CORNING

Specialty Optical Fibers

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RFOC
12-14 October, 2011

Corning Incorporated

Founded:
1851

Headquarters:
Corning, New York

Employees:
~ 26,000 worldwide

2010 Sales:
$6.6 Billion

Fortune 500 Rank (2010):
391

- Corning is the world leader in specialty glass and ceramics
- We succeed through sustained investment in R&D, 160 years of materials science and process engineering knowledge

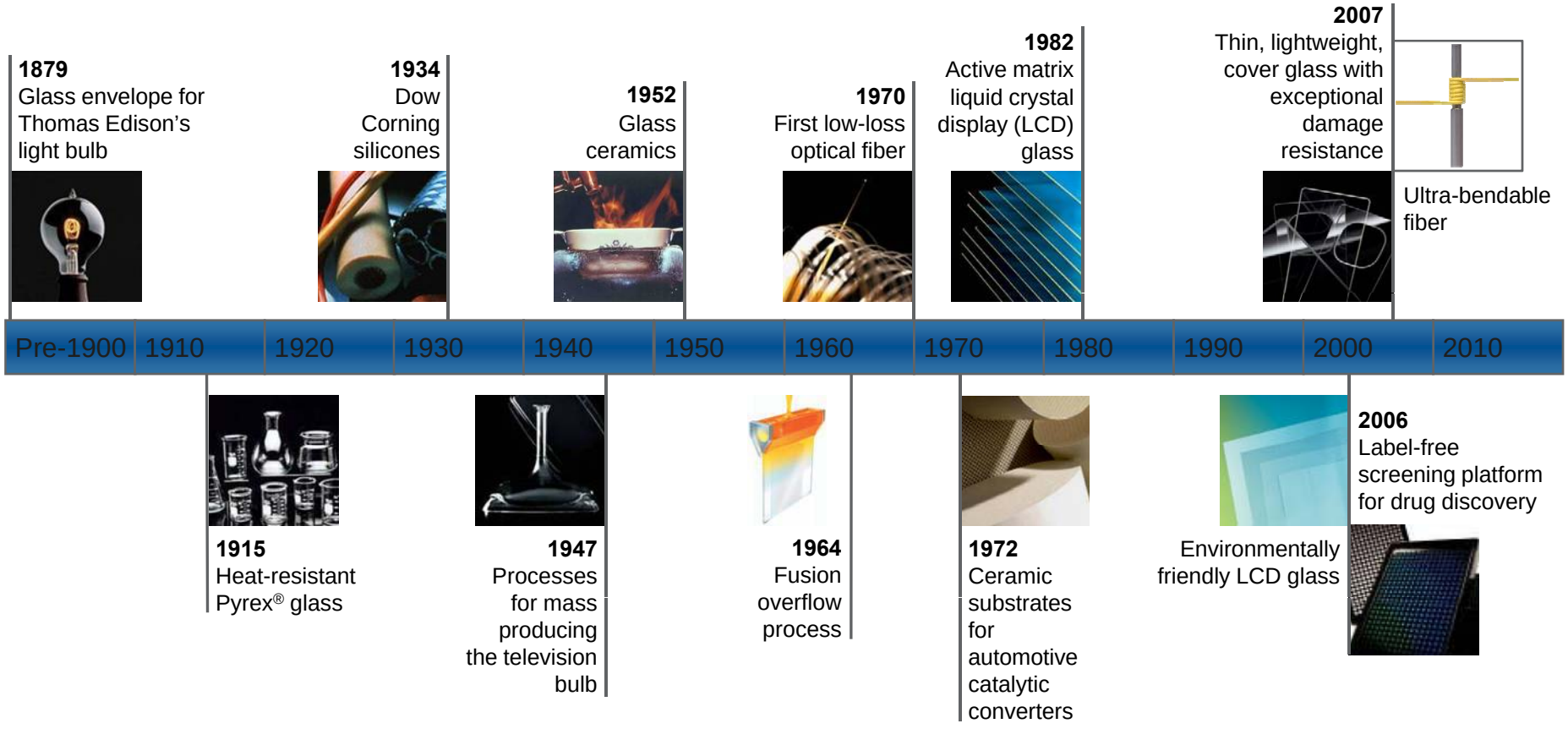
Sullivan Park Connected Globally in Europe, Asia and the U.S. West Coast

Corning West Technology Center
Silicon Valley, California

Corning European Technology Center
Fontainebleau, France

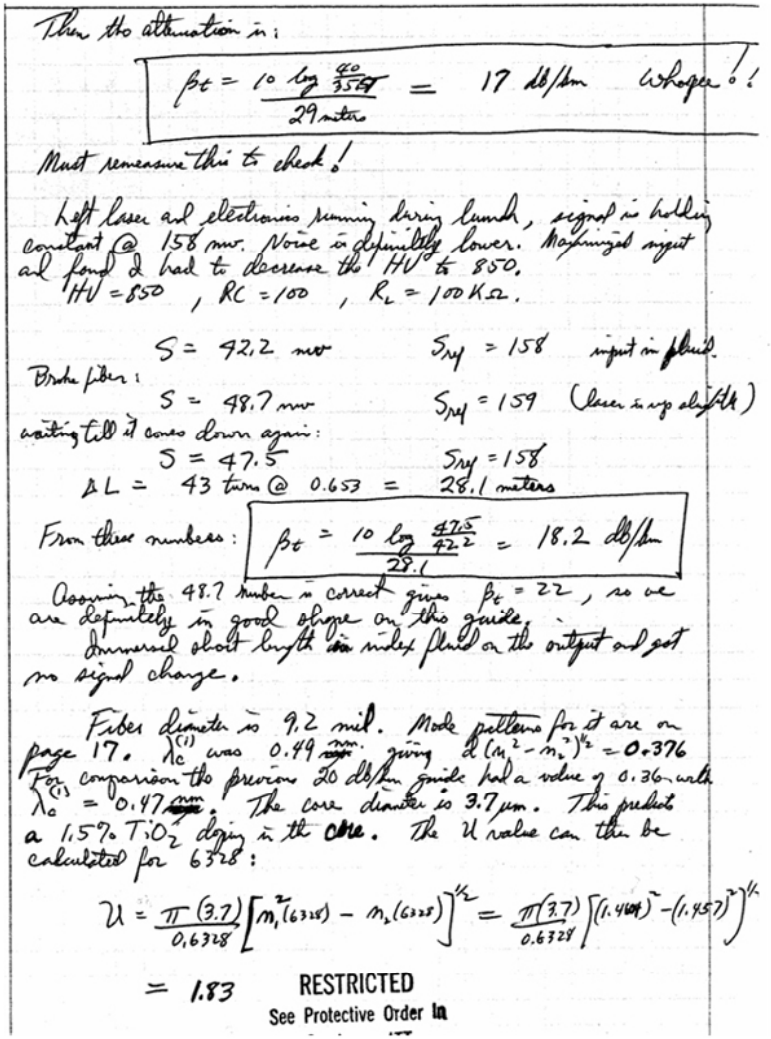
Corning Advanced Technology Center
Taipei, Taiwan

A Culture of Innovation



40 years of optical fiber innovation

- In 1970, three Corning scientists reported the 1st optical fiber with loss below 20 dB/km which demonstrated the feasibility of fiber optics for telecom applications.



Then the attenuation is:

$$\beta_t = \frac{10 \log \frac{40}{3.54}}{29 \text{ meters}} = 17 \text{ db/km}$$ Whoopee!!

Must remeasure this to check!

Left laser and electronics running during lunch, signal is holding constant @ 158 mv. Noise is definitely lower. Maximized input and found I had to decrease the HV to 850.
HV = 850, RC = 100, R_L = 100 KΩ.

