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Fluoride Glasses and Fiber for Mid-IR Applications

Mohammed Saad, Ph.D.
Senior Scientist
Philadelphia Sept 2014

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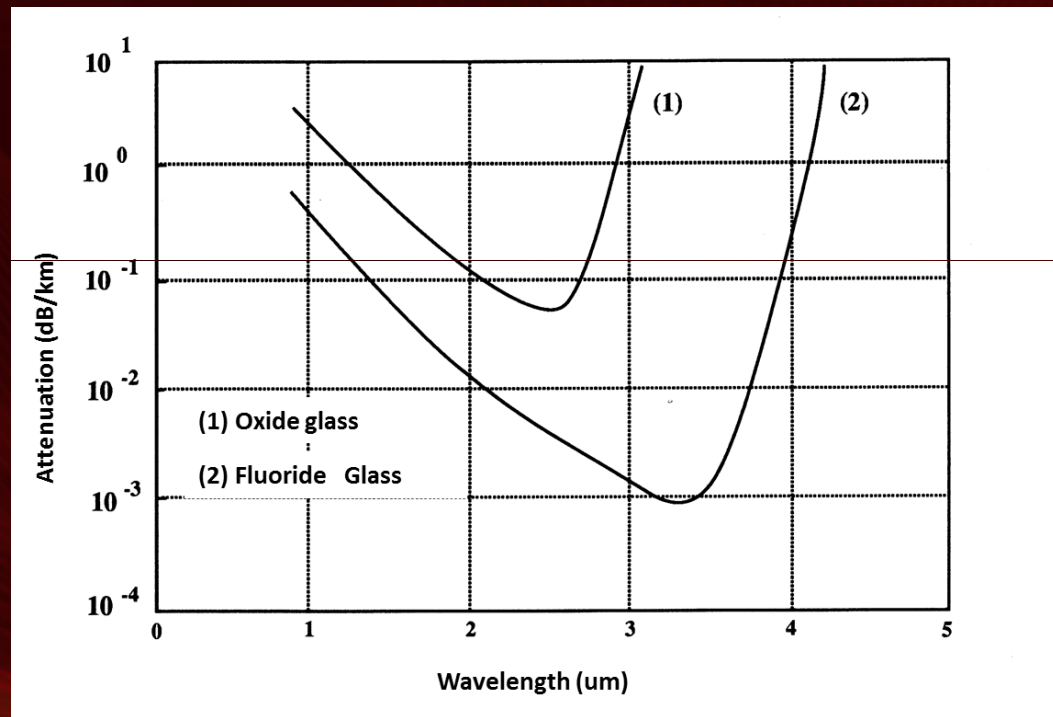
Outline

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

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

Fluoride Vs Silica Theoretical attenuation



Glass Families

- Large choice of compositions
 - ✓ Glass properties can be tailored for each application
- Fluorozirconate ZrF_4 (ZBLAN)
- Fluoroindate InF_3
- Fluoroaluminate (insoluble in hot water)
- Fluorogallate, Fluorozincate,...
- Mix of different glass families

Fluoride glasses properties

Glass	Tg (C)	n _D	CTE 10 ⁻⁷ /k
ZrF ₄	230 to 300	1,48 to 1.53	150 to 200
InF ₃	290 to 320	1.48 to 1.53	170 to 190
CdF ₂	300 to 360	1.48 to 1.50	150 to 180
ZnF ₂	280 to 320	1,50 to 1.54	170 to 200
AlF ₃	380 to 420	1.42 to 1.46	140 to 160

