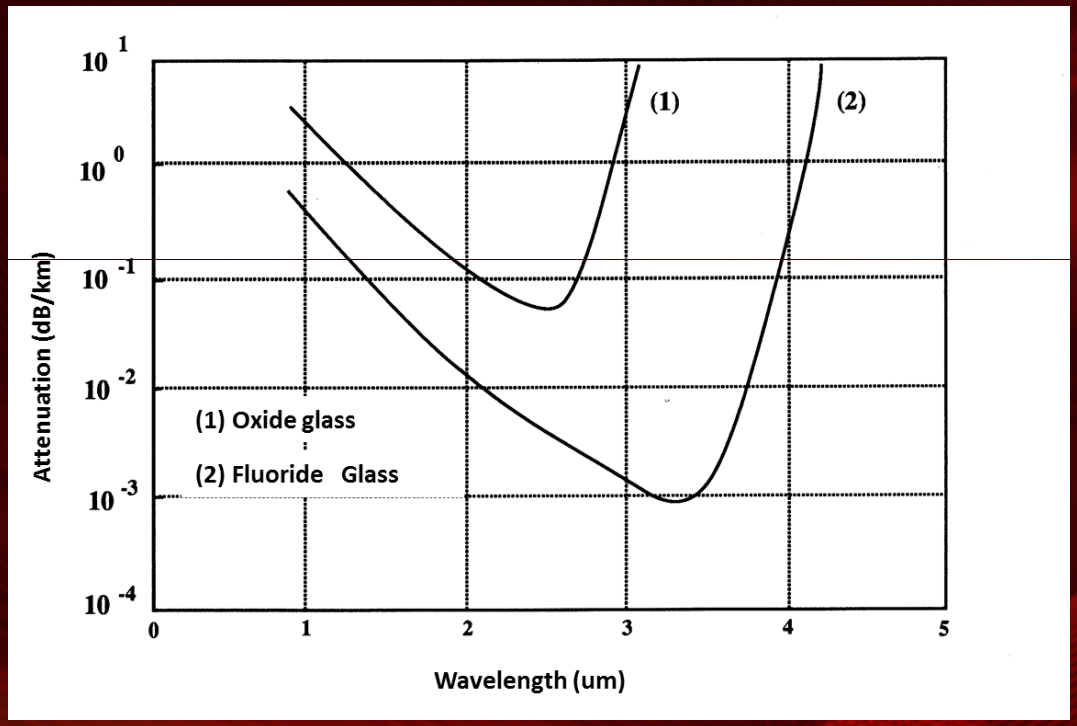
Fluoride Vs Silica Theoretical attenuation



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Glass Families

- Large choice of compositions
  - ✓ Glass properties can be tailored for each application
- Fluorozirconate ZrF4 (ZBLAN)
- Fluoroindate InF3
- Fluoroaluminate (insoluble in hot water)
- Fluorogallate, Fluorozincate,…
- Mix of different glass families

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Fluoride glasses properties

Glass	Tg (C)	n_D	CTE 10^{-7} /k
ZrF4	230 to 300	1,48 to 1.53	150 to 200
InF3	290 to 320	1.48 to 1.53	170 to 190
CdF2	300 to 360	1.48 to 1.50	150 to 180
ZnF2	280 to 320	1,50 to 1.54	170 to 200
AlF3	380 to 420	1.42 t0 1.46	140 to 160

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Outstanding properties

- Multi-spectral window No absorption peaks (UV-Vis-IR)
- Low loss
- Low refractive index (No IR coating)
- Low dispersion
- ~~Low dn/dt~~
- Low phonon energy (new Laser lines)
- High rare earth concentration (up to 100.000ppm)
- CTE (Stainless Steel, Al) Assemblies Reliability

The only fiber material that transmits UV-VIS-IR

Visible light for optical alignment

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ZBLAN Standard fluoride Transmission window

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Fluoride Glasses

- Bulk optics
  - ✓windows
  - ✓Molded lenses
  - ✓Diamond point turned
- Optical fibers
- Channel and planar waveguides

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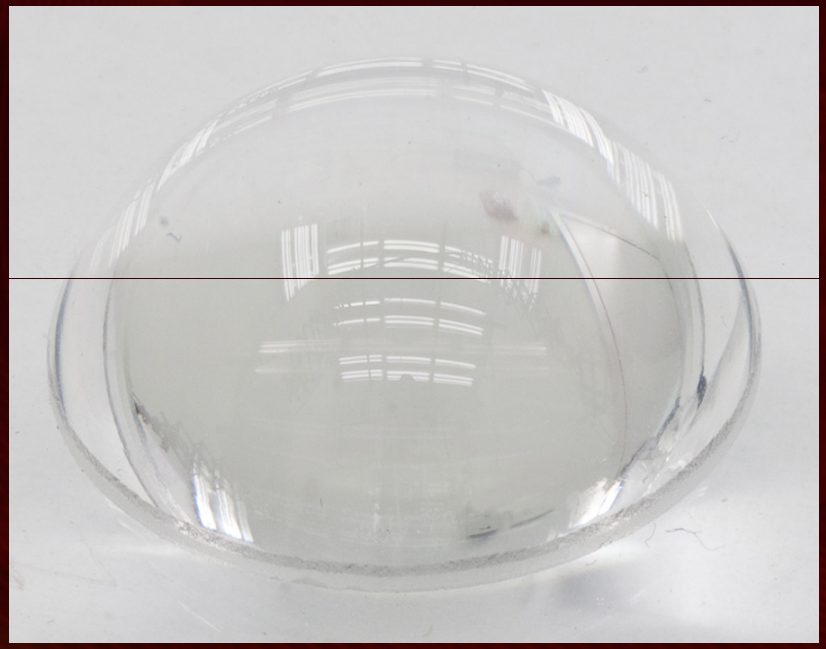
ZBLAN SPDT



Roughness 2 nm

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Fluoride Fibers

- Drawn from solid preforms
- Same technique used for silica
  - ✓ Good control of the fiber parameters
    - Dimension
    - Concentricity
    - Numerical Aperture (NA)
- Single & multimode fibers
- Exotic shapes are possible
    - Hexagonal, D shaped, PCF….

