ISSRDC

ZBLAN Optical Fibers Manufactured in Space:

Commercial-Grade Standard Requirements from an Industry Perspective

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Prof. William A Goddard - Caltech; Prof Qi An - Iowa State University

AIRBUS

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BACKGROUND

1974: discovery of the first fluorozirconate glasses (Rennes Univ. - France)

1977: **first fluoride glass fiber** (CNET, Rennes Univ.)
founding of Le Verre Fluoré (LVF)

1980: typical ZBLAN glass compositions (Rennes Univ.)
first fluoroindate glasses (Rennes Univ.)

1987: **fluoride glass fiber laser** (BTRL, CNET)

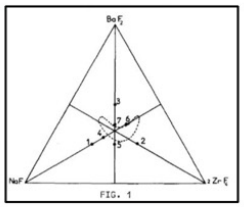
1991: typical InF_3 glass compositions (Rennes Univ.)

2006: Mid-IR SC ZBLAN fiber source (Michigan Univ, Omni Science, LVF)

2009: **first commercial mid-IR SC fluoride fiber source** (LVF)

2013: Mid-IR SC InF_3 fiber source (DRDC, INRS-EMT)

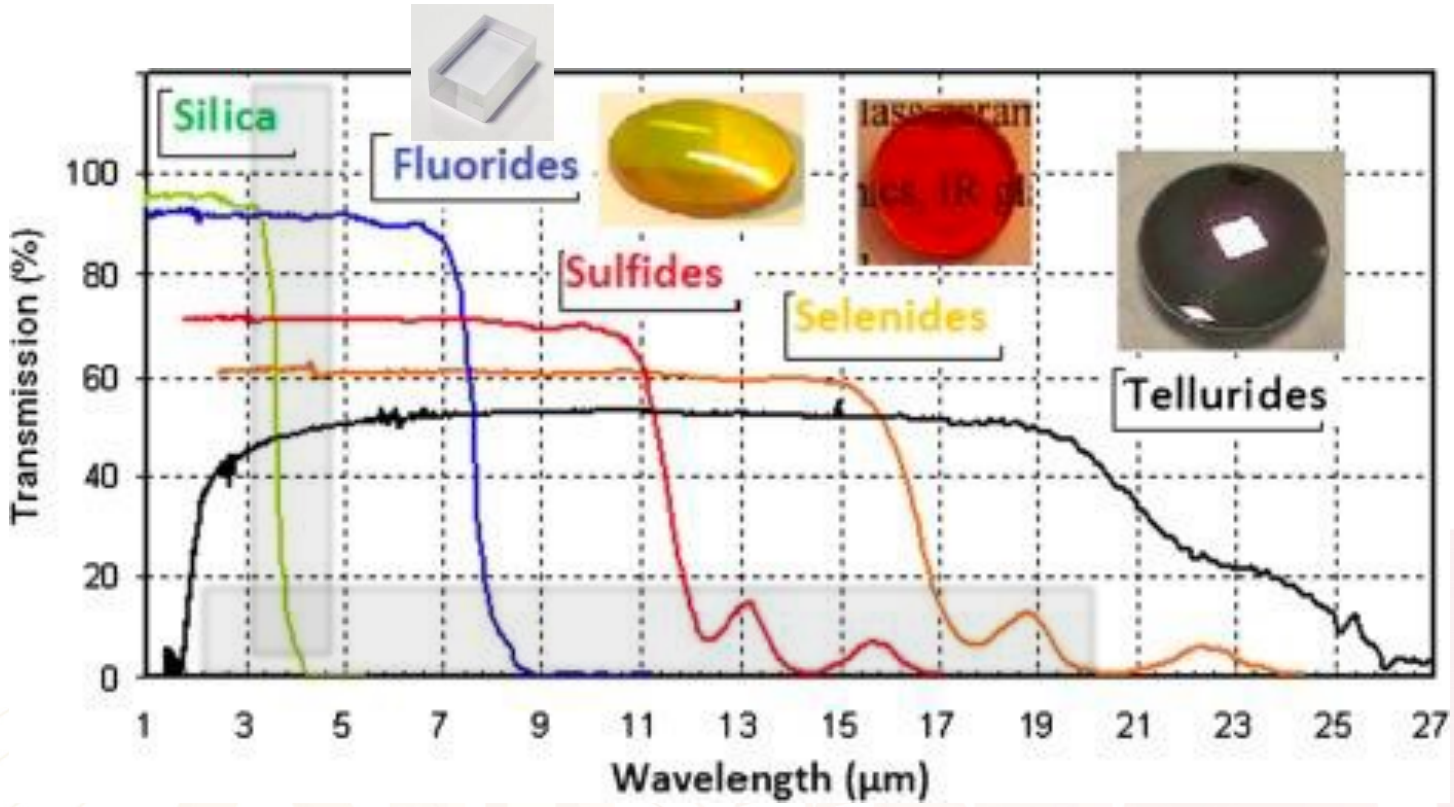
Fluorozirconate glass discovery (1974)


ZrF4-BaF2-NaF glass forming area (1)


Fluoride glass casting (1982)

(1) M. Poulain et al. , «Verres fluores au tetrafluorurede zirconium proprieties optiques d'un verre dope au Nd3+», *Mater. Res. Bull.*, vol. 10, no 4, p. 243-246, (1975).