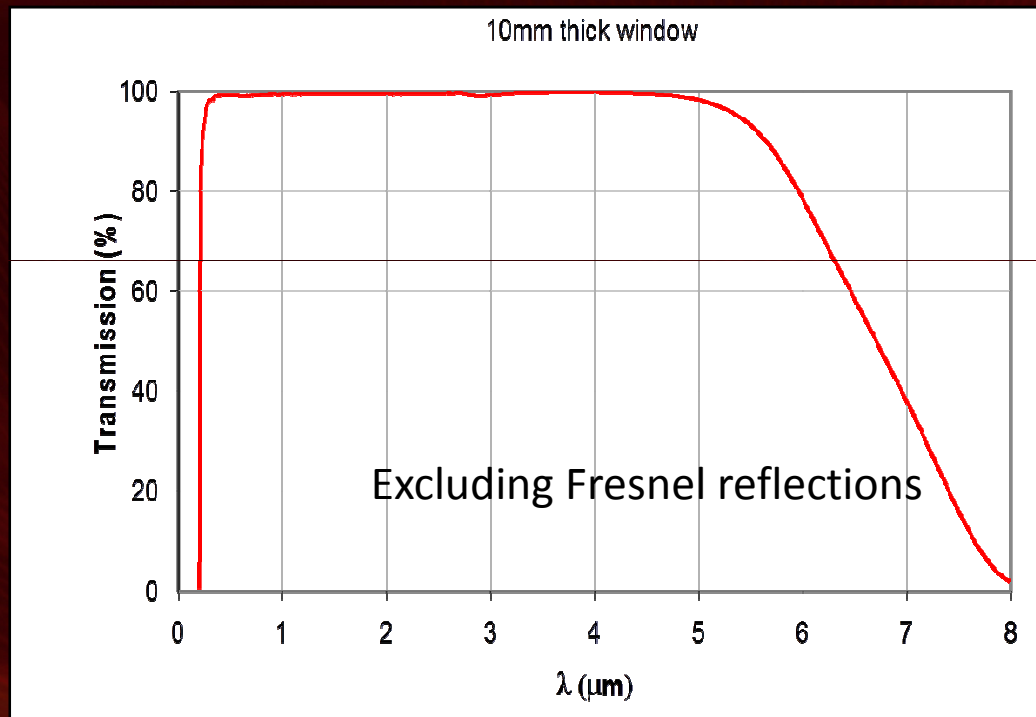
Outstanding properties

- 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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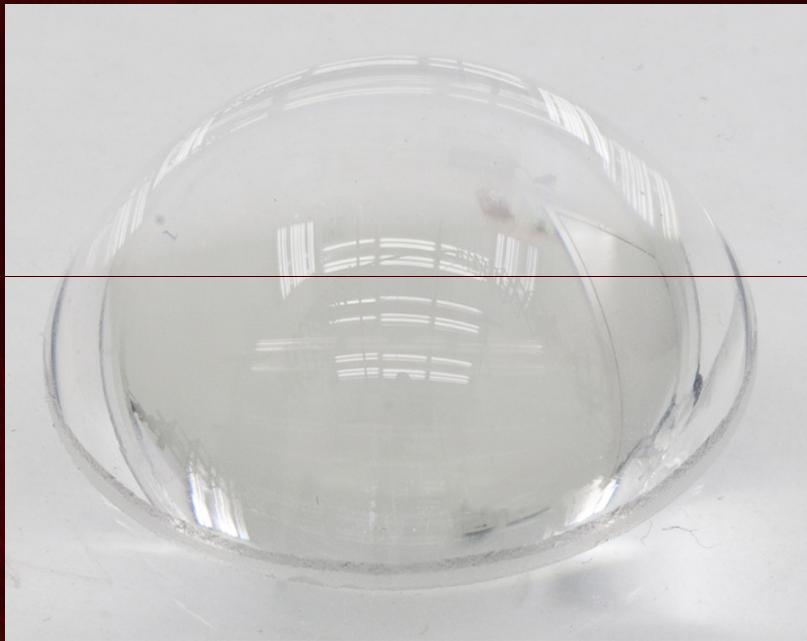
ZBLAN Standard fluoride Transmission window



Fluoride Glasses

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

ZBLAN SPDT



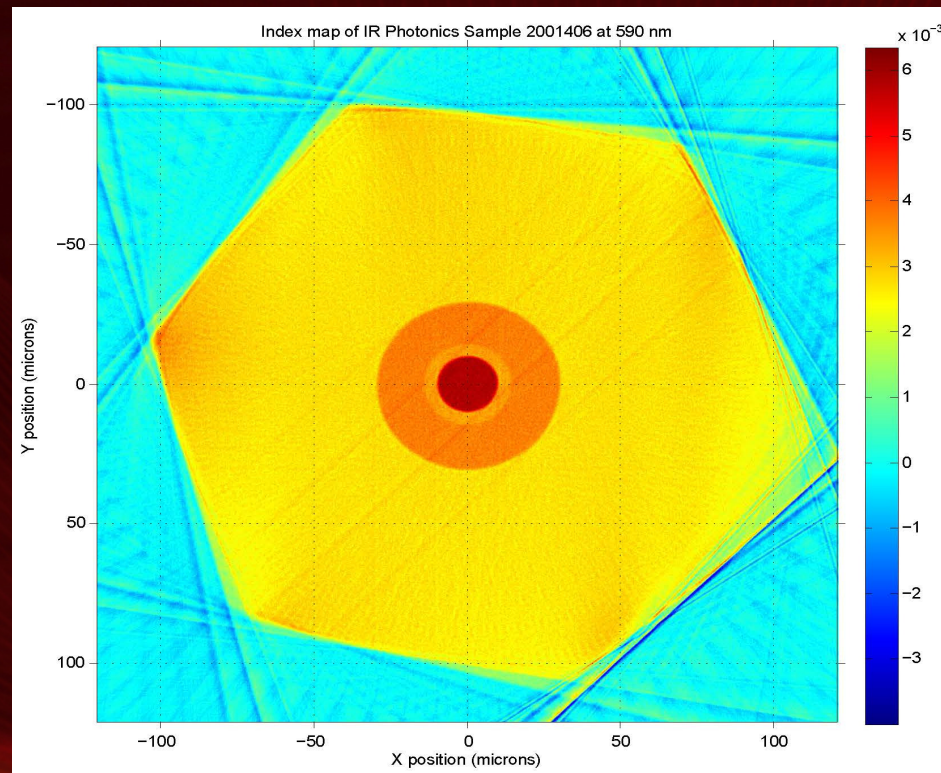
Roughness 2 nm

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Fluoride Fibers

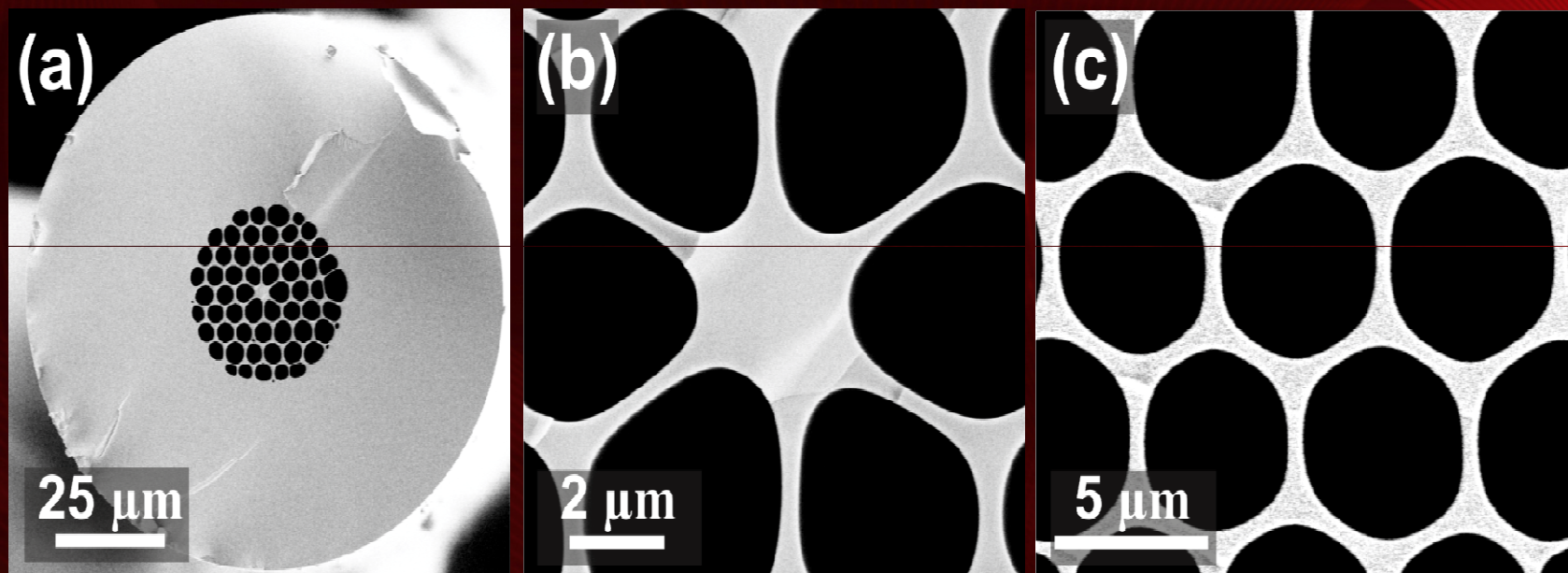
- Drawn from solid preforms
- Same technique used for silica
 - ✓ Good control of the fiber parameters
 - Dimension
 - Concentricity
 - Numerical Aperture (NA)
- Single & multimode fibers
- Exotic shapes are possible
 - Hexagonal, D shaped, PCF....