S = 42.2 mv S_{sq} = 158 input in fluid.

Broke fiber:
S = 48.7 mv S_{sq} = 159 (laser is up slightly)

waiting till it comes down again:
S = 47.5 S_{sq} = 158
ΔL = 43 turns @ 0.653 = 28.1 meters

From these numbers: $\beta_t = \frac{10 \log \frac{47.5}{42.2^2}}{28.1} = 18.2$ db/km

Assuming the 48.7 number is correct gives β_t = 22, so we are definitely in good shape on this guide.
Immersed short length in index fluid on the output and got no signal change.

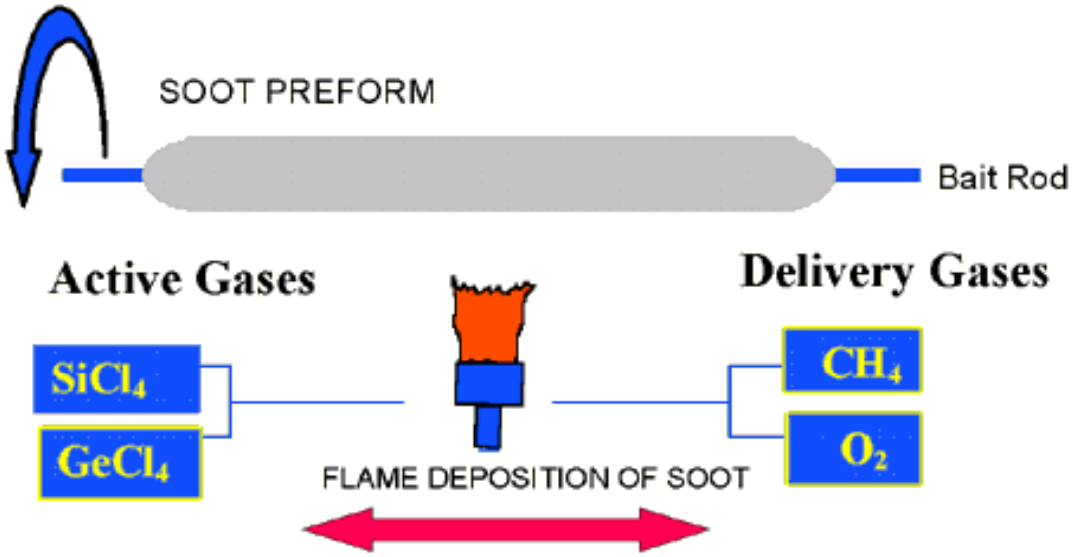
Fiber diameter is 9.2 mil. Mode patterns for it are on page 17. $\lambda_c^{(1)}$ was 0.49 mm, giving $d(n_1^2 - n_2^2)^{1/2} = 0.376$
For comparison the previous 20 db/km guide had a value of 0.36 with $\lambda_c^{(1)}$ = 0.47 mm. The core diameter is 3.7 μm. This product a 1.5% TiO_2 doping in the core. The U value can then be calculated for 6328:

$$U = \frac{\pi(3.7)}{0.6328}\left[n_1^2(6328) - n_2(6328)\right]^{1/2} = \frac{\pi(3.7)}{0.6328}\left[(1.464)^2 - (1.457)^2\right]^{1/2}$$

$$= 1.83$$

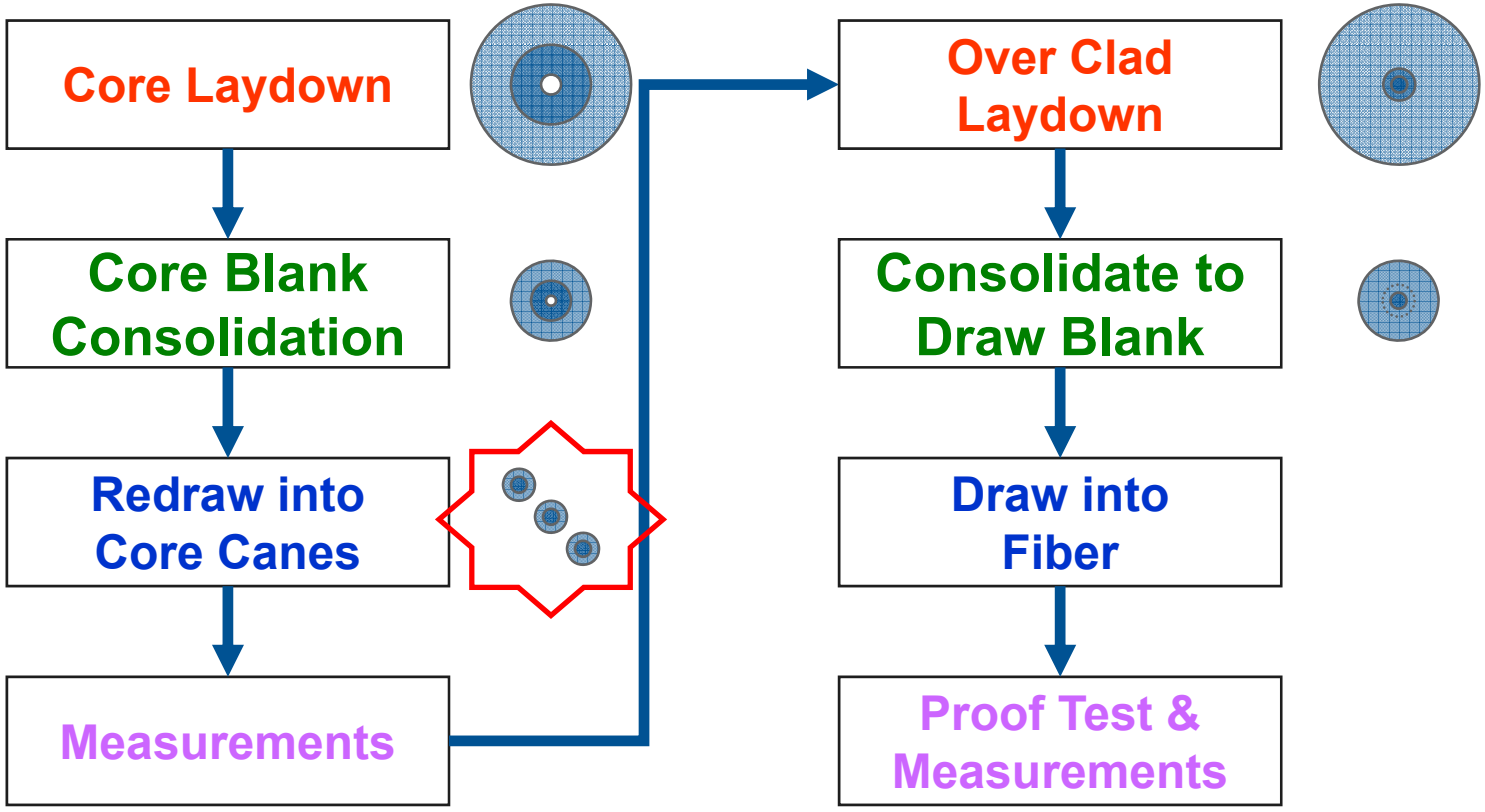
RESTRICTED
See Protective Order in

Outside Vapor Deposition (OVD) – method of choice at Corning



- Invented, developed, and used by Corning
- Consistency for fiber profile and geometry
- Higher process efficiencies; scalable to large blanks