GENERAL PROPERTIES



3-5 μm: atmospheric transparency window
2-20 μm: molecular fingerprinting window

1. ZBLAN GLASSES – ZFG

$53ZrF_4$-$20BaF_2$-$4LaF_3$-$3AlF_3$-20 NaF

Transmission (3-4 mm thick sample): *0.220-7* μm

2. InF_3 GLASSES – IFG

$40InF_3$-$20ZnF_2$-$20SrF_2$-$20BaF_2$

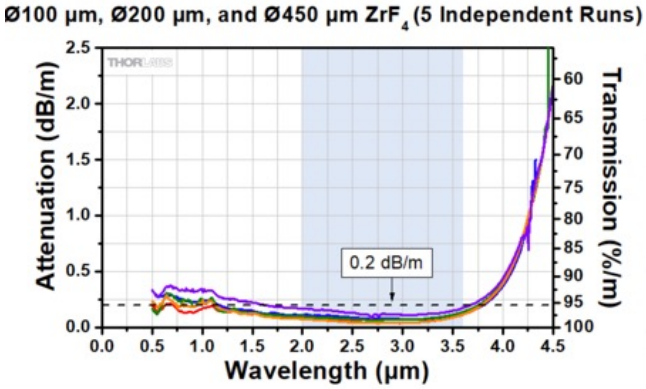
Transmission (3-4 mm thick sample): *0.255-8* μm

LEADING TERRESTRIAL MANUFACTURERS

50 years of experience;
Thousands of compositions

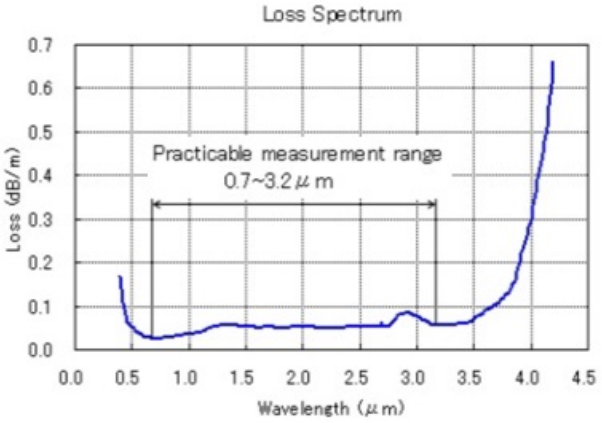
There are 3 high quality fluoride fibers providers in the world today

THORLABS



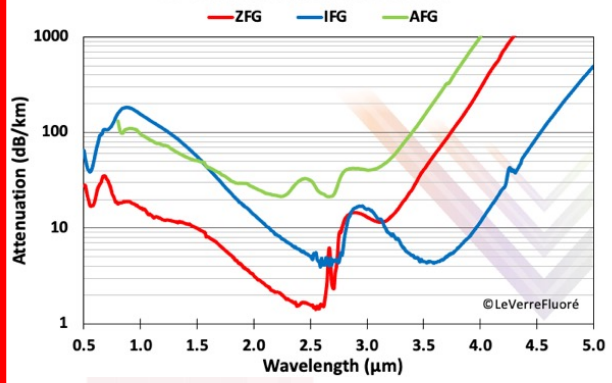
Thorlabs: 200-250dB/km at 2500nm

FiberLabs Inc.



FiberLabs: 50 dB/km at 2500nm

LE VERRE FLUORÉ
INFRARED SOLUTIONS



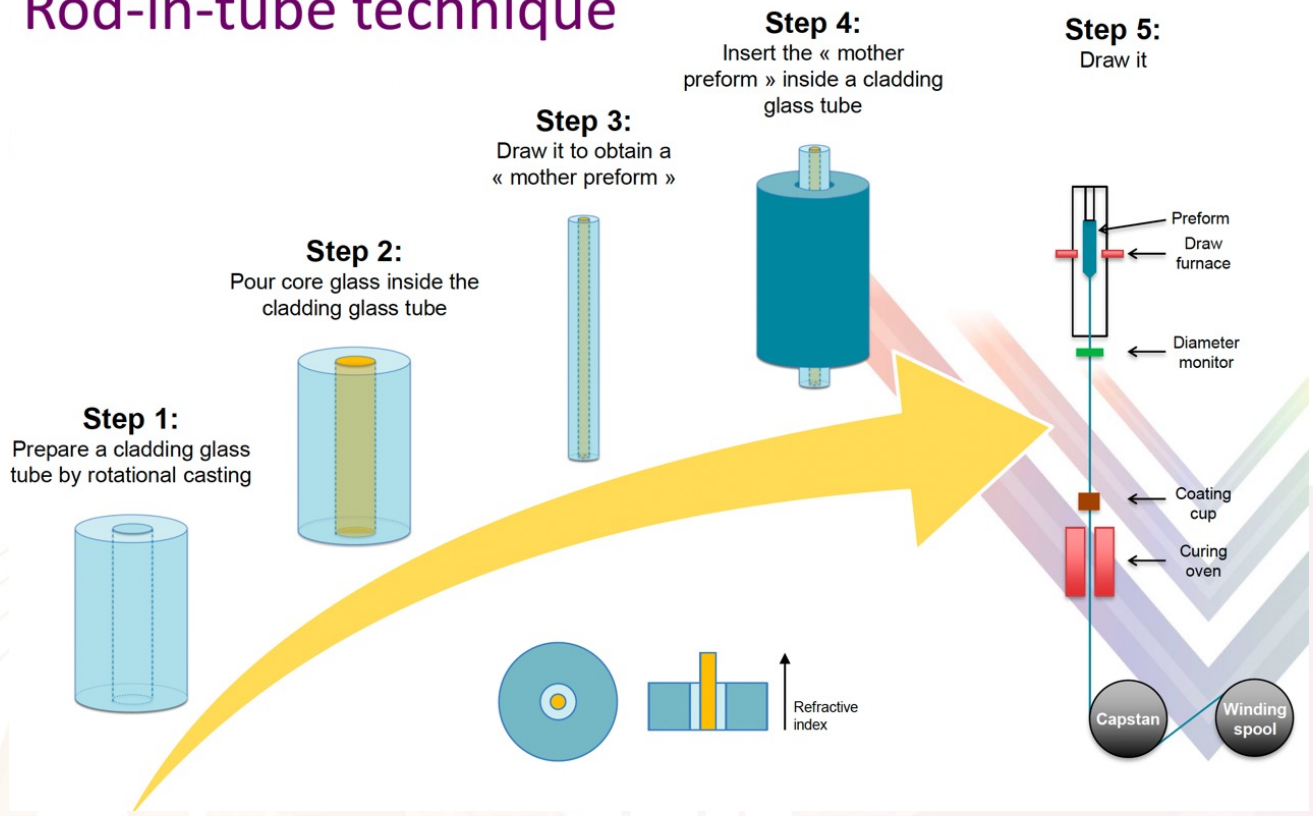
Industry best:
MM: **<10** dB/km at 2560nm (ZFG)
<10 dB/km at 3670nm (IFG)
SM: **1.04** dB/km at 2560nm (ZFG)
2.20 dB/km at 3670 nm (IFG)