Hexagonal ZBLAN Fiber



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ZBLAN PCF Fiber



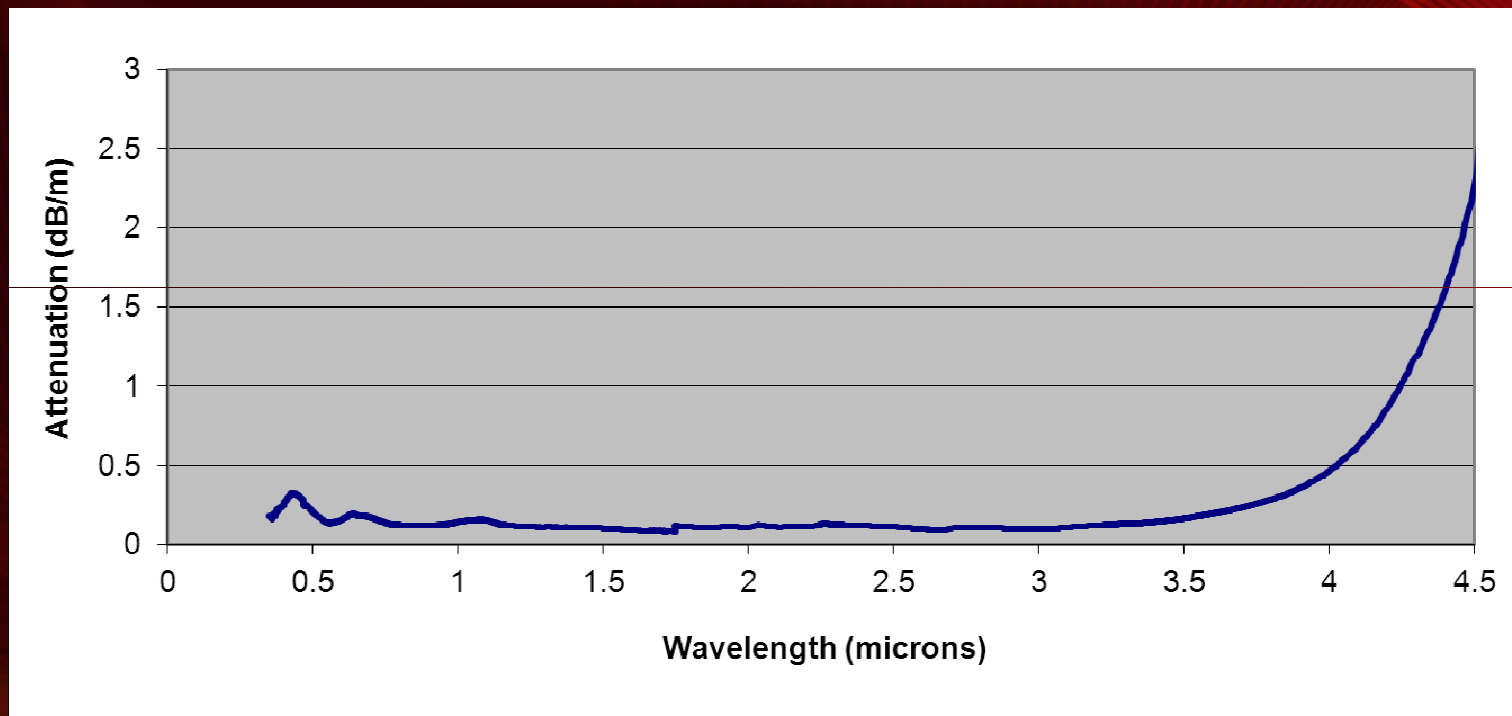
Collaboration work with Max Planck Institute