Typical OVD fiber making process



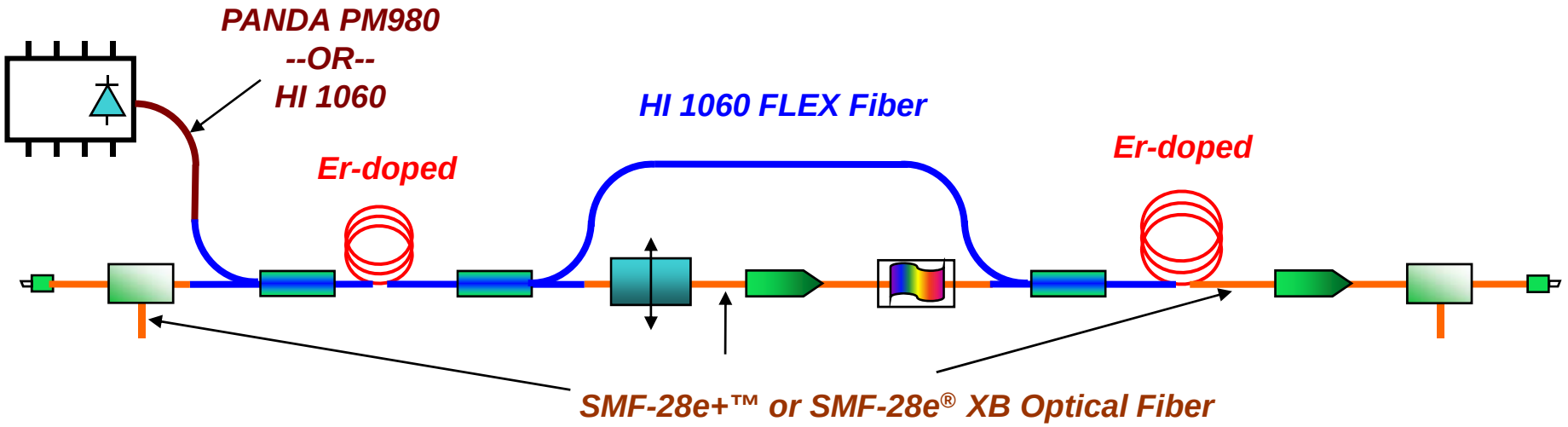
- **OVD** 100's to 1000's of kilometers total "Sister" Fiber with Identical Composition per Core Blank delivers greater lot to lot consistency
- **MCVD/PCVD** 1 to 1 core usage gives greater lot to lot variation.

Corning market segments

Display Technology	Telecom	Environmental Technologies	Life Sciences	Specialty Materials	Other Products & Services

• LCD Glass Substrates
• Glass Substrates for OLED and LTPS-LCD
	• Optical Fiber & Cable
	• Hardware & Equipment
	  • Fiber optic connectivity products
		• Emissions Control Products
		  • Light-duty gasoline vehicles
		  • Light-duty and heavy-duty on-road diesel vehicles
		  • Heavy-duty non-road diesel vehicles
		  • Stationary
			• Cell Culture & Bioprocess
			• Assay & High-Throughput Screening
			• Genomics & Proteomics
			• General Laboratory Products
				• Corning® Gorilla® Glass
				• Display Optics & Components
				• Optical Materials
				  • Semiconductor materials
				  • **Specialty fiber**
				  • Polarcor™
				• Optics
				• Aerospace and Defense
				• Ophthalmic
					• Emerging Display Technology
					• Drug Discovery Technology
					• New Business Development
					• Equity Companies
					  • Cormetech, Inc.
					  • Dow Corning Corp.
					  • Eurokera, S.N.C.
					  • Samsung Corning Precision Materials Co., LTD (SCP)

EDFA-module and component fibers

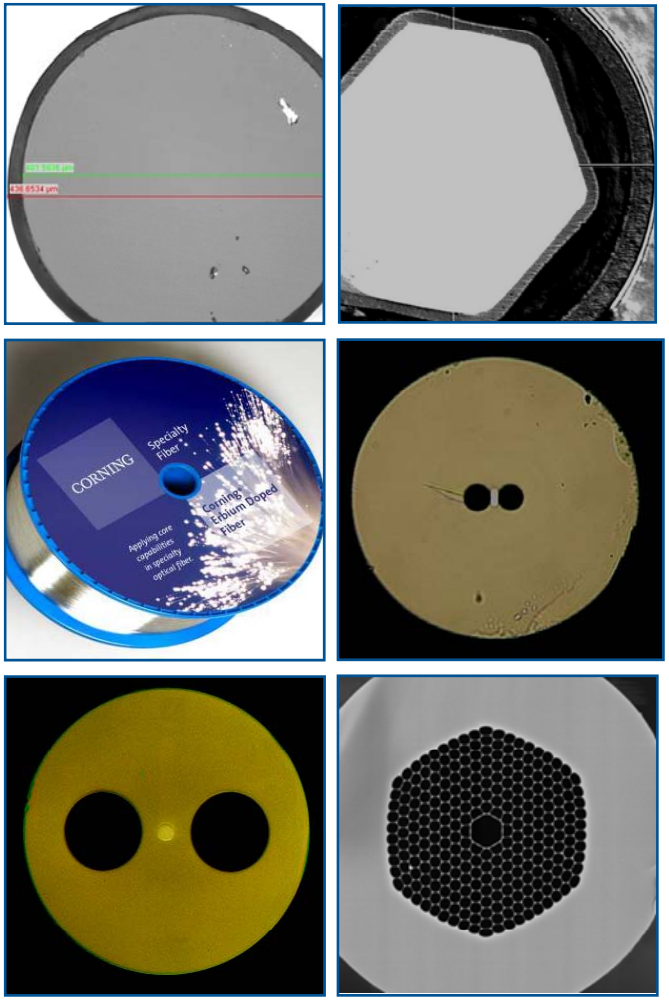


- We believe the use of Corning fibers enables better EDFA manufacturing yields which lowers our customers costs
  - Photonic Fiber
  - PANDA PM Fiber
  - High Index Fiber
  - Erbium Doped Fiber