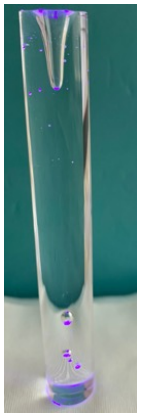
G-SPACE
MICROGRAVITY MADE SIMPLE

G-SPACE is the US Representative for Le Verre Fluore

MANUFACTURING

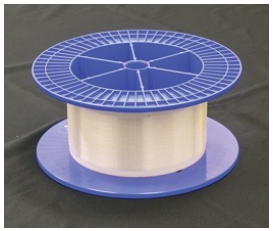
Rod-in-tube technique





1. RODS
Glass + Coating

2. PREFORMS
Core +Cladding +Coating



1. Fiber pulled from rods has no commercial value
2. *Pulling rods is an important step in mastering processing*

CURRENT COMMERCIAL FIBER

Fiber geometries

- Various configurations (double clad, double D-shape, polarization maintening, low birefringence…)
- High geometry control (core/cladding eccentricity, dimensions)
- 125µm fibers with core diameters as small as 1µm (adjusted cut-off wavelength)
- **High core/cladding interface quality**

COMMERCIAL GRADE OFFERINGS

1. Immediate availability of a wide spectrum of these fiber products
2. Can accommodate high volumes (effective no limitation in length of manufacturing)
3. Highest quality on the market
4. Repeatable and reliable manufacturing

Commercial grade ZBLAN fiber optics products

Standard fiber	Core/clad diameter	Numerical aperture	Short term bend radius	Long term bend radius
ZFG MM (0.15) 90/150	90/150 µm	0.15	≥ 15 mm	≥ 45 mm
ZFG MM (0.20) 90/150	90/150 µm	0.20	≥ 15 mm	≥ 45 mm
ZFG MM (0.20) 200/260	200/260 µm	0.20	≥ 25 mm	≥ 75 mm
ZFG MM (0.20) 300/360	300/360 µm	0.20	≥ 35 mm	≥ 100 mm
ZFG MM (0.20) 400/460	400/460 µm	0.20	≥ 45 mm	≥ 120 mm
ZFG MM (0.20) 600/680	600/680 µm	0.20	≥ 70 mm	≥ 150 mm

Standard fiber	Core/clad diameter	Numerical aperture	Cutoff wavelength	Operating wavelength	Short term bend radius	Long term bend radius
ZFG SM [1.95] 6.5/125	6.5/125 µm	0.23	1.95 µm	0.3-3.90 µm	≥ 15 mm	≥ 45 mm
ZFG SM [2.55] 8.5/125	8.5/125 µm	0.23	2.55 µm	0.3-4.5 µm	≥ 15 mm	≥ 45 mm

NEW PRODUCTS:

1. Pr-doped fiber for visible fiber laser applications
2. GeO_2 fibers
3. Custom ZFH, IFG fibers and bulk glasses

PASSIVE APPLICATIONS

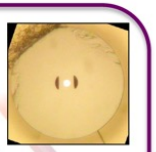
MULTIMODE FIBERS

- **Remote detection**
  - ✓ Spectrometry (pollutants concentration)
  - ✓ Temperature (optical pyrometry)
  - ✓ Process control (wet paint thickness, oil refinery)

- **Pigtailing** Interband / Quantum Cascade Lasers (from 2 up to 5µm)
- **Laser power transmission** (Er-YAG)
  - ✓ Continuous wave: ZFG can withstand more than **188W**
  - ✓ Pulsed laser: ZFG can withstand **1.6J** pulses at 2.94µm
- **Mode scrambling**