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Fluoride Fibers

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

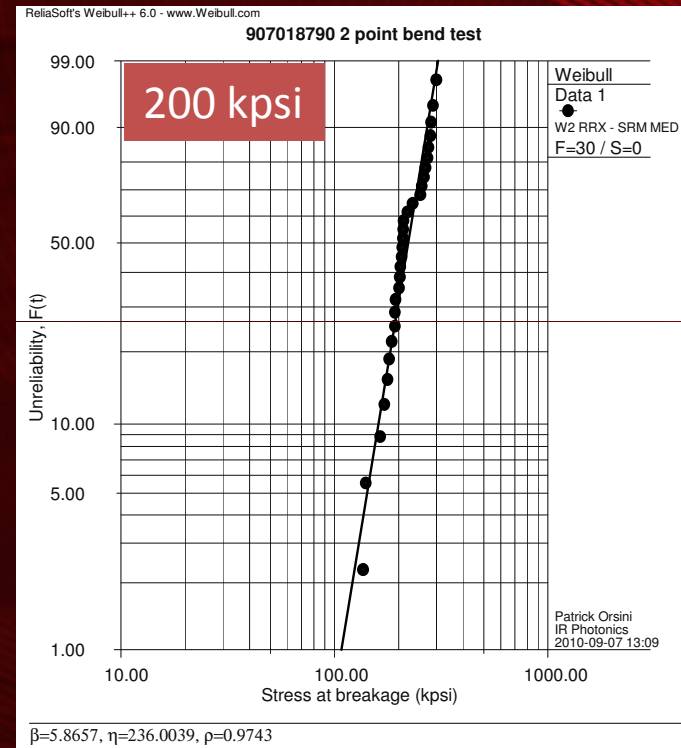
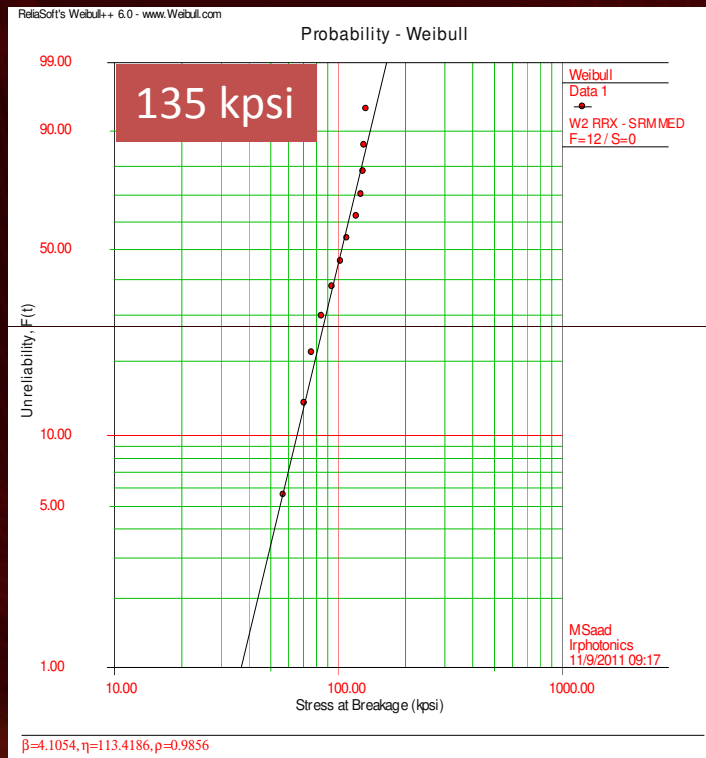
Standard ZBLAN fiber transmission (Vis-Mid-IR up to 4.3 μm)





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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)