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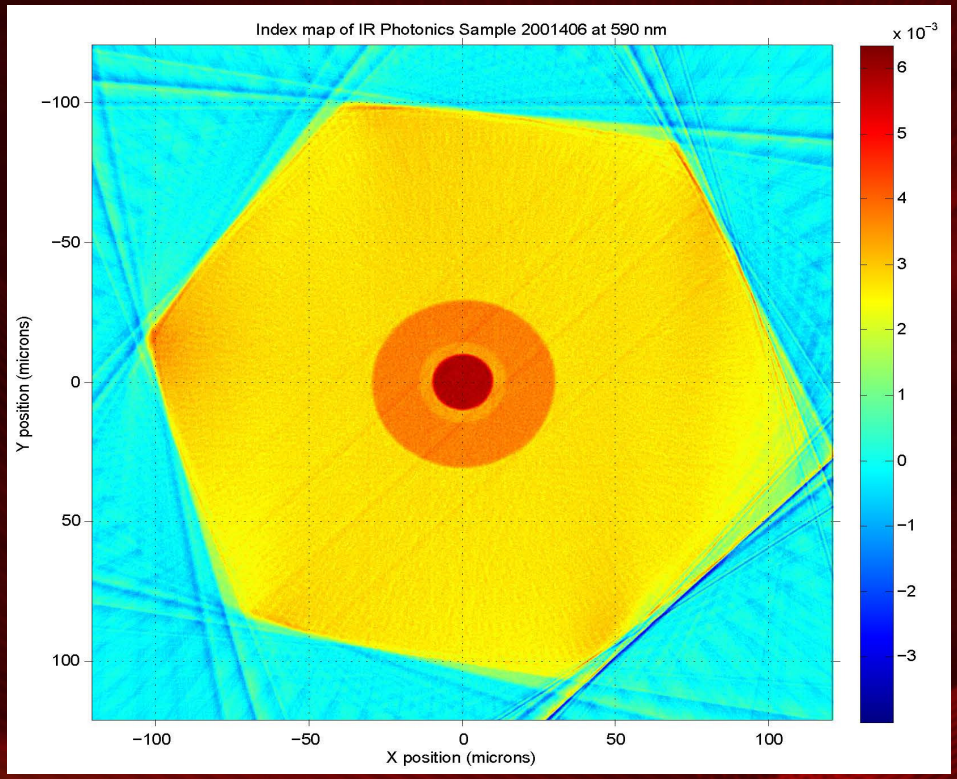
Hexagonal ZBLAN Fiber



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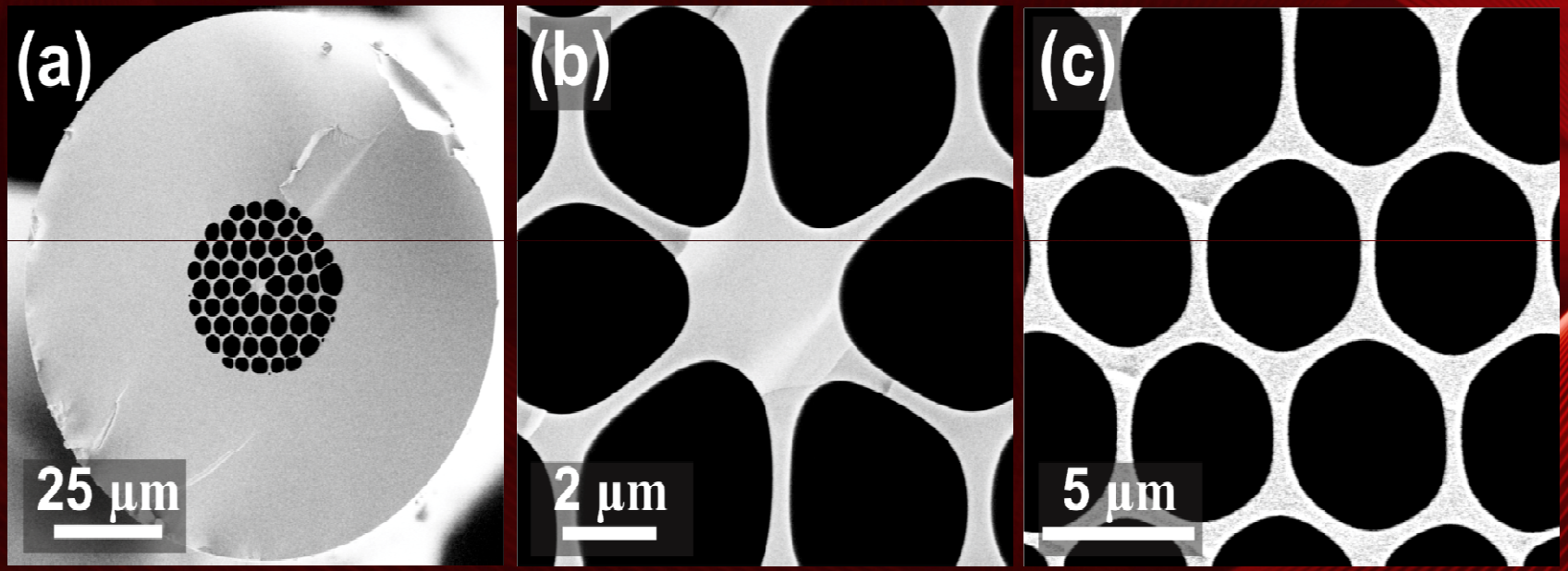
ZBLAN PCF Fiber



Collaboration work with Max Planck Institute

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Fluoride Fibers

- Transmission from 0.3 to 4.5 and 5.5 um
- Low Loss (10 to 100 dB/km)
- 0.05 < NA< 0.4
- High mechanical strength (50 to 100 kpsi)
- Spliced, tapered, cleaved
- Fiber Bragg Grating