SINGLE MODE FIBERS

- **Instrumentation**
  polarization maintening fibers



- **Astronomical projects**
  low birefringence fibers

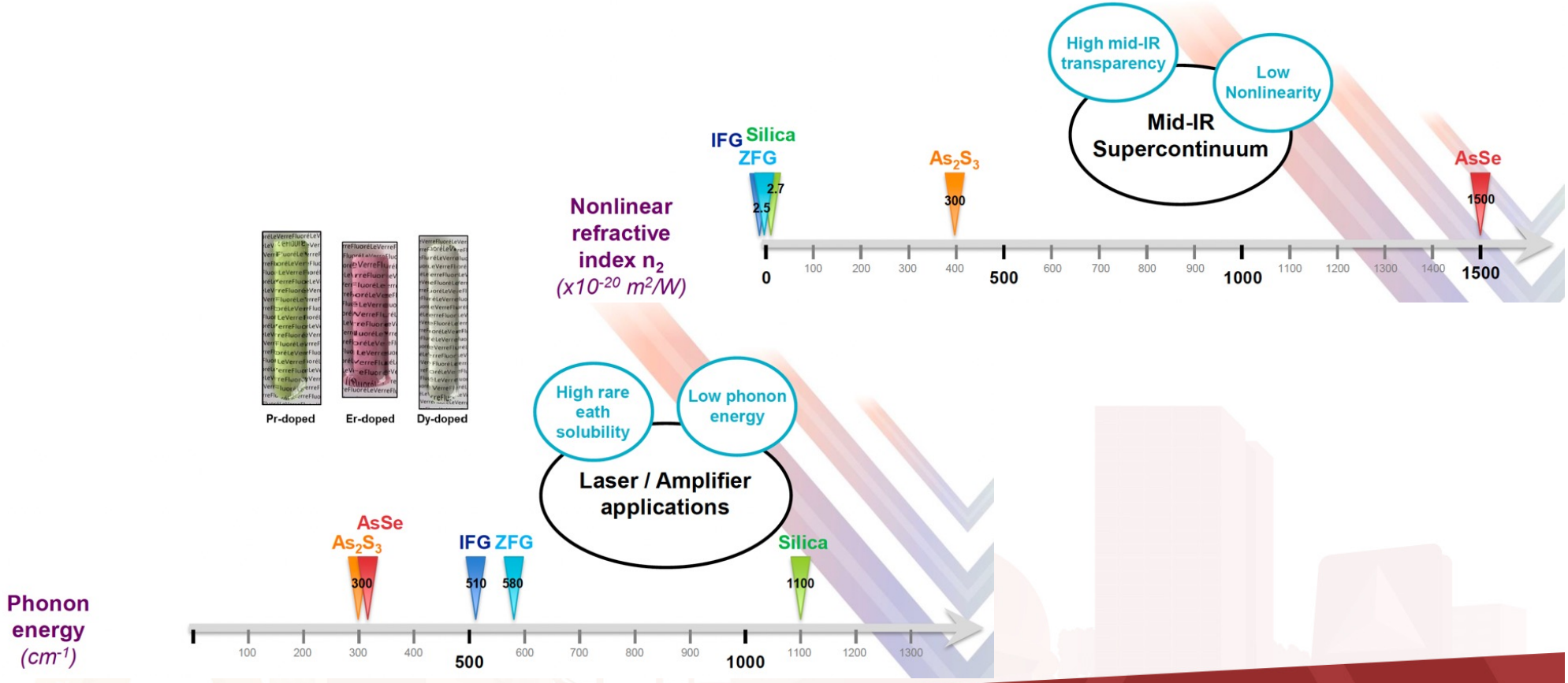
SINGLE MODE FIBERS:

- Low birefringence
- Low dispersion
- Low attenuation in K-Band

HARSH ENVIRONMENTAL TESTING:

- Moist Heat
- Thermal cycle under vacuum
- Thermal cycle under dry nitrogen

ACTIVE APPLICATIONS



ZBLAN IN-SPACE MANUFACTURING (ISM)

New Space, Vol. 5, No. 3 | Original Articles

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Exotic Optical Fibers and Glasses: Innovative Material Processing Opportunities in Earth's Orbit

is corrected by

Ioana Cozmuta and Daniel J. Rasky

2017

Published Online: 1 Sep 2017 | https://doi.org/10.1089/space.2017.0016

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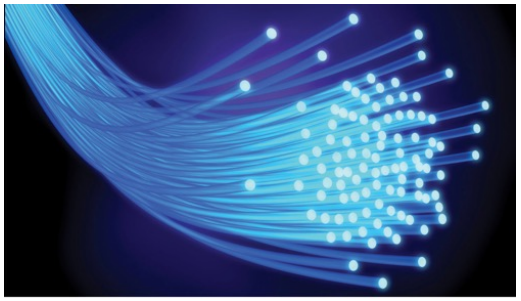
Abstract

Exotic optical fibers and glasses a
transmission (speed, low attenuati
Gravitational effects (convection s
melting properties, crystallization t
factors constitute limits to the yiel
of applications. Manufacturing in a
fabrication process (i.e., improved

Manufacture in Orbit ...