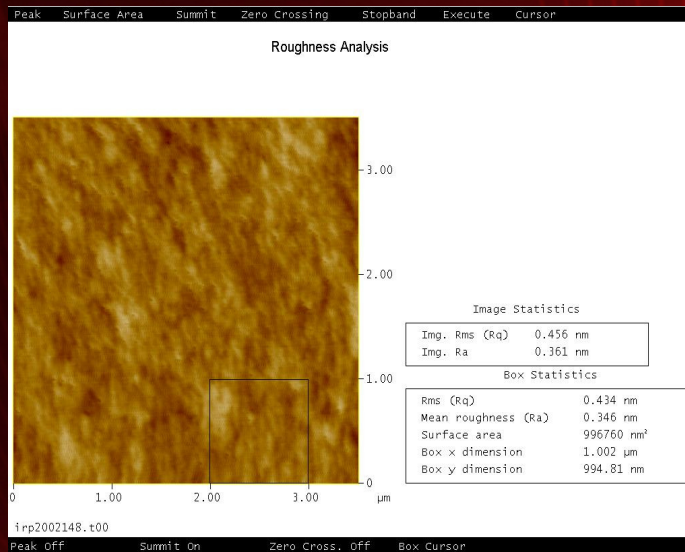
Fiber Handling

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

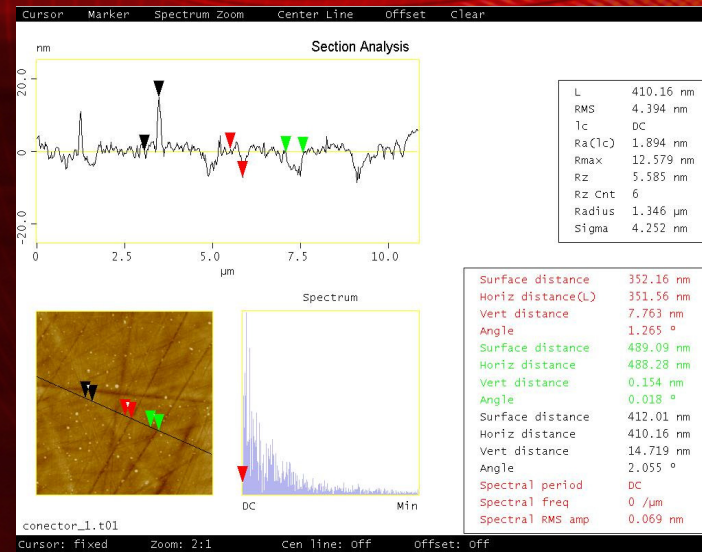
Cleaving and polishing

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

AFM Scan of Cleaved and Polished 450 umfiber



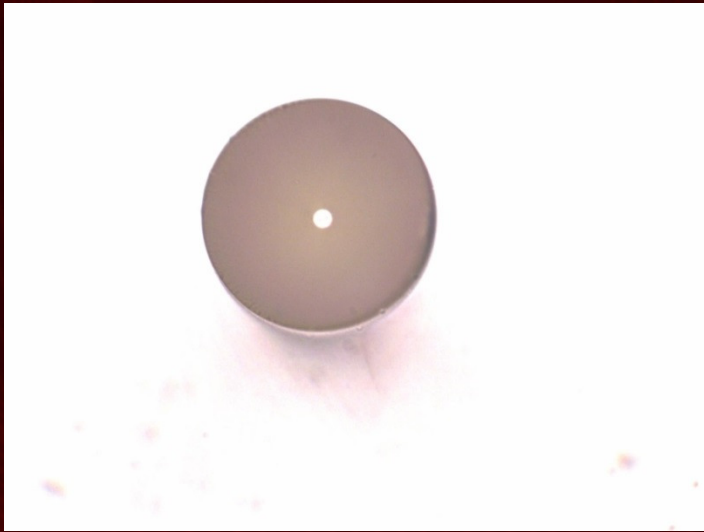
Cleaved
0.456nm rms



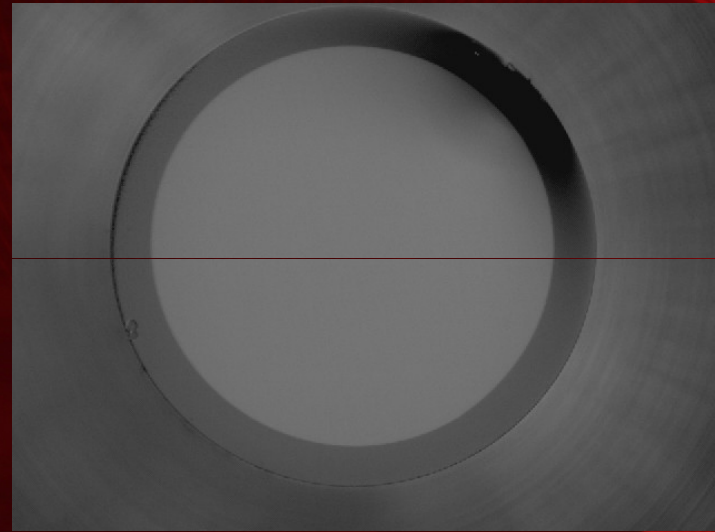
Polished
4.394nm rms

Cleaving recommended for higher power handling

Cleaved Fluoride Fibers



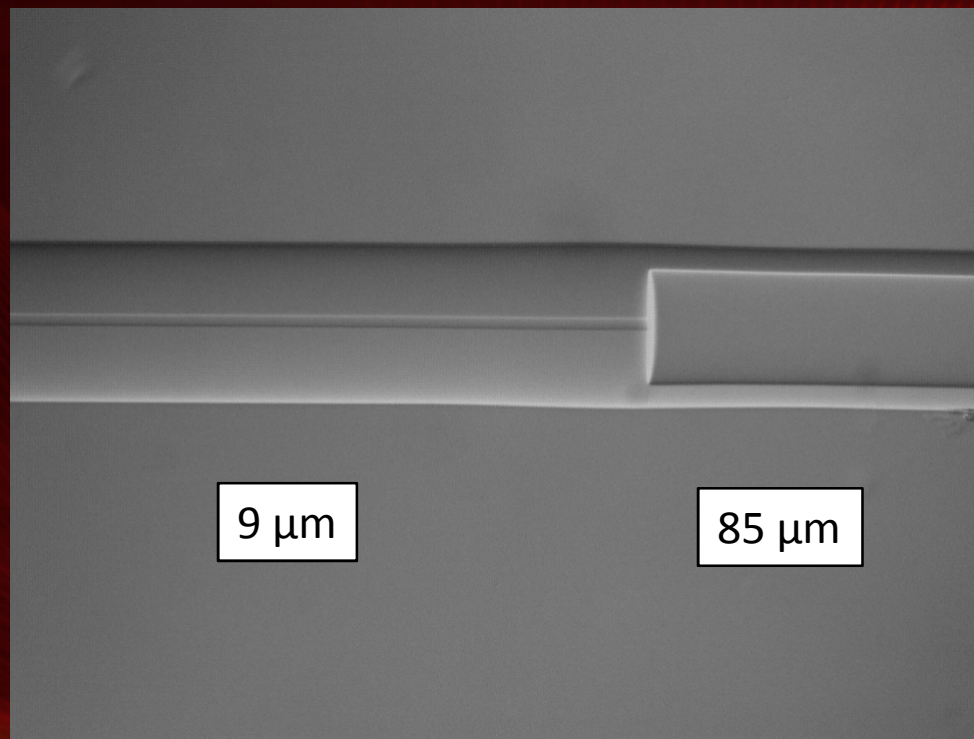
SM 9 μm core



450 μm core

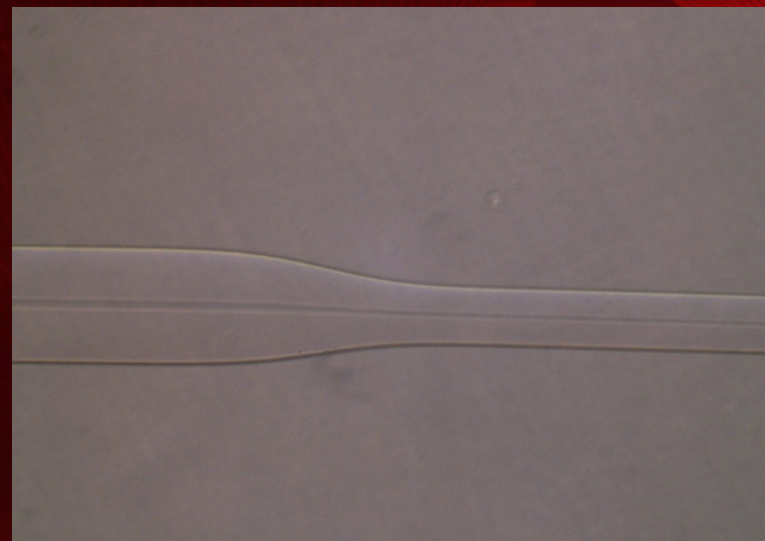
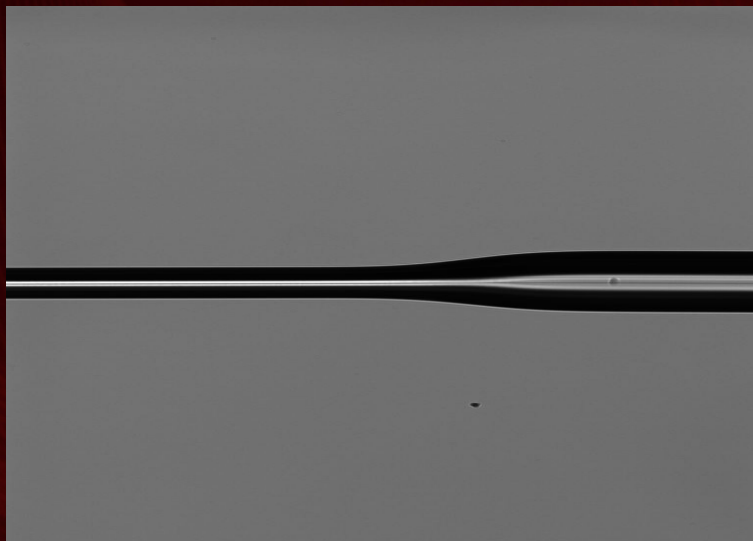
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Splice 9 & 85 μm ZBLAN Fibers