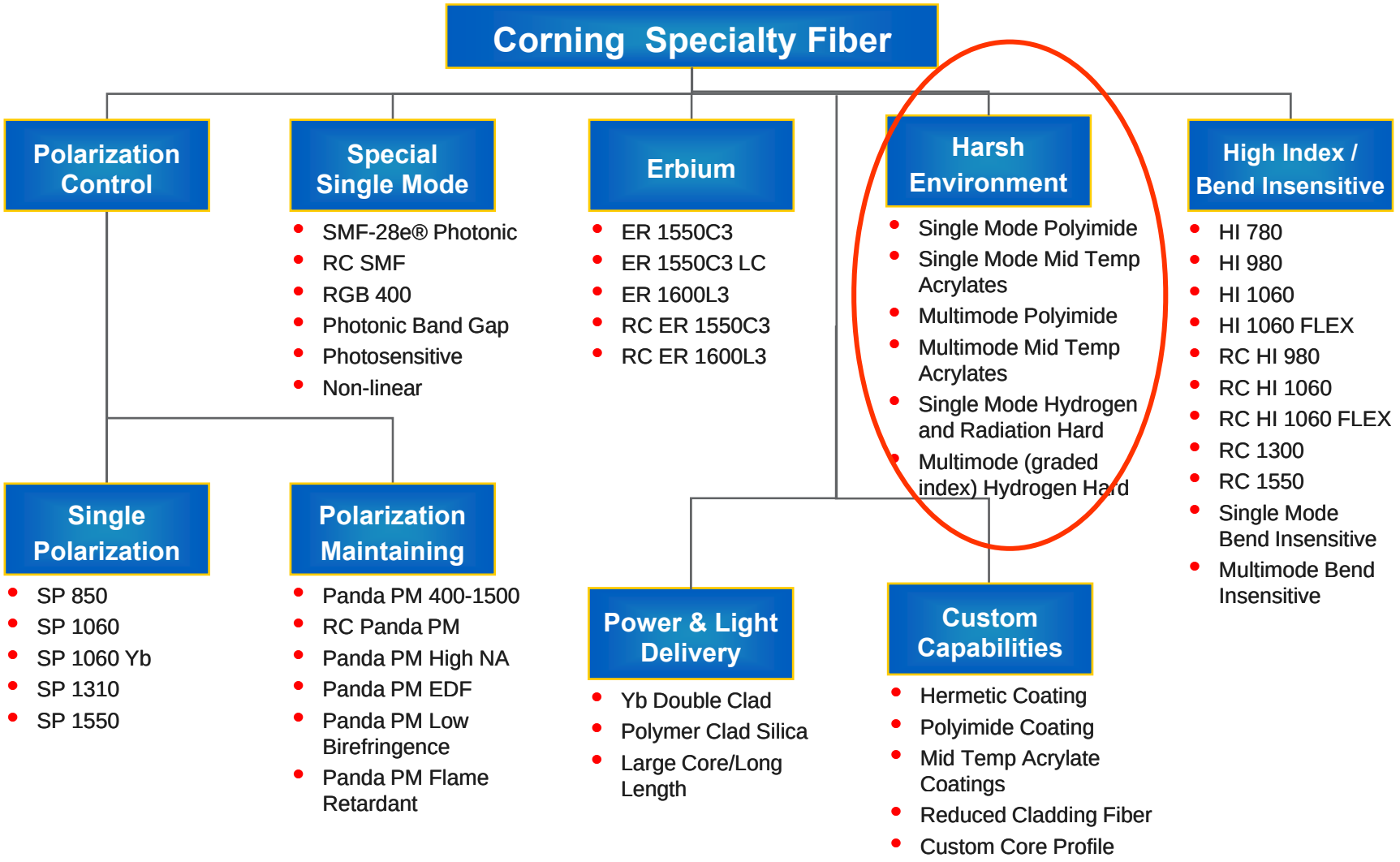
Corning Specialty Fiber Group

- **Develops and manufactures 'low volume' fibers for niche applications**

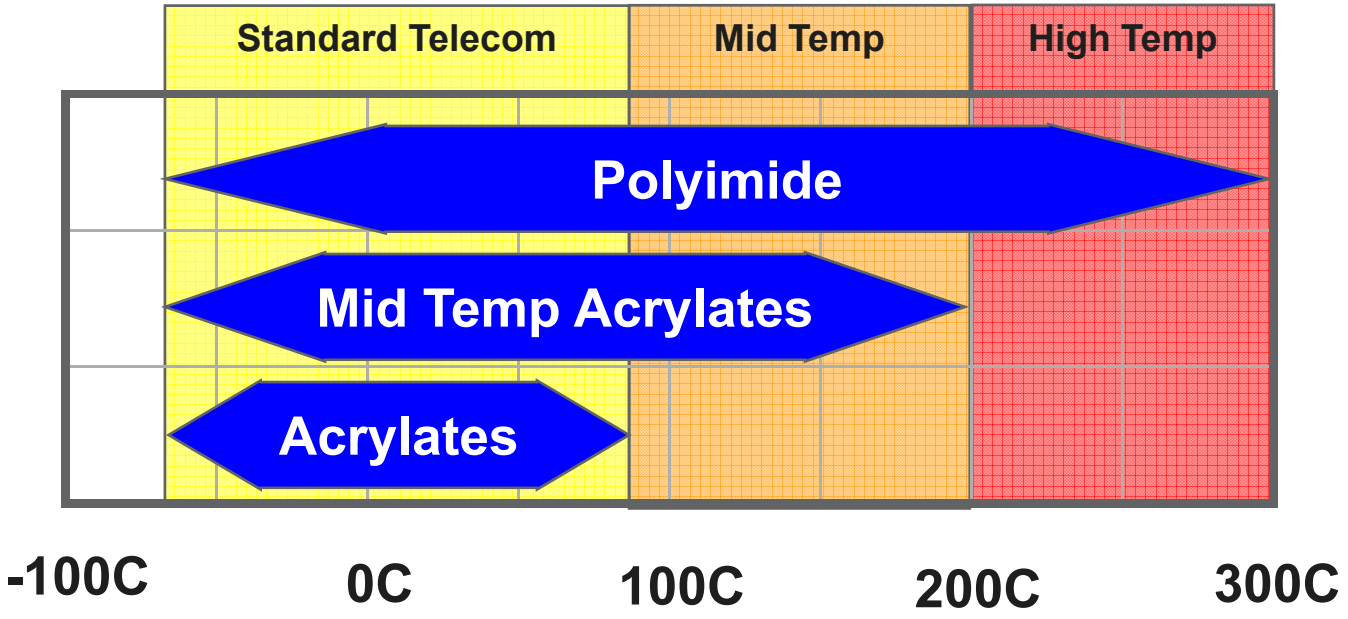
- Major Fiber Types:
  - High Index
  - Erbium Doped
  - Elevated Temperature
  - Polarization Maintaining
  - Polymer Clad Silica
- Capabilities:
  - Custom Glasses
    - Dopants, Profile, Geometry
  - Custom Coatings
    - Hermetic, Materials, Geometry