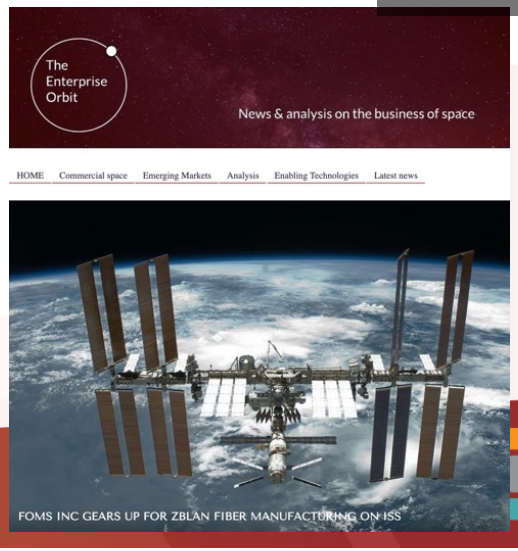
2019



Sparking the space economy

BY DEBRA WERNER | JANUARY 2020

2020



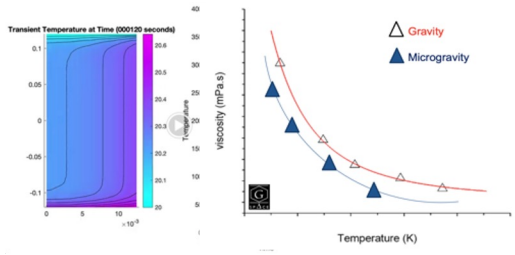
ISSRDC

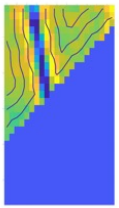
COMMERCIAL GRADE CRITERIA FOR ZBLAN ISM

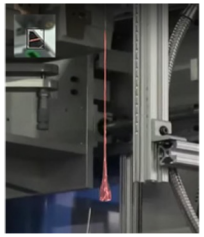
- **Fiber Diameter Uniformity and Concentricity**
- **Attenuation and Diffusivity**
- **Mechanical Strength**
- **Numerical Aperture**
- **Fiber Designs (geometries)**
- **Spectral Transmission Range**
- **Environmental Stability**
- **Repeatability and Scalability of Production**
- **Product Optimization in Microgravity**
- **Product Design Driven by Market Applications**
- **Economic Feasibility**

SPACE ENHANCED VALUE CHAIN

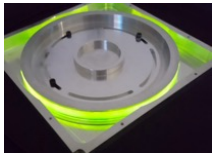
Market needs-based: performance required by a certain application; preferably lead by an industry player







The only segment in space



(1) Raw material from the market leader

(2) Process control in the space hardware terrestrially

(3) Optimize hardware operational parameters for microgravity
(4) Real-time monitoring

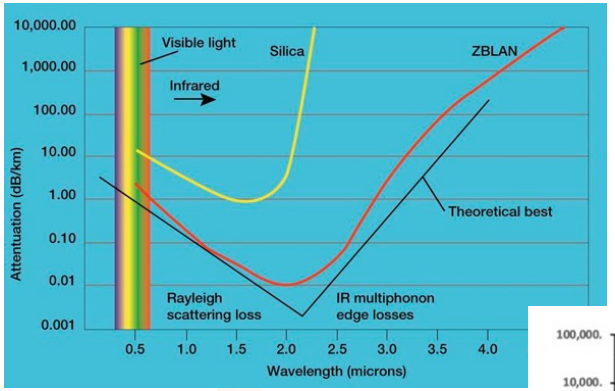
(5) Manufacture fiber in space according to specs

(6) Integrate in products & sell

Compare performance with market leader

G-SPACE CAPABILITIES IN ZBLAN ISM

1990



2020

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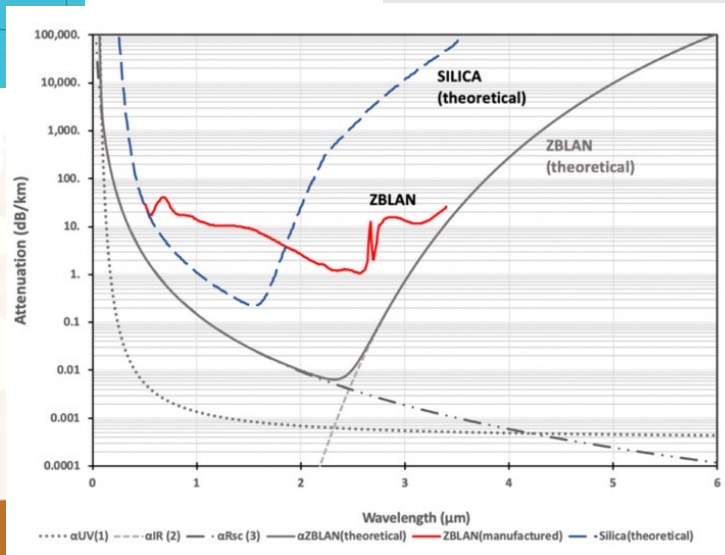
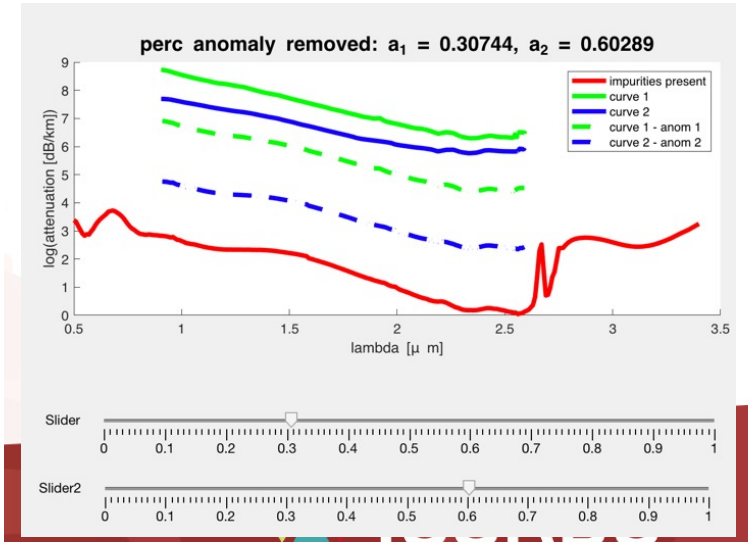
3 March 2020