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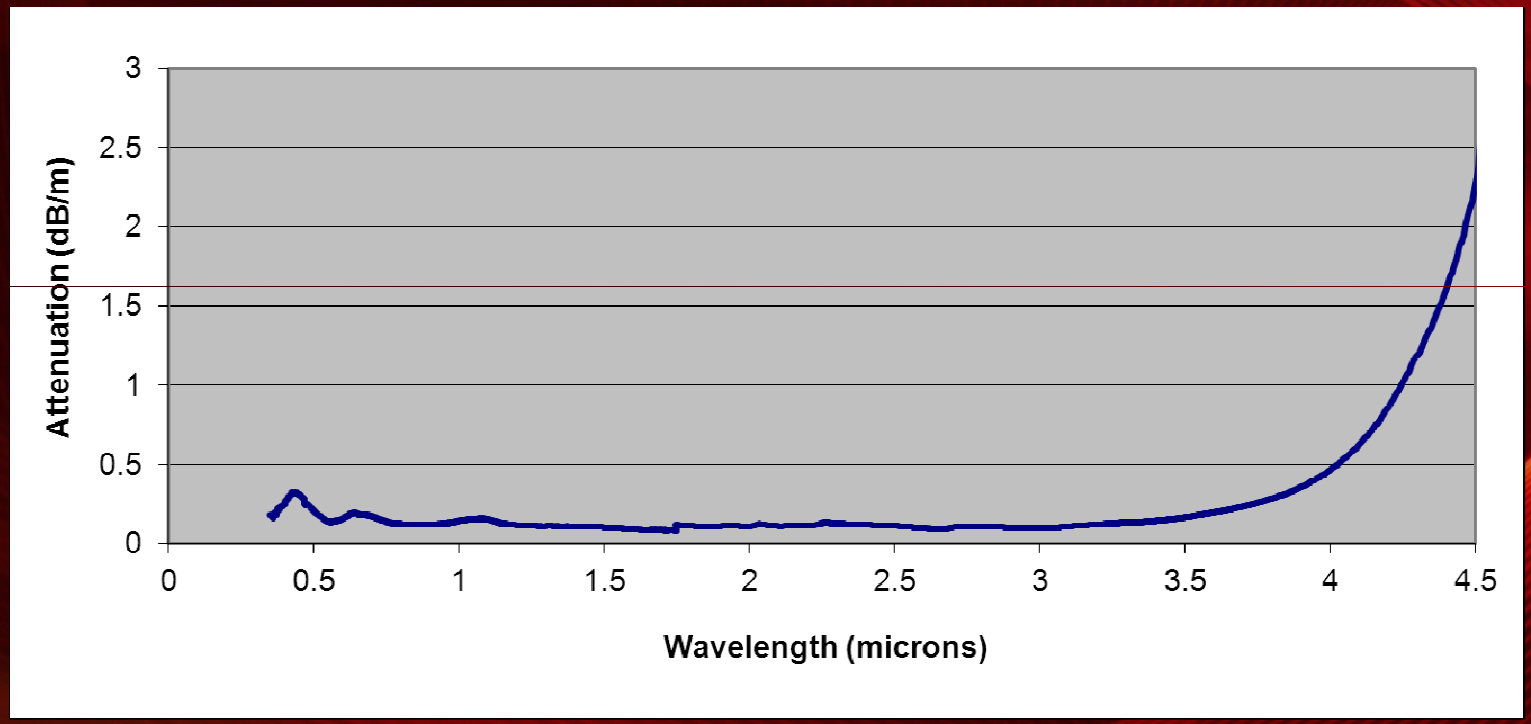
Standard ZBLAN fiber transmission (Vis-Mid-IR up to 4.3 um)



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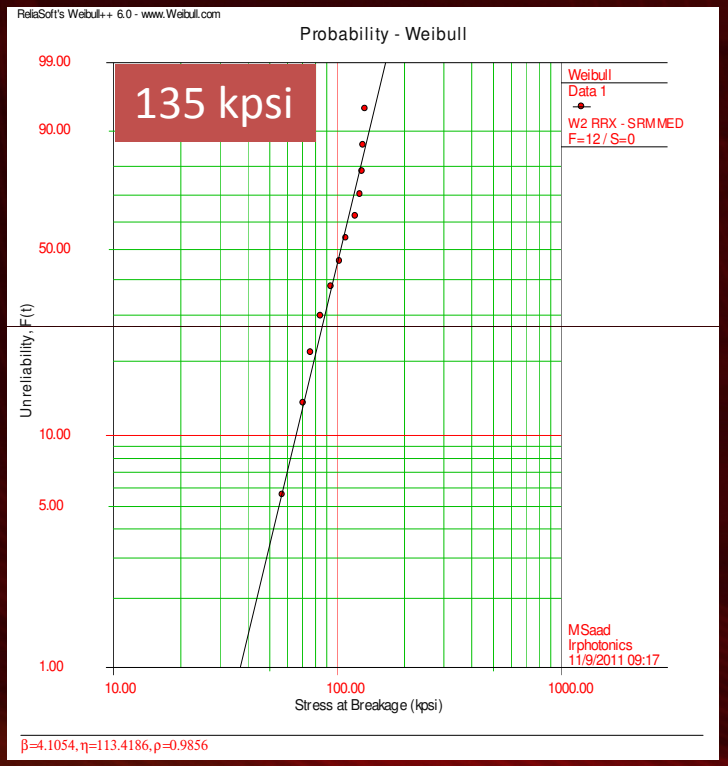
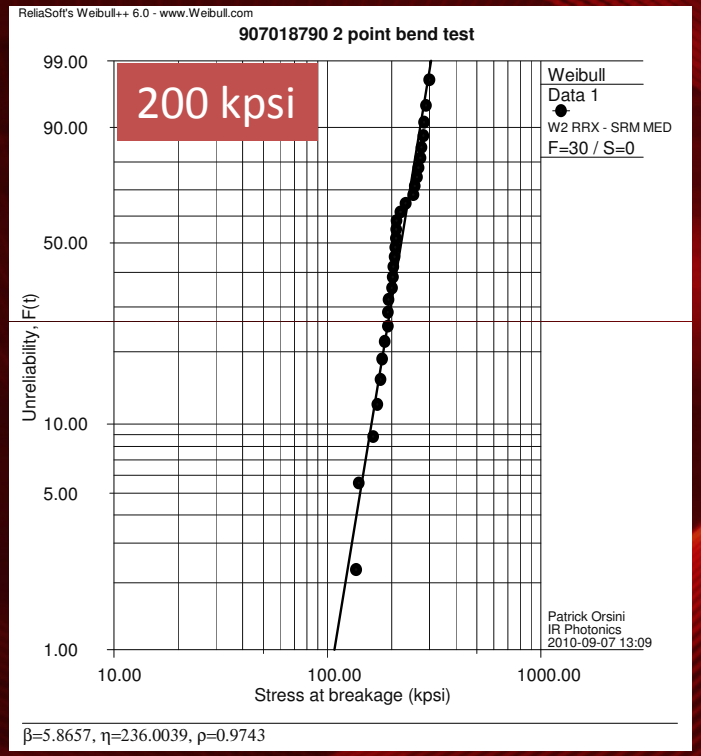
Fluoride Fibers Tensile & Bending Strength