Corning specialty fibers



Corning specialty fiber coatings for harsh environment applications

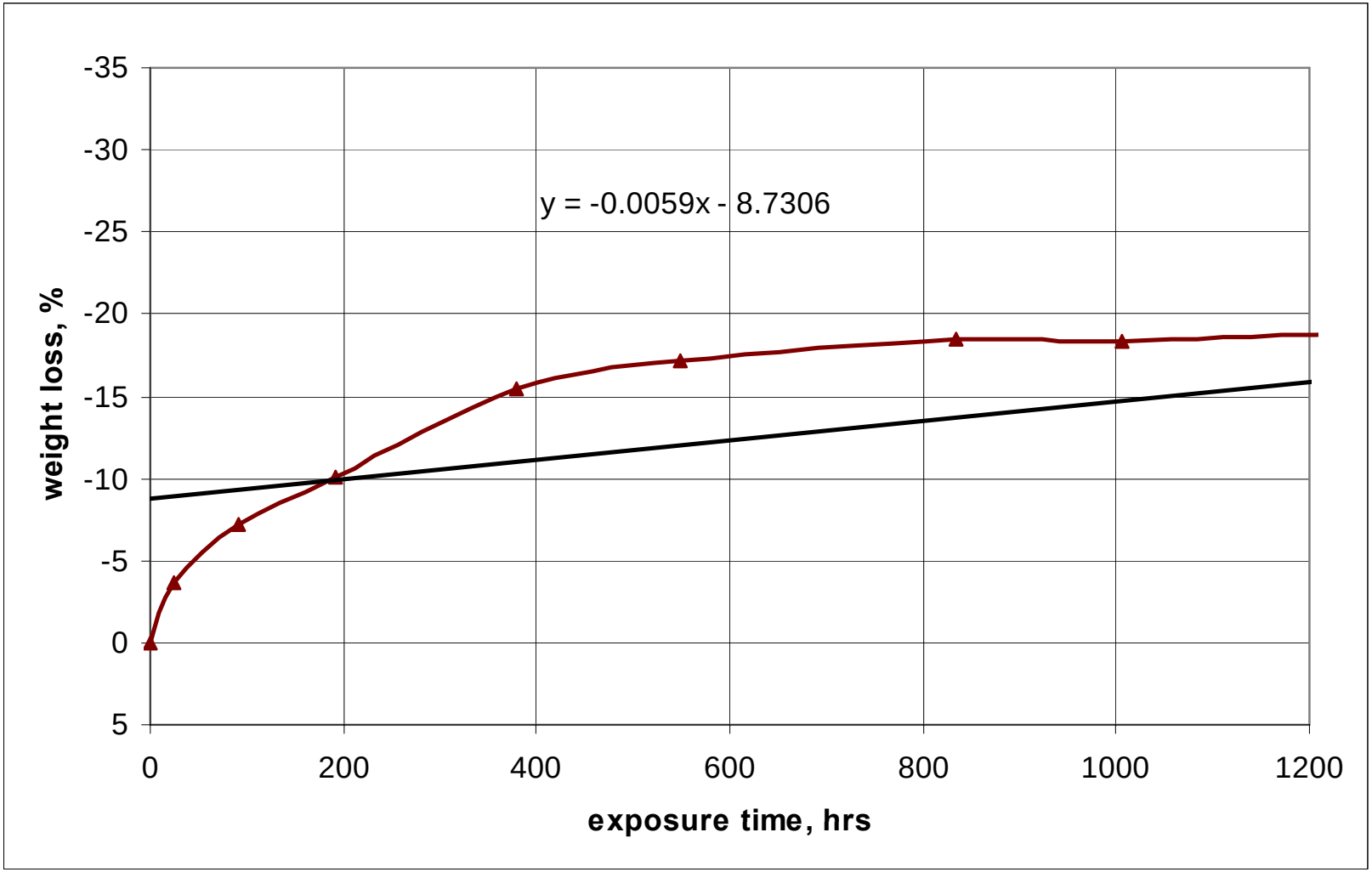


Corning elevated temperature specialty fibers

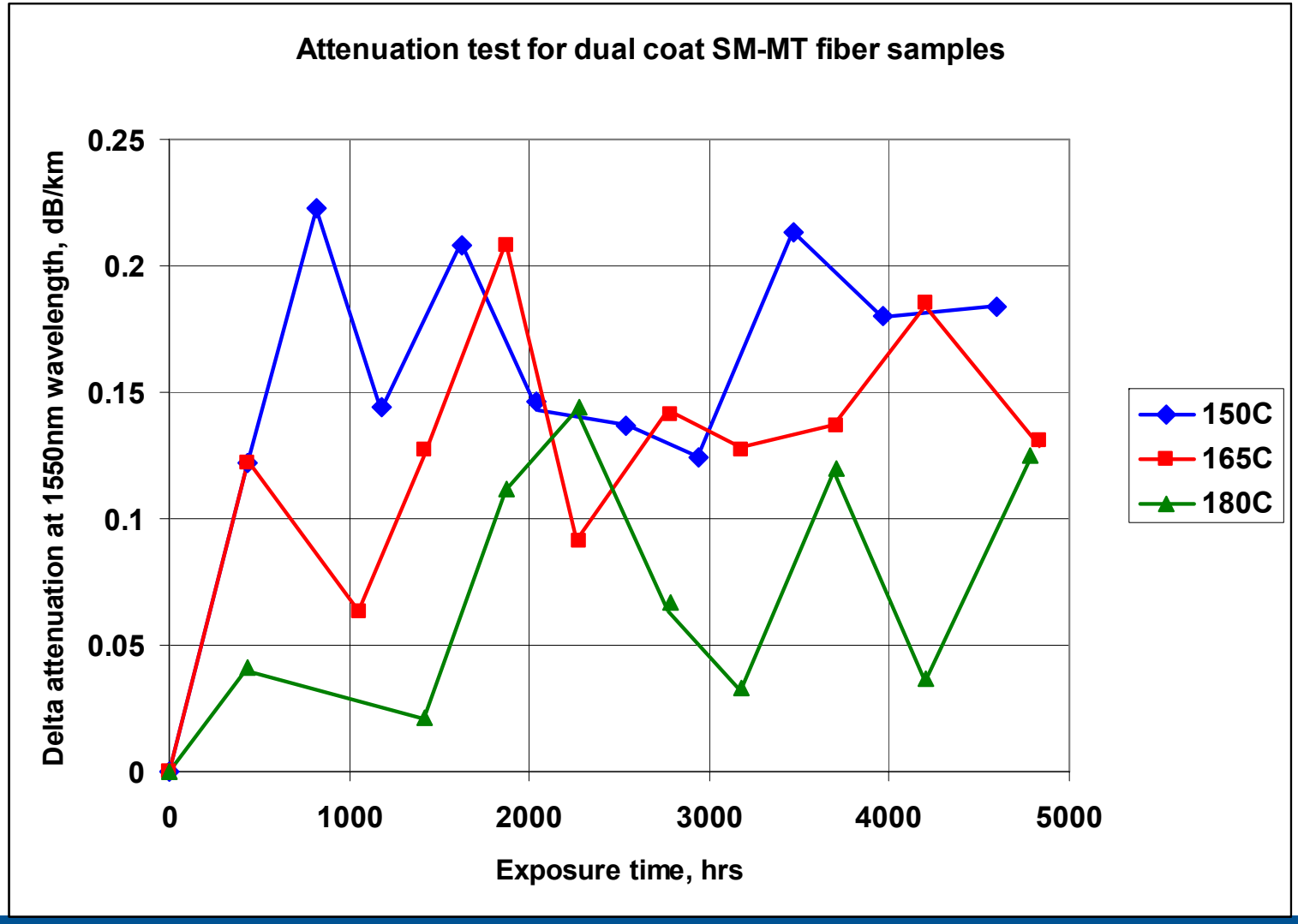
- **Elevated temperature optical fibers**
  - Mid temperature acrylate coating: single or dual coat (coating diameter of 200 or 245 micron)
    - SM-MT, SMH-MT, MM-MT, MMH-MT
  - Polyimide coating (coating diameter of 155 micron)
    - SM-HT, SMH-HT, MM-HT, MMH-HT

- **ClearCurve® optical fiber family glass design**
  - Bend insensitive single-mode fibers
    - SMBI-5-MT, SMBI-7.5-MT, SMBI-10-MT
    - Same with Hermetic coating
  - Bend insensitive multimode fibers (50/125 µm, NA=0.20, GI)
    - MMBI-MT, MMBIH-MT