Breaking the silica ceiling: ZBLAN-based opportunities for photonics applications

Ioana Cozmuta, Solenn Cozic, Marcel Poulain, Samuel Poulain, Jose R. L. Martini





CAPABILITIES:

1. Derived ZBLAN attenuation including microgravity

STATE OF THE ART EXPERIMENTAL CHARACTERIZATION

Raw materials (highest quality rods)
Terrestrial Reference Drawing
Fiber Design
- Imaging
- Core-clad concentricity
- Coating-cladding concentricity

Mechanical Properties
- short- and long-term bending radius
- tensile strength

Optical Properties (at 2.5 microns)
- power transmission
- attenuation measurement
- identify scattering local defects (count, size)
- fiber diffusion
- if possible: dispersion (mode, mode field diameter), polarization, Rayleigh scattering

In partnership with

LE VERRE FLUORÉ
INFRARED SOLUTIONS

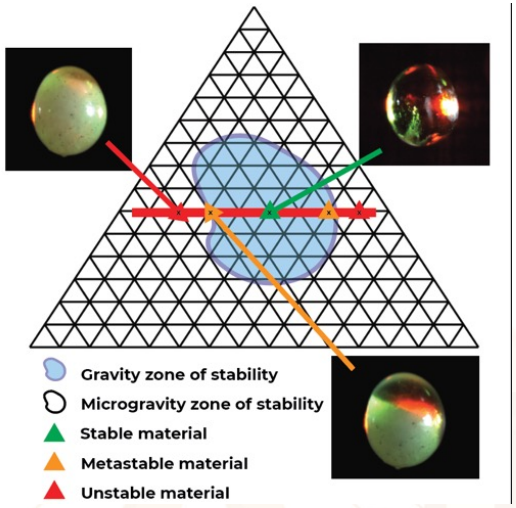
CAPABILITIES:

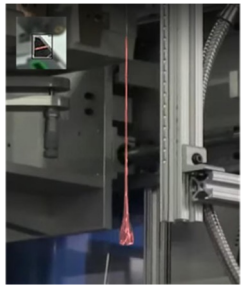
2. G-SPACE DELTA-TO-GRAVITY™

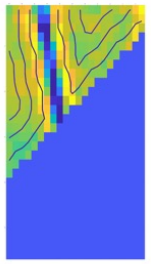
AI/ML ZBLAN MICROGRAVITY PRODUCT DESIGN

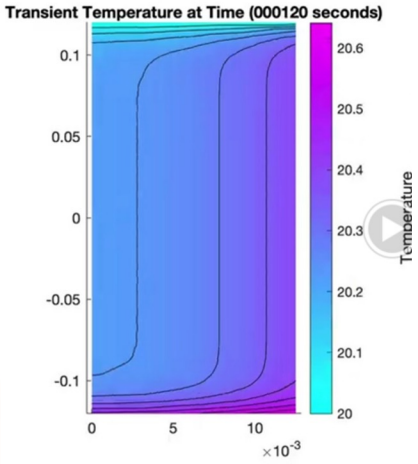
CAPABILITIES:

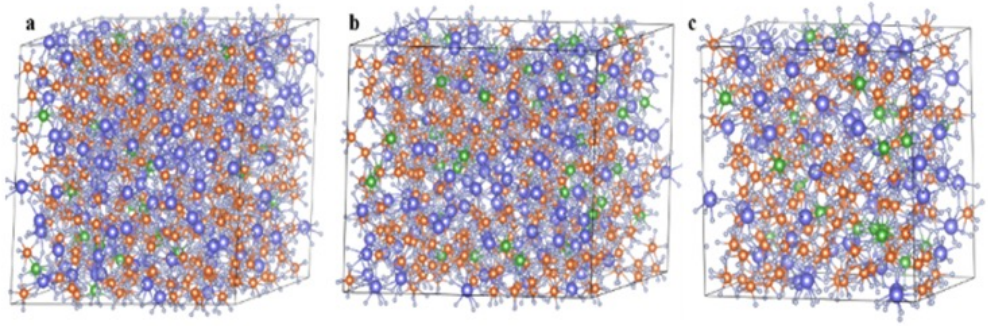
3.Optimizing formulations and manufacturing process control