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Applications

- Spectroscopy (multispectral)
- Sensing
- Laser Power delivery
- Medical
- Fiber lasers and amplifiers
- Defense and Aerospace
  - ✓ Infrared countermeasure (IRCM)

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Fiber Handling

- Fiber cleaving
- Fiber polishing
- Fiber Stripping
- Fiber Splicing
- Fiber tapering

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Cleaving and polishing

- Fluoride fibers are cleaved using standard cleavers
  - ✓Vytran; York…..
  - ✓The tension has to be adjusted
- Fiber can be also polished

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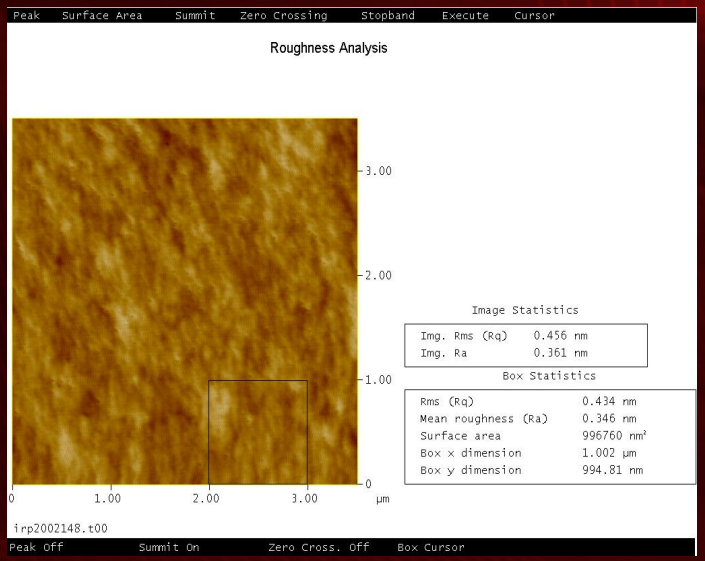
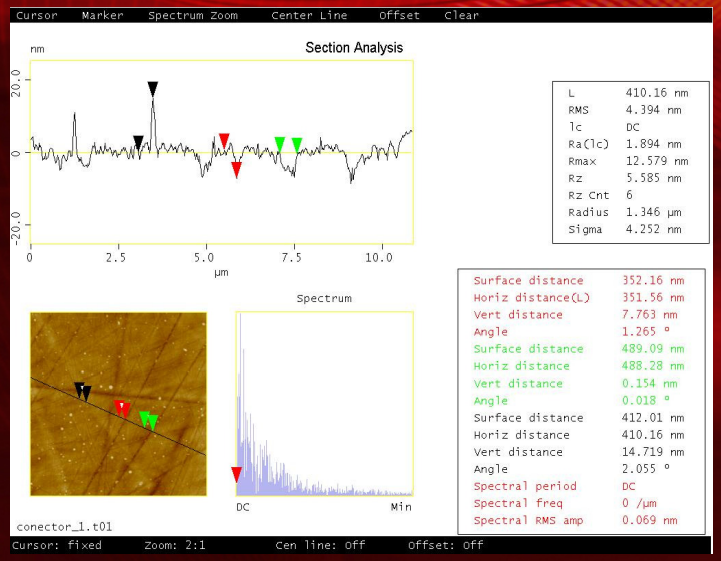
AFM Scan of Cleaved and Polished 450 umfiber