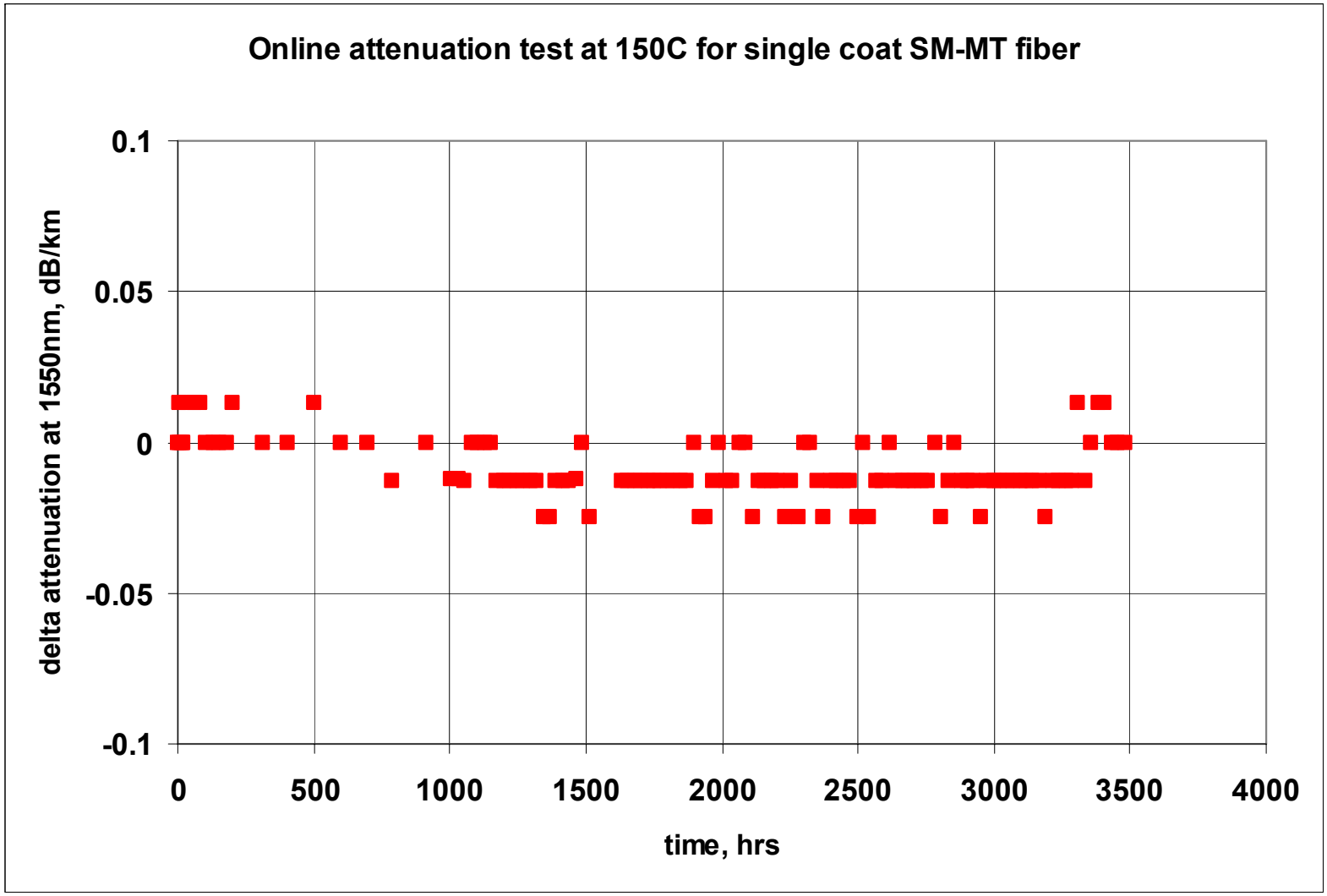
SM-MT fiber coating weight change: aging at 180C



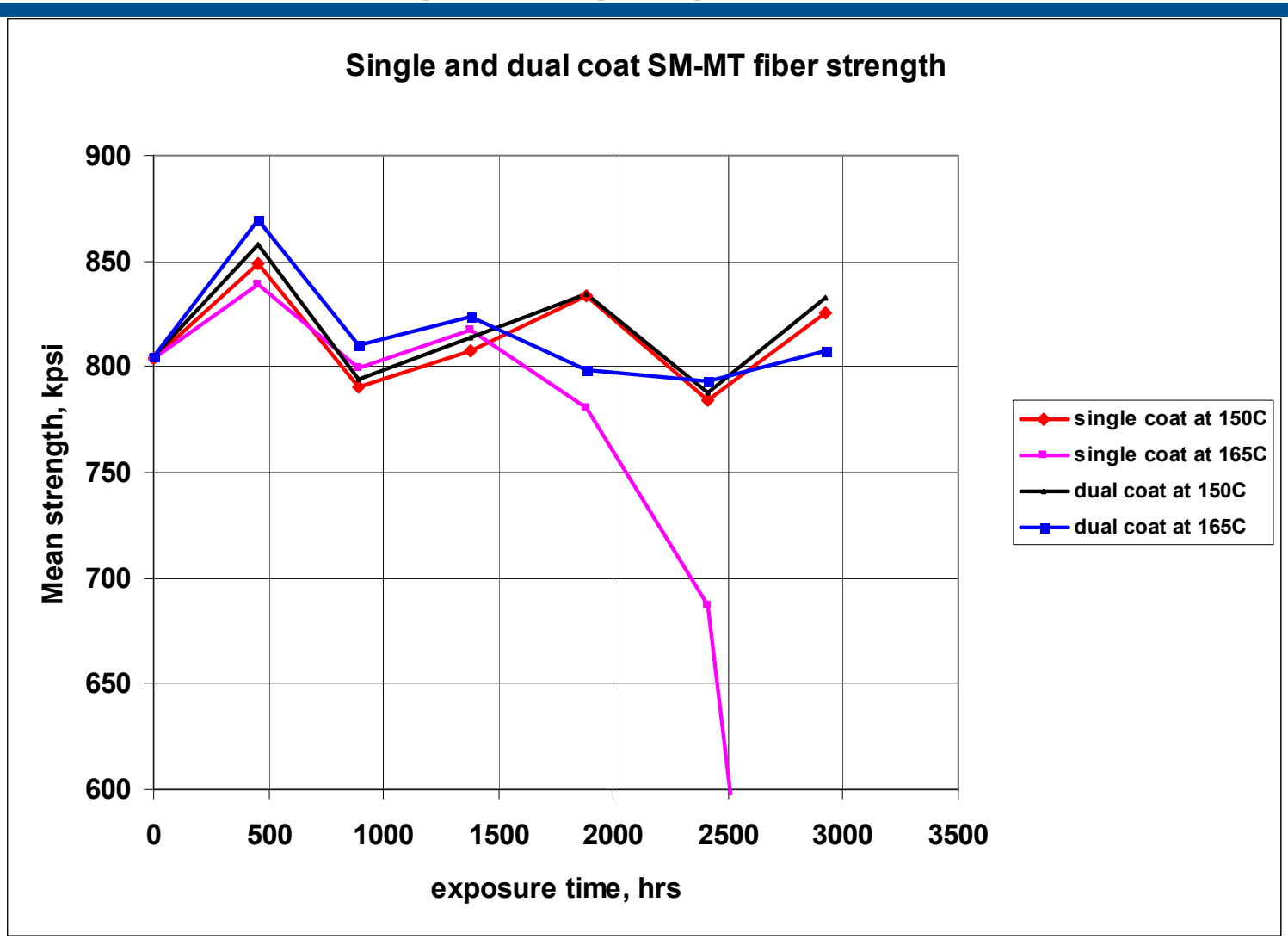
SM-MT fiber attenuation: aging at 150C, 165C, and 180C (manual test, in air)