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ZBLAN Taper



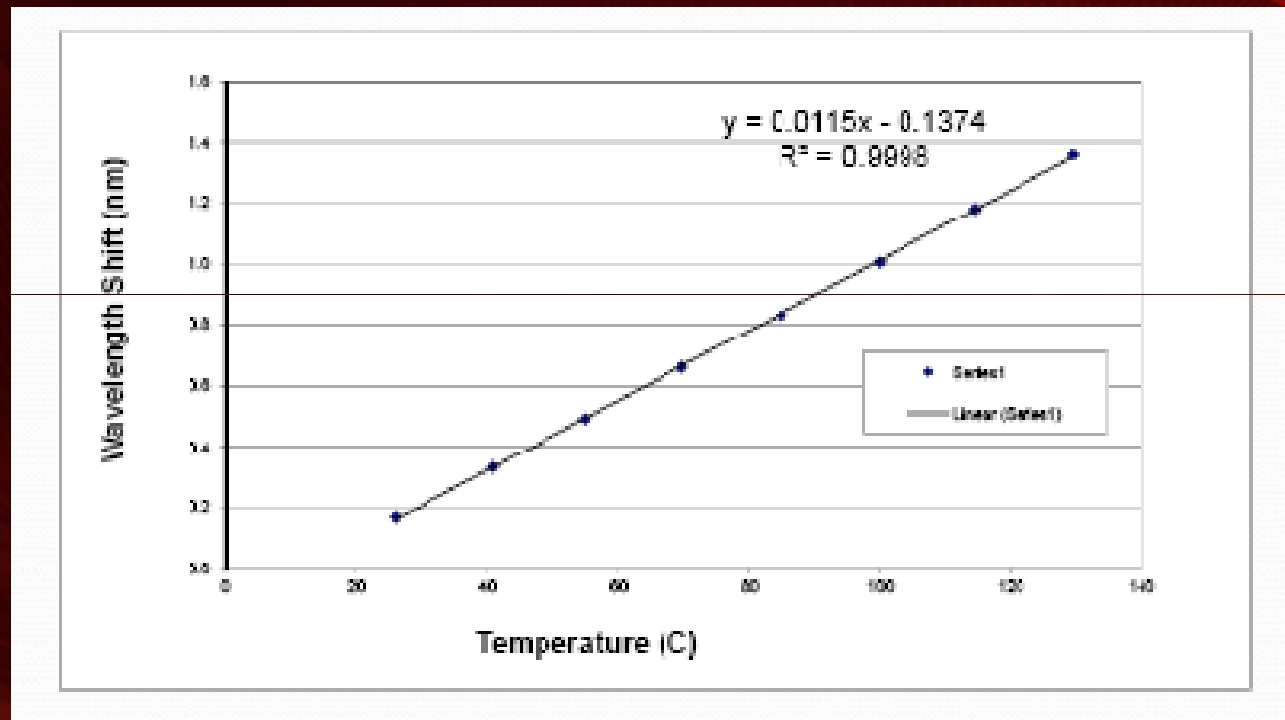
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Bragg Grating

- 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)