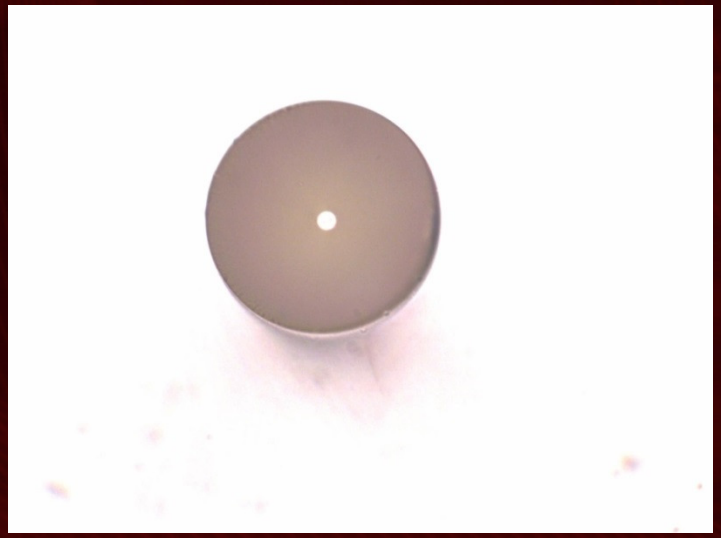


Cleaved
0.456nm rms

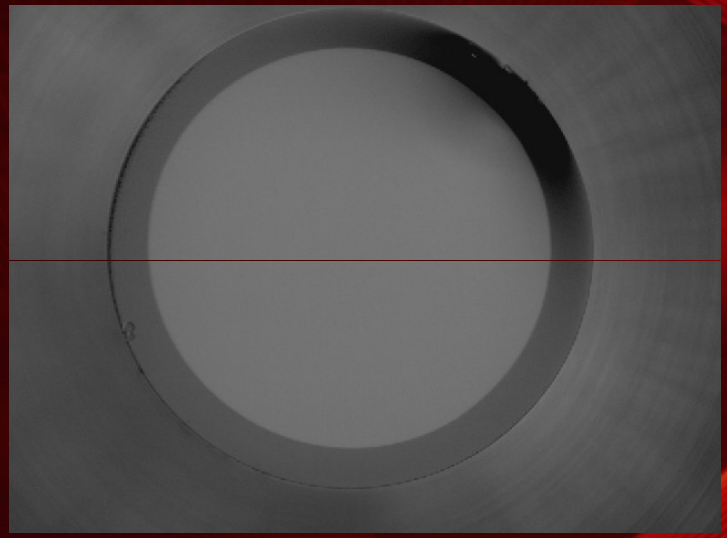
Polished
4.394nm rms

Cleaving recommended for higher power handling

Cleaved Fluoride Fibers



SM 9 µm core



450 µm core

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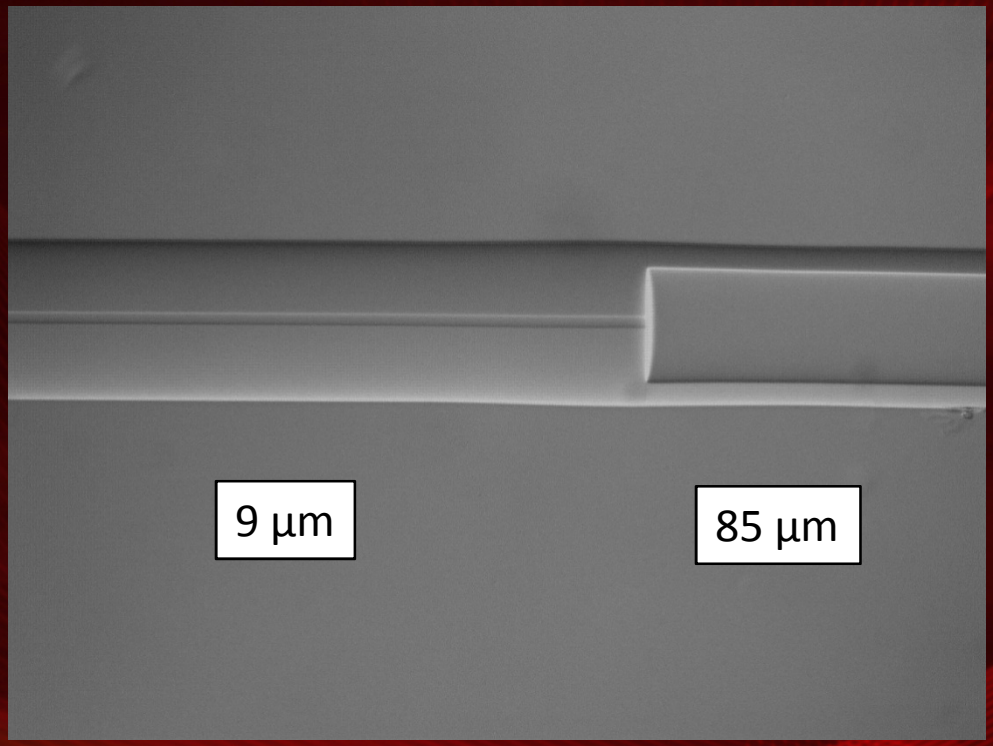
Splice 9 & 85 µm ZBLAN Fibers



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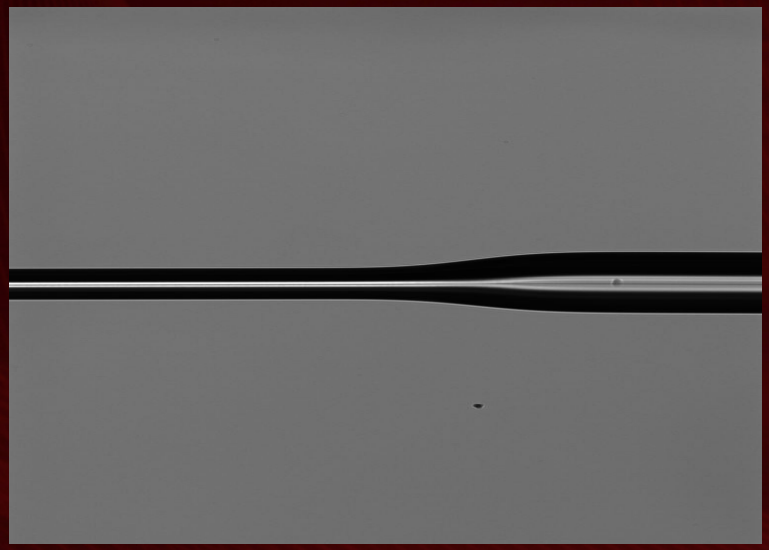
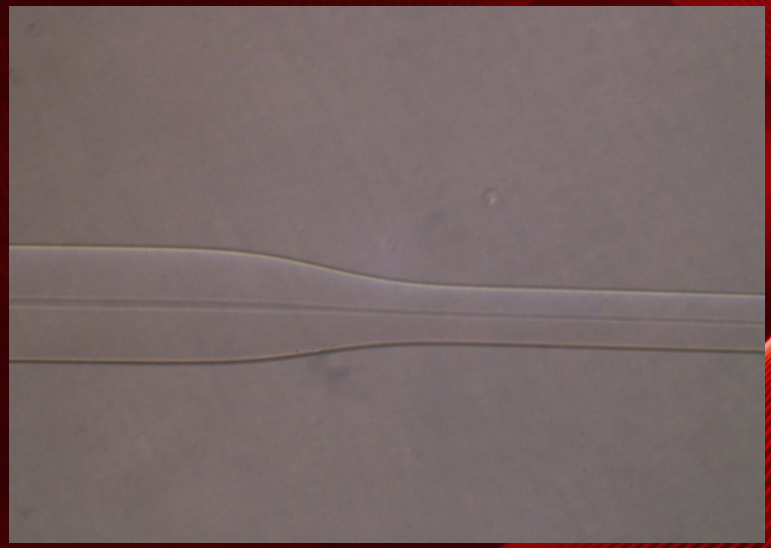
ZBLAN Taper





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Bragg Grating

- Femtosecond 800 nm laser
  - Laval University (Quebec city)
  - CNRC laboratory (Ottawa)
- Ce-doped Fibers (CNET)
  - ✓ CNET 10000 ppm Ce
  - ✓ Ryerson University/Irphotonics (Thorlabs)
    - 50.000 ppm Ce (97% Reflectivity)