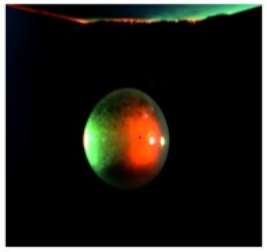


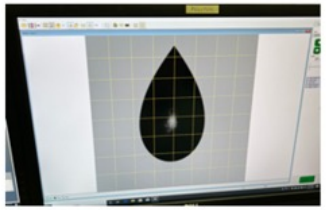


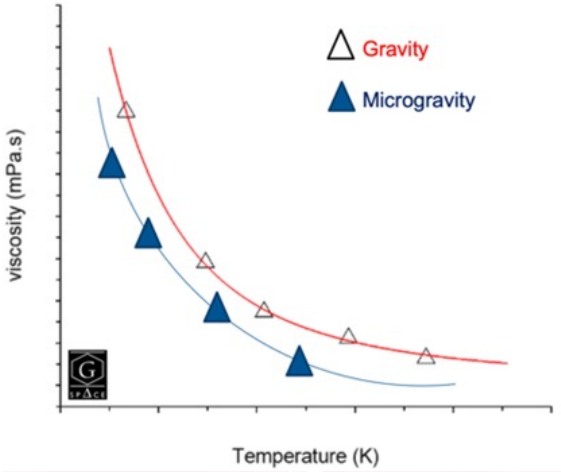








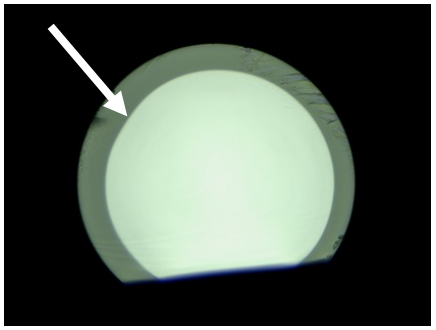




Reduce trial and error in ZBLAN microgravity manufacturing and accelerate time to market

ZBLAN ISM CASE STUDY

SpX-25 and Spx-26



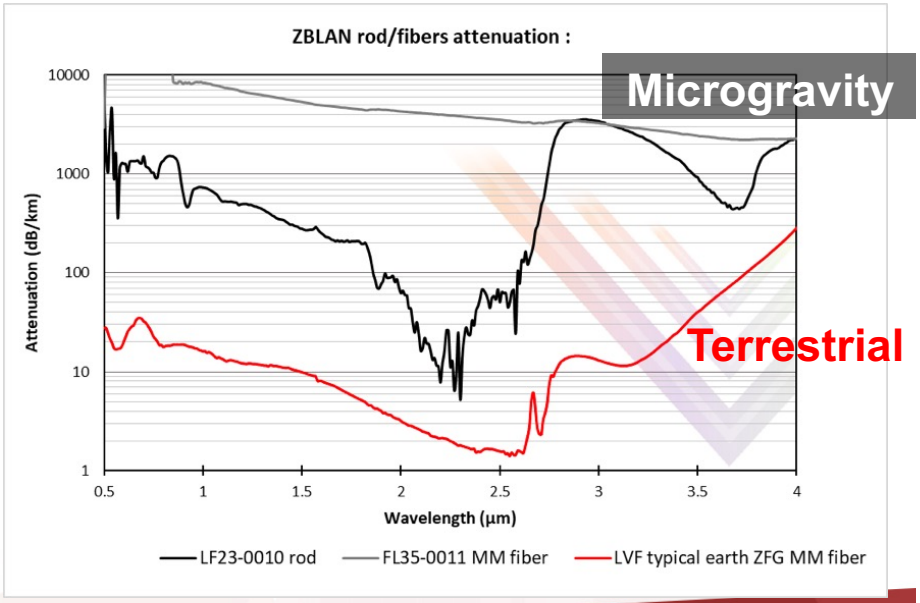
Coating-cladding non-concentricity

DIFFUSIVITY

Terrestrial

Micrograv

ATTENUATION



ZBLAN ISM EVOLUTION

2014:

One ZBLAN ISM manufacturer (US based);

No product

2024:

10 ZBLAN ISM manufacturers (worldwide);

No commercial product

Successful processing of **rods** into long length fibers

CHALLENGES

Lack of quantifiable, repeatable scientific evidence on microgravity processing

Microgravity can not remove impurities

Length and quality misconceptions

No requirement to establish terrestrial baseline

Lack of standardization

Vertical integration for ISM companies

A systemic problem

Space Manufacturing today is slow, risky, expensive and NOT SCALABLE

Gravity impact is often overlooked and hard to visualize

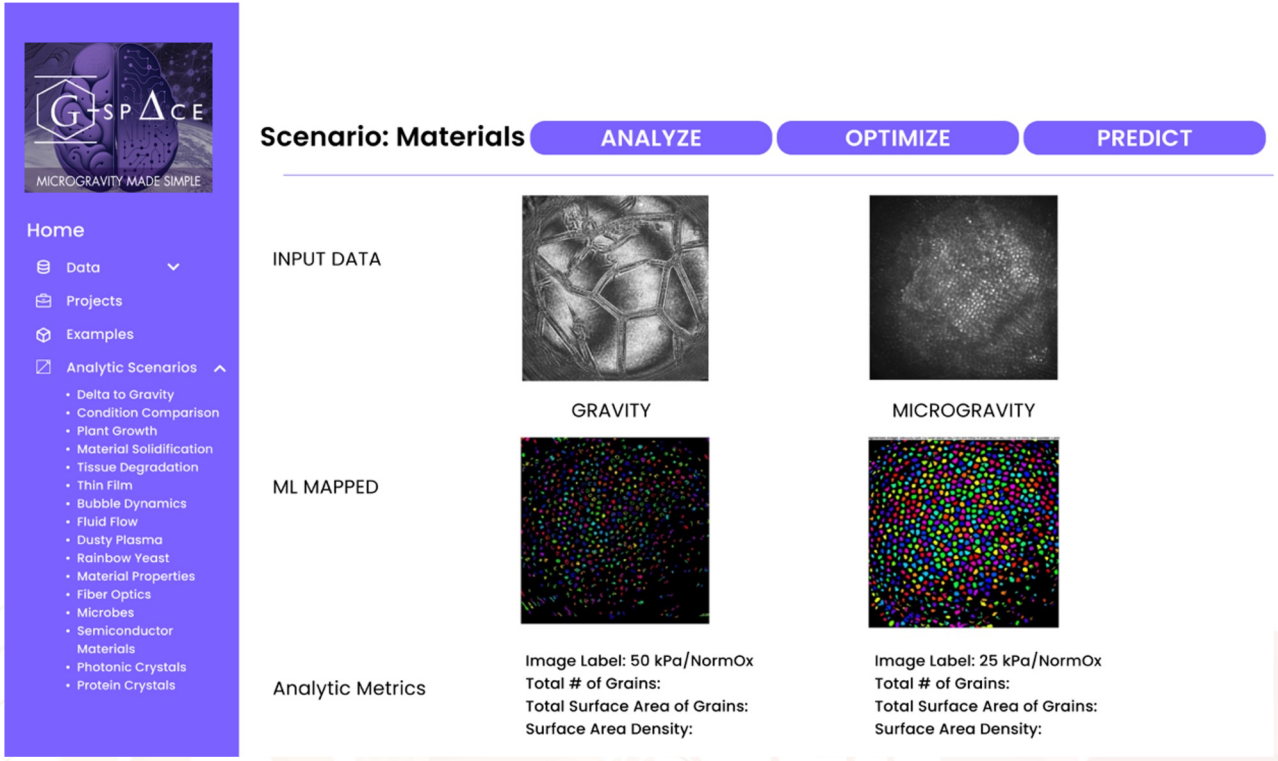
No standardized tools to quantify & leverage microgravity impact

What we build today in microgravity is very low yield

High risk of losing data and process control during microgravity

G-SPACE ISM SOLUTION

AI/ML SaaS Platform to Accelerate Microgravity Innovation and Production at Scale



G-SPACE provides

an AI-driven platform for predicting, optimizing, and analyzing microgravity effects, streamlining space research and manufacturing

KEY BENEFITS:

- Saves time
- Reduces cost
- Lowers risk

G-SPACE GO TO MARKET OFFERING

AVAILABLE IMMEDIATELY:

Analysis, Optimization & Prediction*
Real Time Process Control**
New Materials discovery***
ISM market prediction model*

* expert services + software platform
** expert services + hardware recommendation
*** expert services + experimental facility

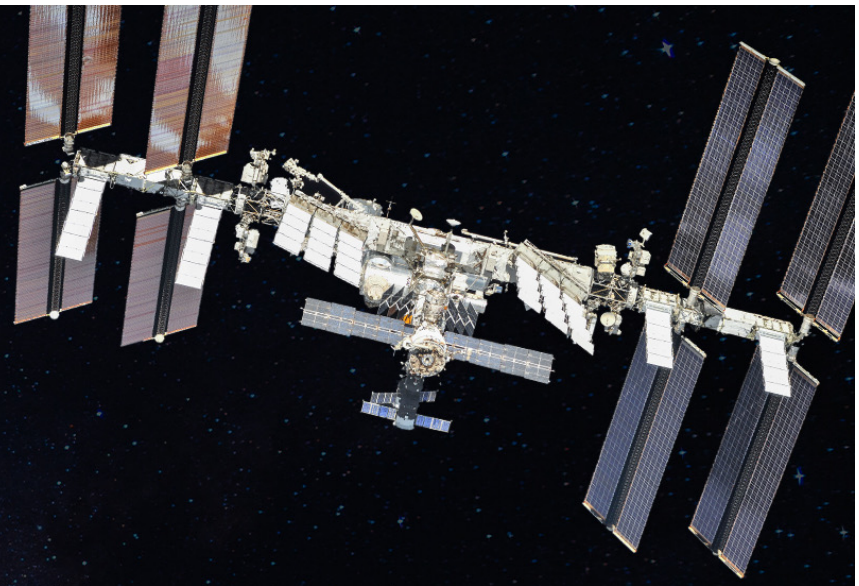
INCREASED ROI

Faster time to Market: **Accelerate your R&D with sophisticated experiment design and analysis, less waiting between flights, lower risk, less trial and error and faster product development cycles**

More insights: **Predict results, monitor your experiments in real time, extract every byte of insight using G-Space analytical tools before, during and after the flight**

Higher yields: **With near-real-time visibility into your experiment as it happens in space, our monitoring suite unlocks higher yields and makes it more profitable to experiment and manufacture in space**

GRAVITY FREE REGARDS



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