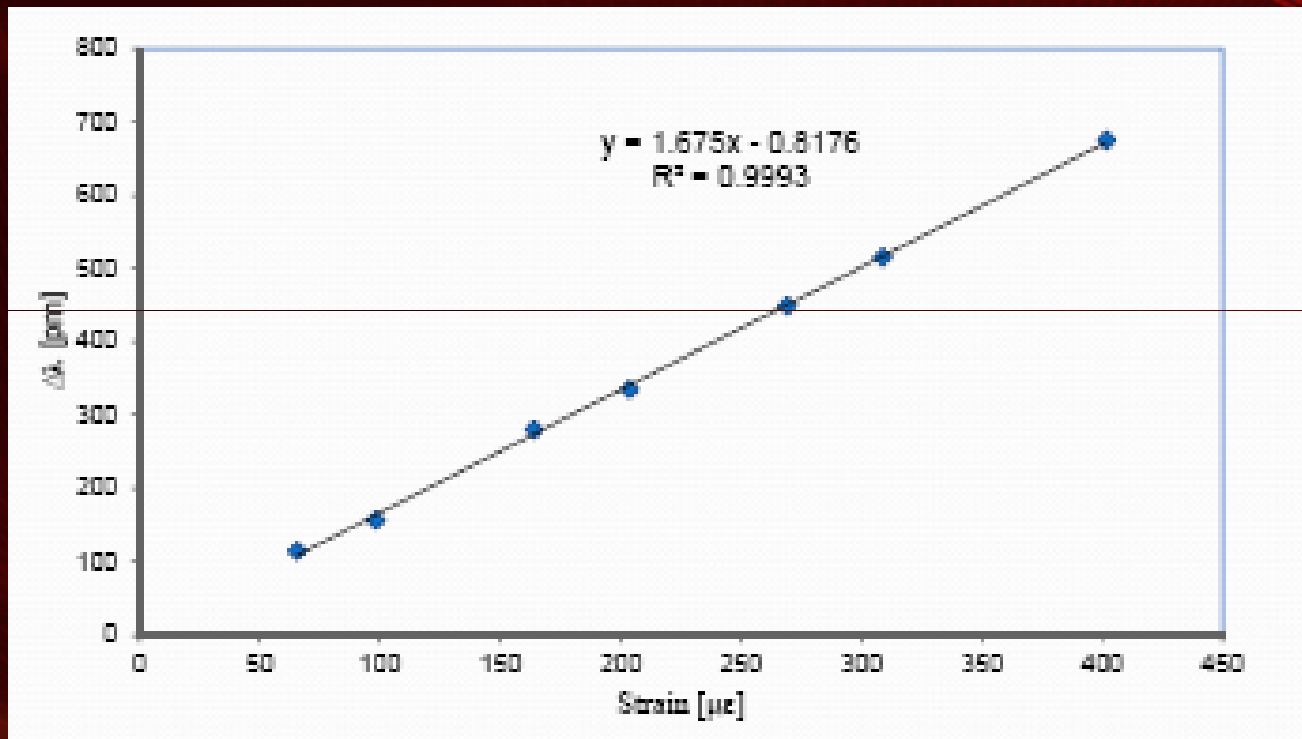
Ce FBG's Temperature dependence

11.5pm/c 15 % larger than Silica FBG



Ce FBG's Strain dependence

1.67pm/ $\mu\epsilon$ 40% larger Silica FBG



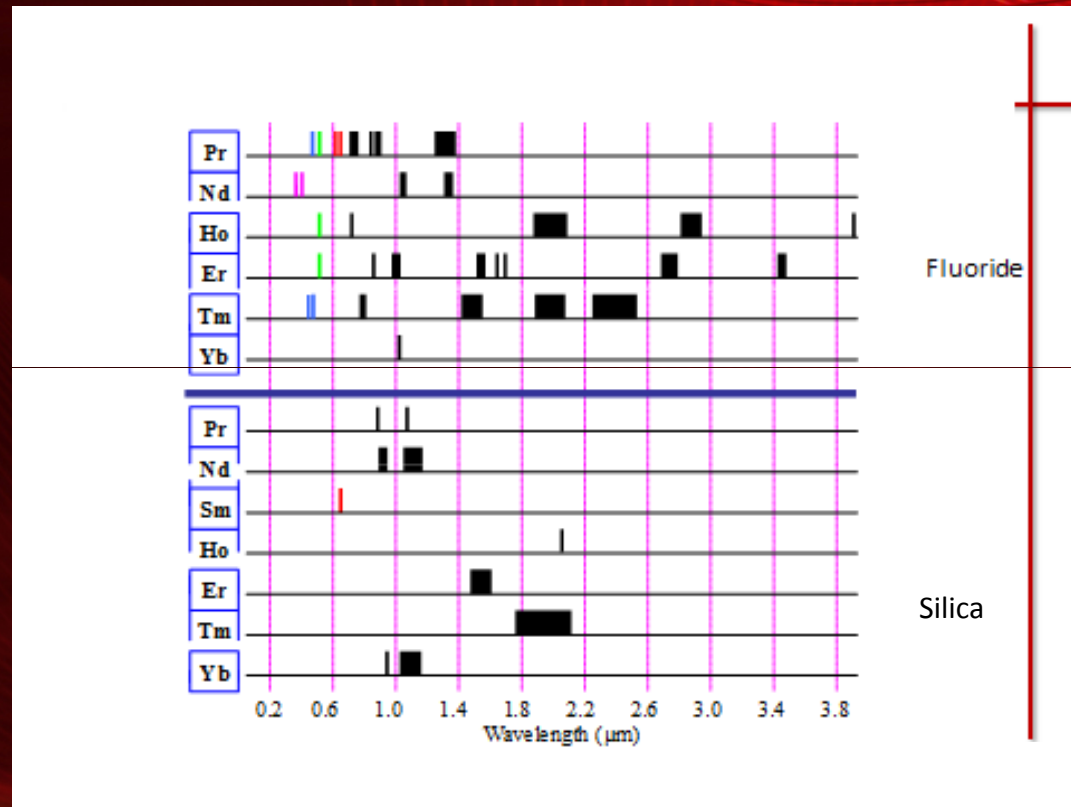
Fiber lasers

- 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

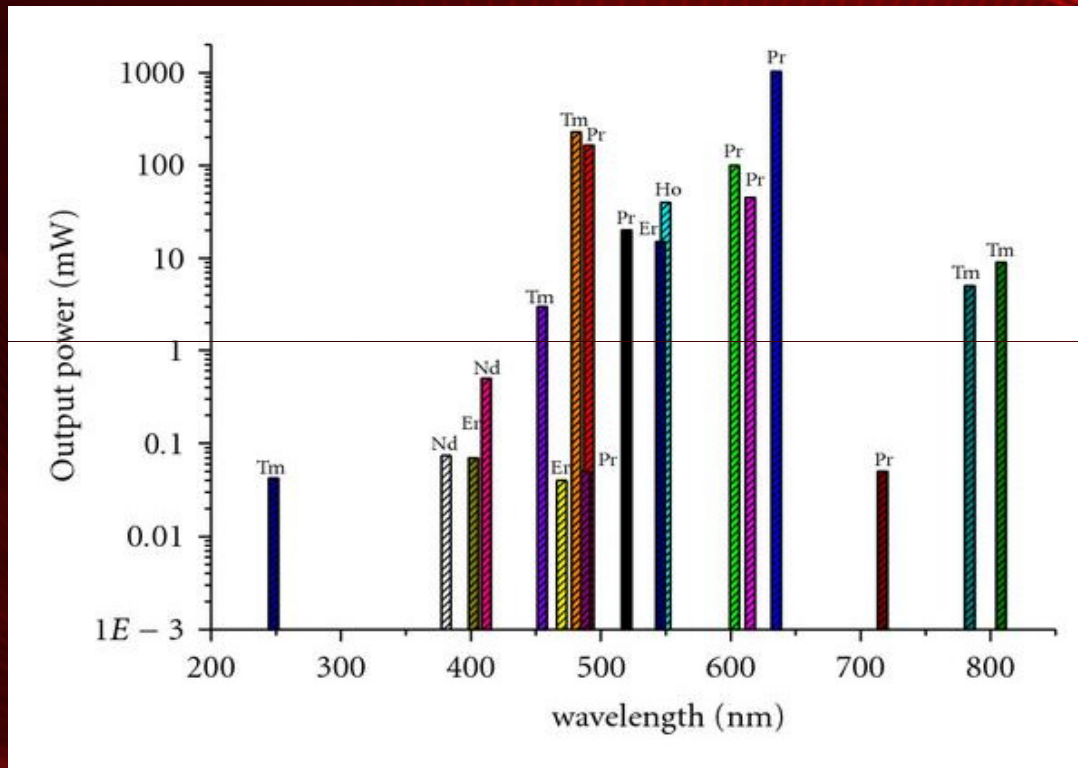


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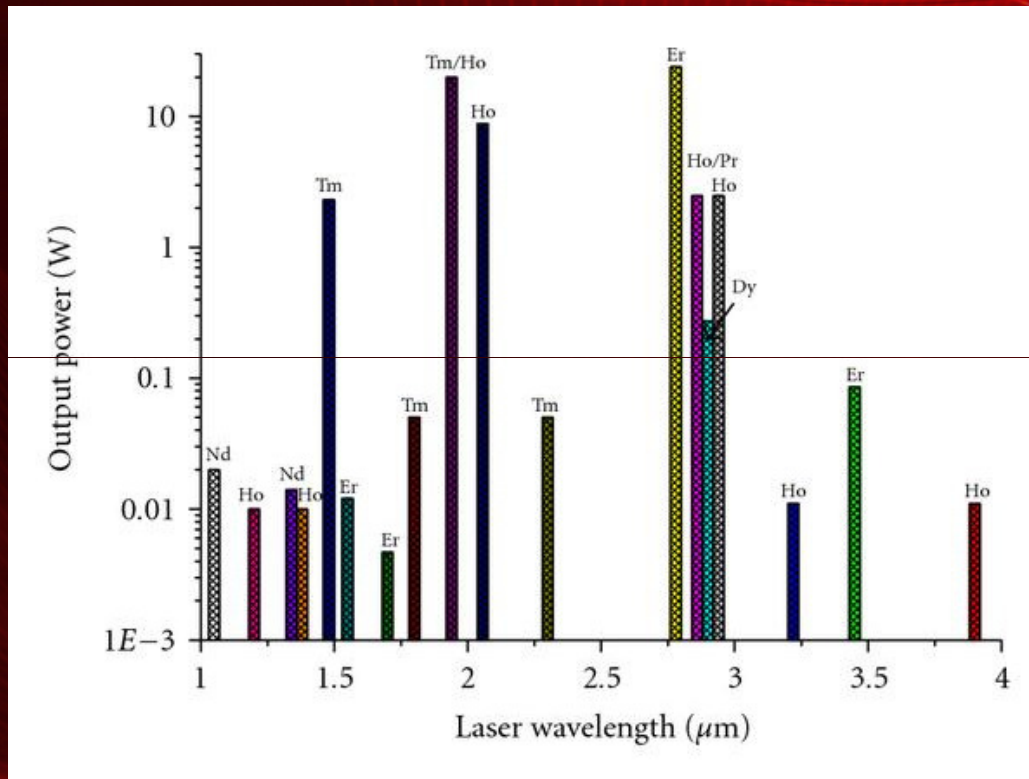
Fiber Laser lines in Fluoride and silica



UV-Vis ZBLAN Lasers



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