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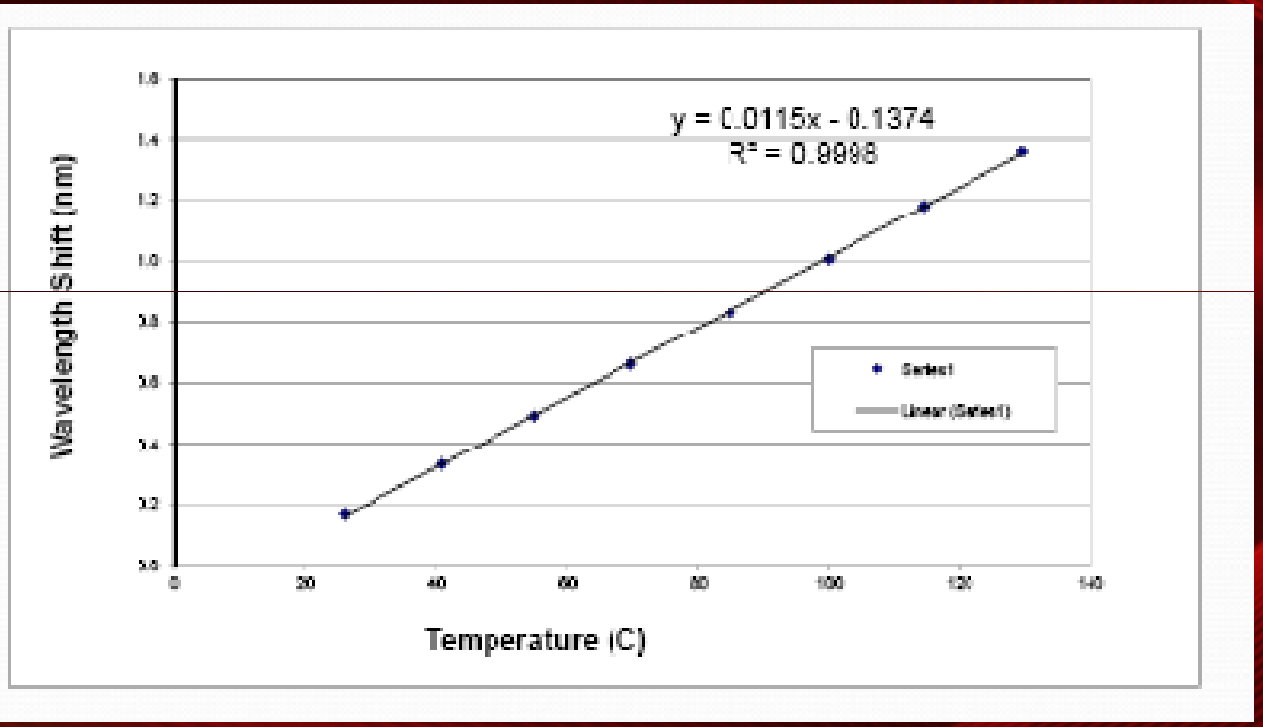
Ce FBG's Temperature dependence

11.5pm/c 15 % larger than Silica FBG



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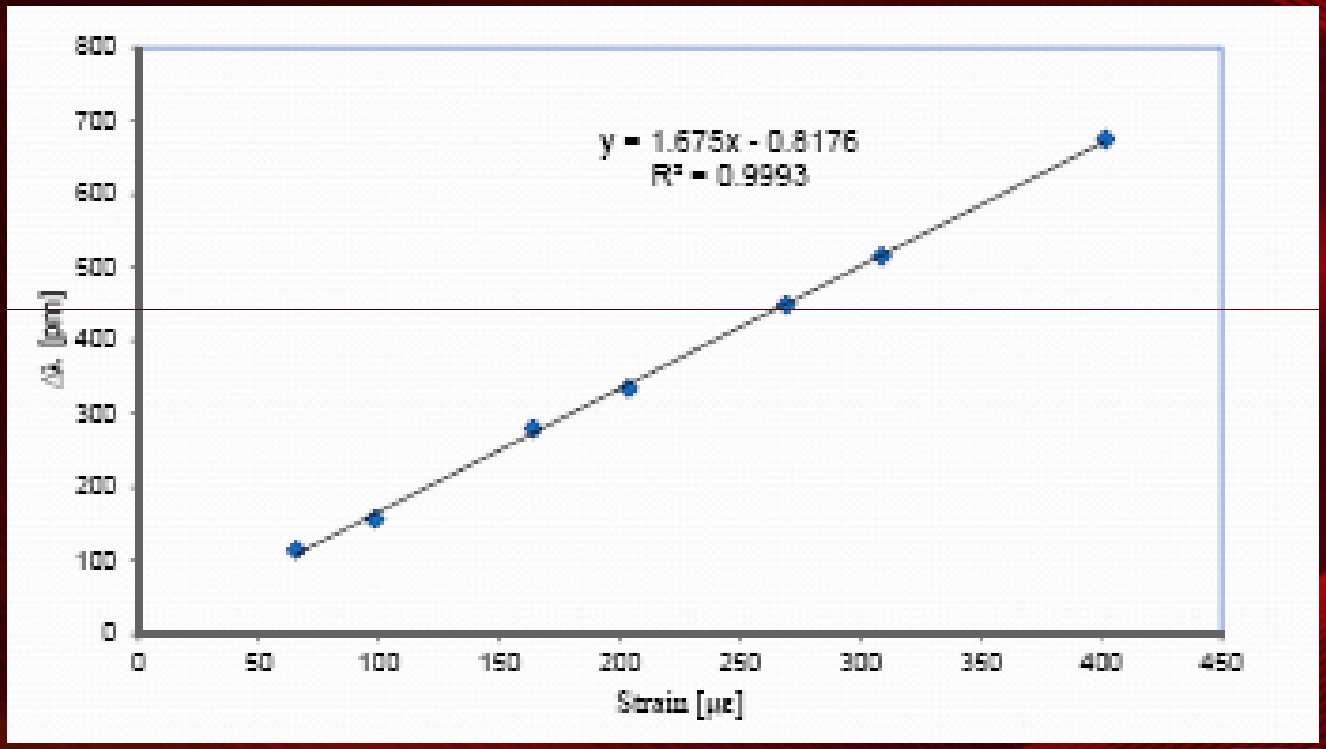
Ce FBG's Strain dependence

1.67pm/με 40% larger Silica FBG



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Fiber lasers

- Fluoride Glasses have low phonon energy
- High solubility of rare-earth elements
  - ✓Up to 100000 ppm
- Doped and co-dope
- New Laser lines
- Transparent at many pump λ