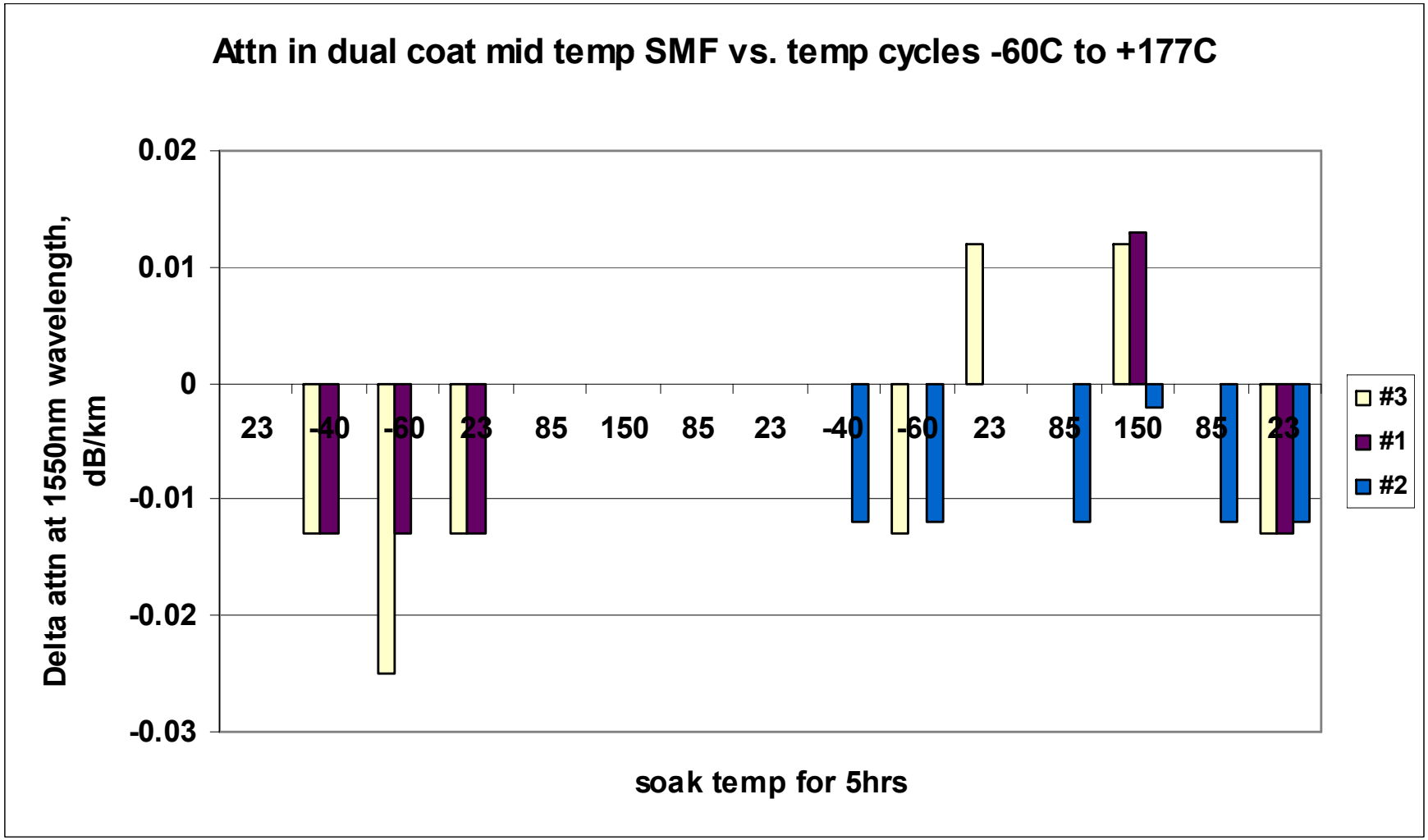
SM-MT fiber online attenuation test: aging at 150C



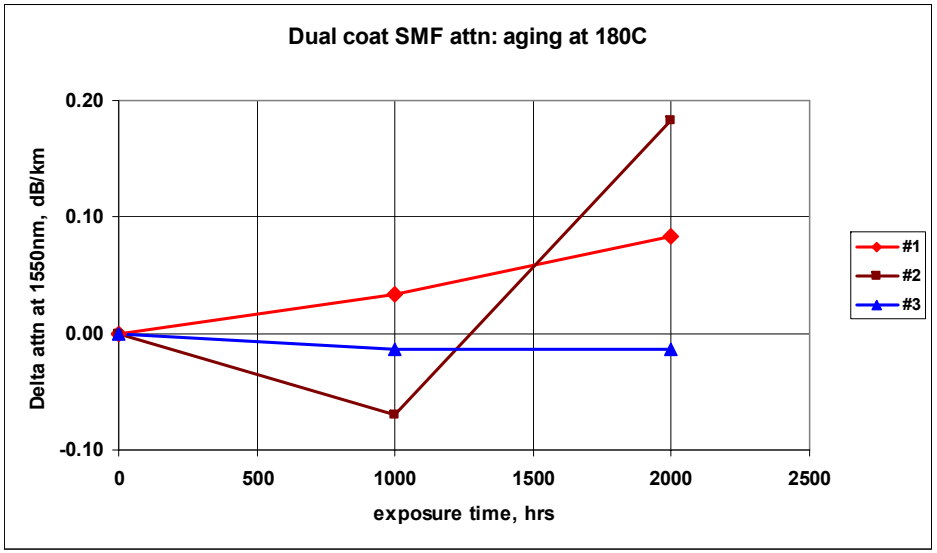
SM-MT fiber strength: aging at 150C and 165C