 - ✓ Ion implantation ($dn \sim 10^{-3}$)
 - ✓ 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

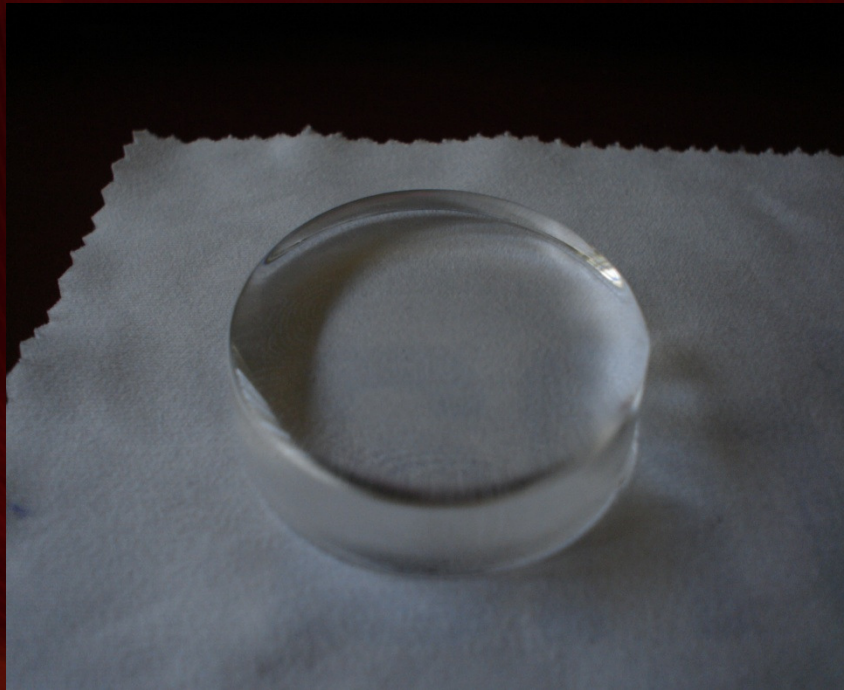
Some Integrated Devices

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

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

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

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

Thank you



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Omics group international

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