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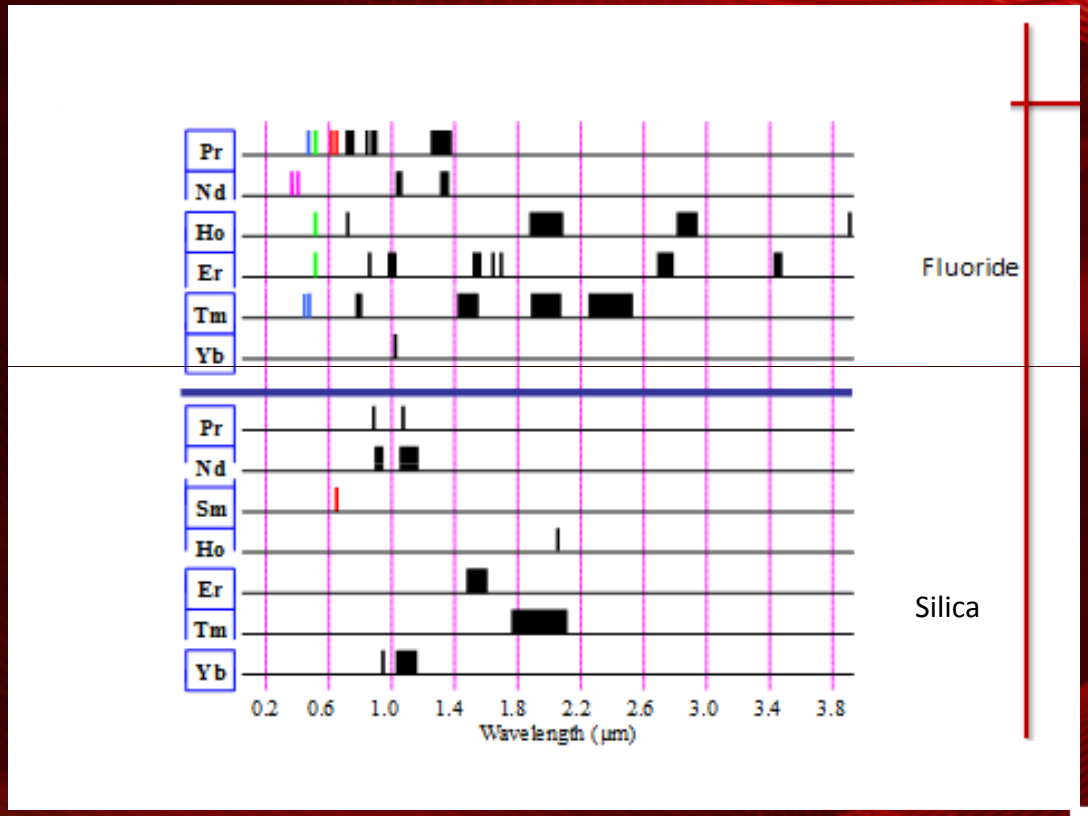
Fiber Laser lines in Fluoride and silica



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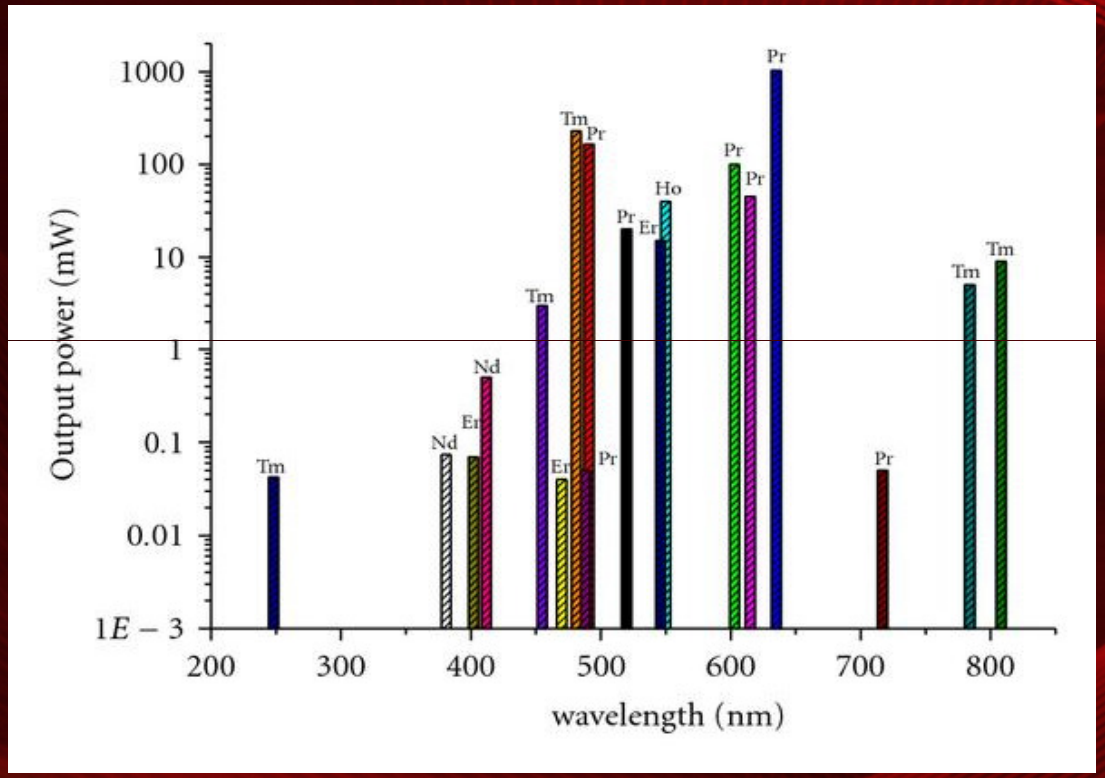
UV-Vis ZBLAN Lasers



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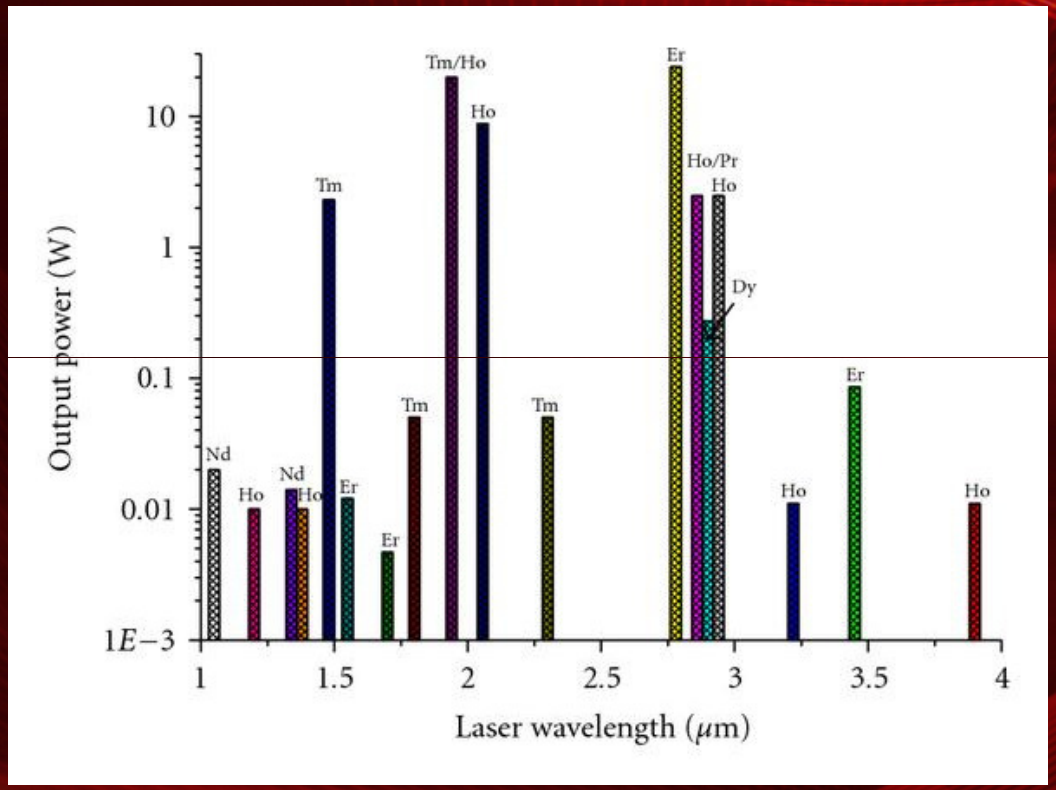
Mid-Infrared ZBLAN lasers



Xiushan Zhu and N. Peyghambarian;
"High Power ZBLAN Glass fiber Lasers: Review and Prospect"

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Planar and Channel Waveguides

- Planar and channel wave guides have investigated using fluoride glasses
  - ✓ Photolithography
  - ✓ Ions plantation (dn -1 10^{-3})
  - ✓ ~~Ion exchange (graded –index profile)~~
  - ✓ Physical vapor deposition (PVD)
  - ✓ Sputtering
  - ✓ Metallography chemical deposition
  - ✓ Pulsed laser deposition
  - ✓ Sol Gel
- Loss 0.1 to 0.3 dB/cm

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Some Integrated Devices

- INO has developed a Fiber-pigtailed integrated spectrometer (2 to 6 µm)
  - ✓ ~~Fluoride fiber & slab waveguide~~
- Tm doped ZBLAN waveguide laser
- Optical waveguide amplifier

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Reliability

- Very limited interaction with atmospheric water
- Fluoride glasses are stable in standard environment
  - ✓ Glass samples can be hold for years in ambient air
  - ✓ Our fiber are stored in standard environment

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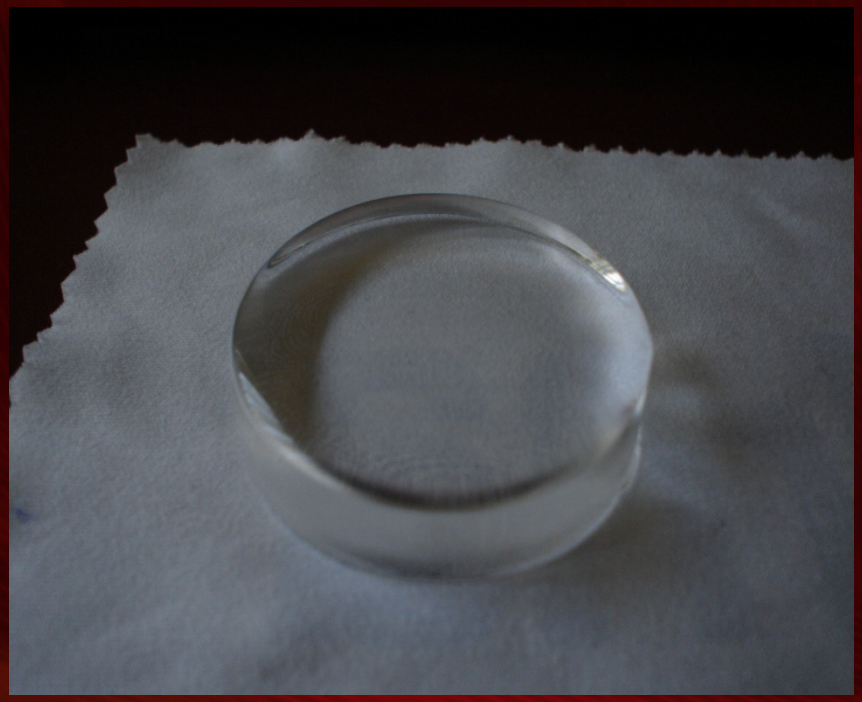
ZBLAN Fluoride glasses 8 years in ambient air



InF3 Glass is much more resistant to liquid water attack than ZBLAN

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Reliability

- Liquid water will attack fluoride glass over time,
  - ✓ Water pH strongly influences dissolution rate
    - Most studies performed with acidic DI water (pH 5)
  - Condensation is a real world deployment concern
- But Solutions exist!
- Straightforward hermetic sealing of fiber cables is the norm for harsh deployment of any fiber, SiO2 included
- We have developed a complete hermitic cable for harsh environment

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Conclusion

- Tremendous progress has been made in Infrared fluoride glass technology
- High quality Infrared fibers with extended transmission have been developed (InF3)
- Many new laser lines have been reported
- High quality channel and planar waveguides and integrated devices have been reported

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