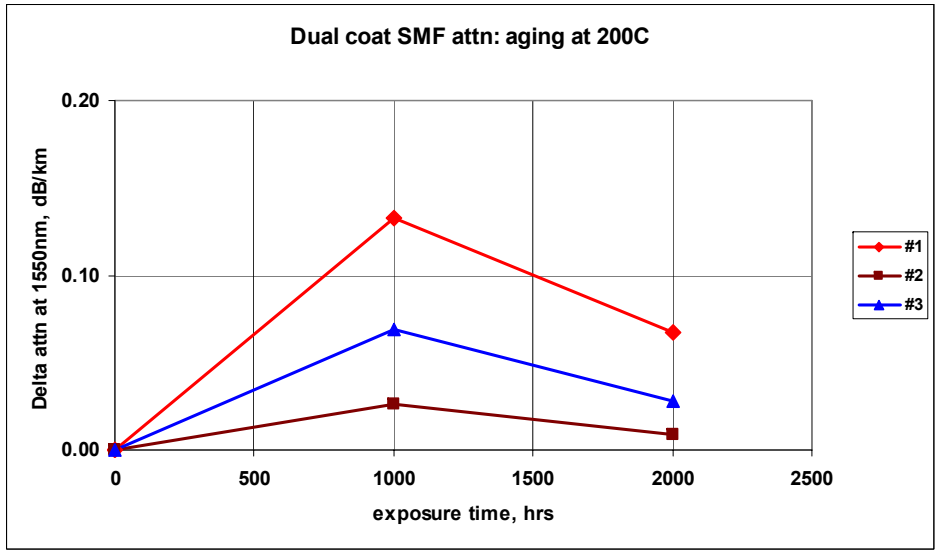


SM-MT attn vs. temperature cycles -60C to +177C

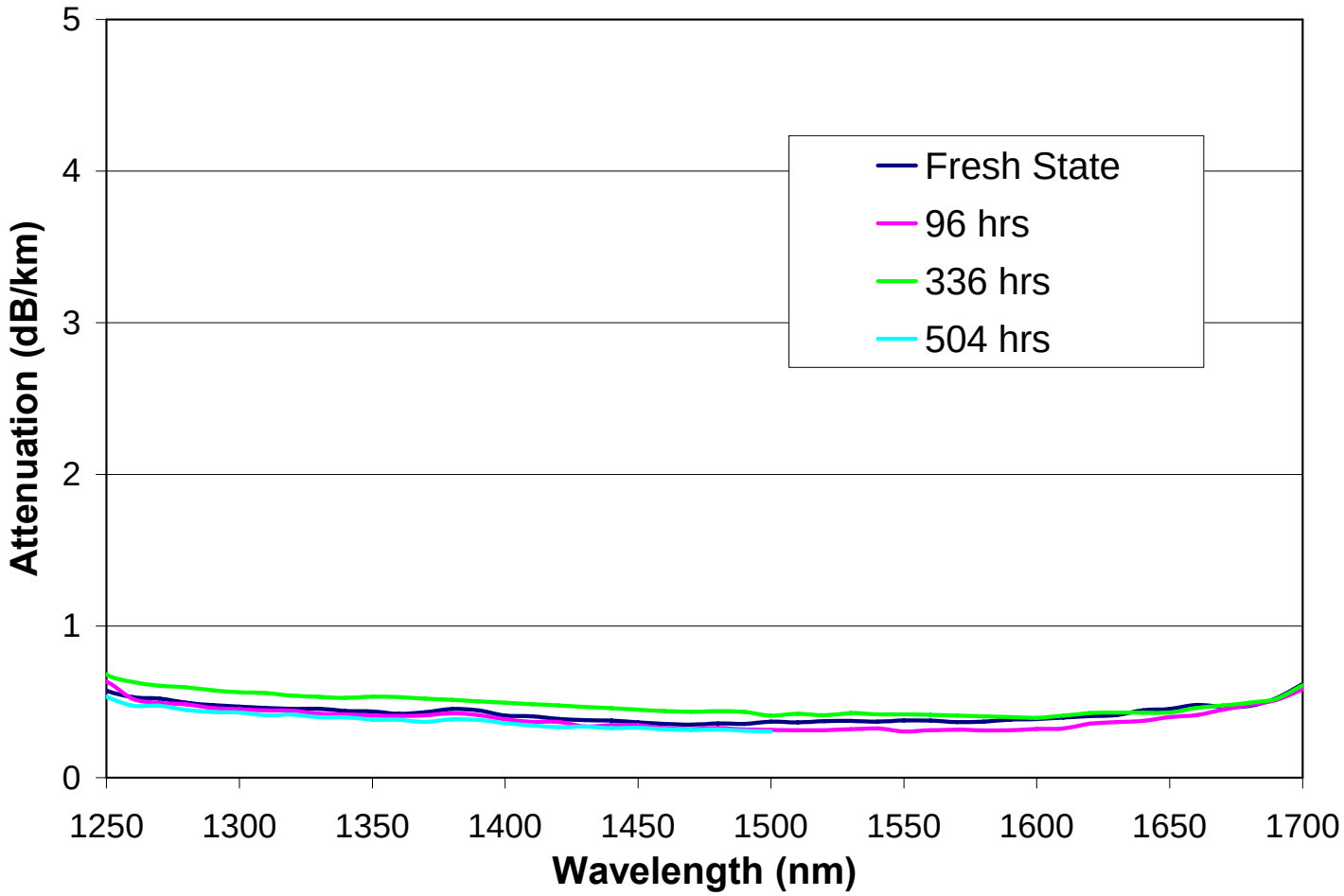


SM-MT fiber attenuation test: aging at 180C and 200C

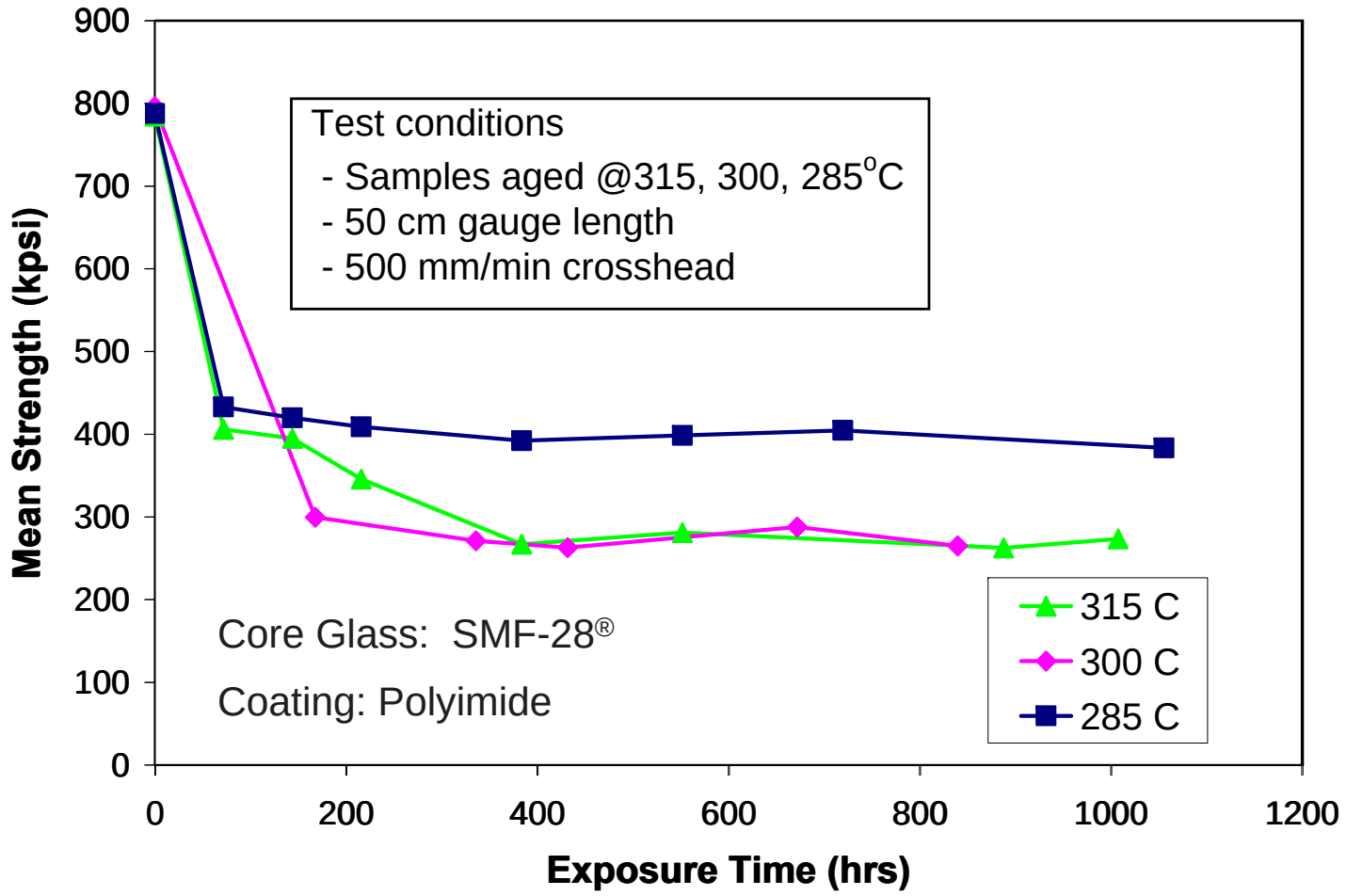




SM-HT fiber attenuation: aging at 300°C

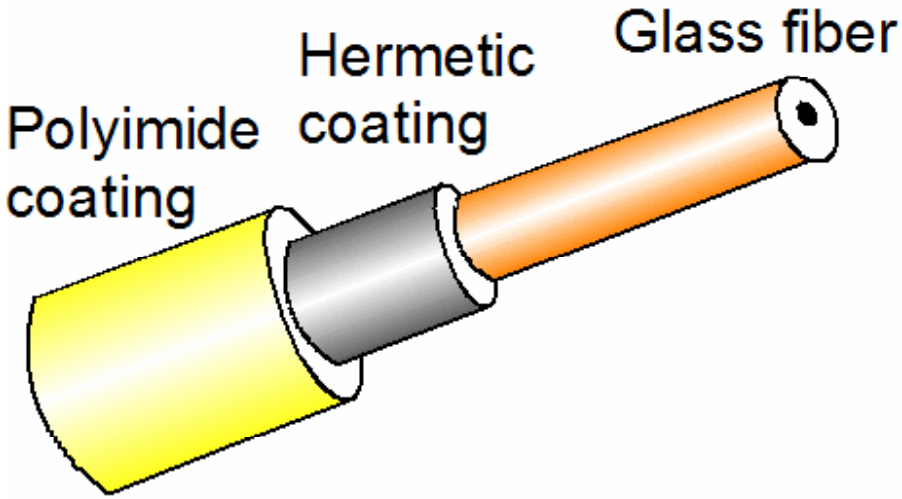


SM-HT fiber strength: aging at 285C, 300C, and 315C

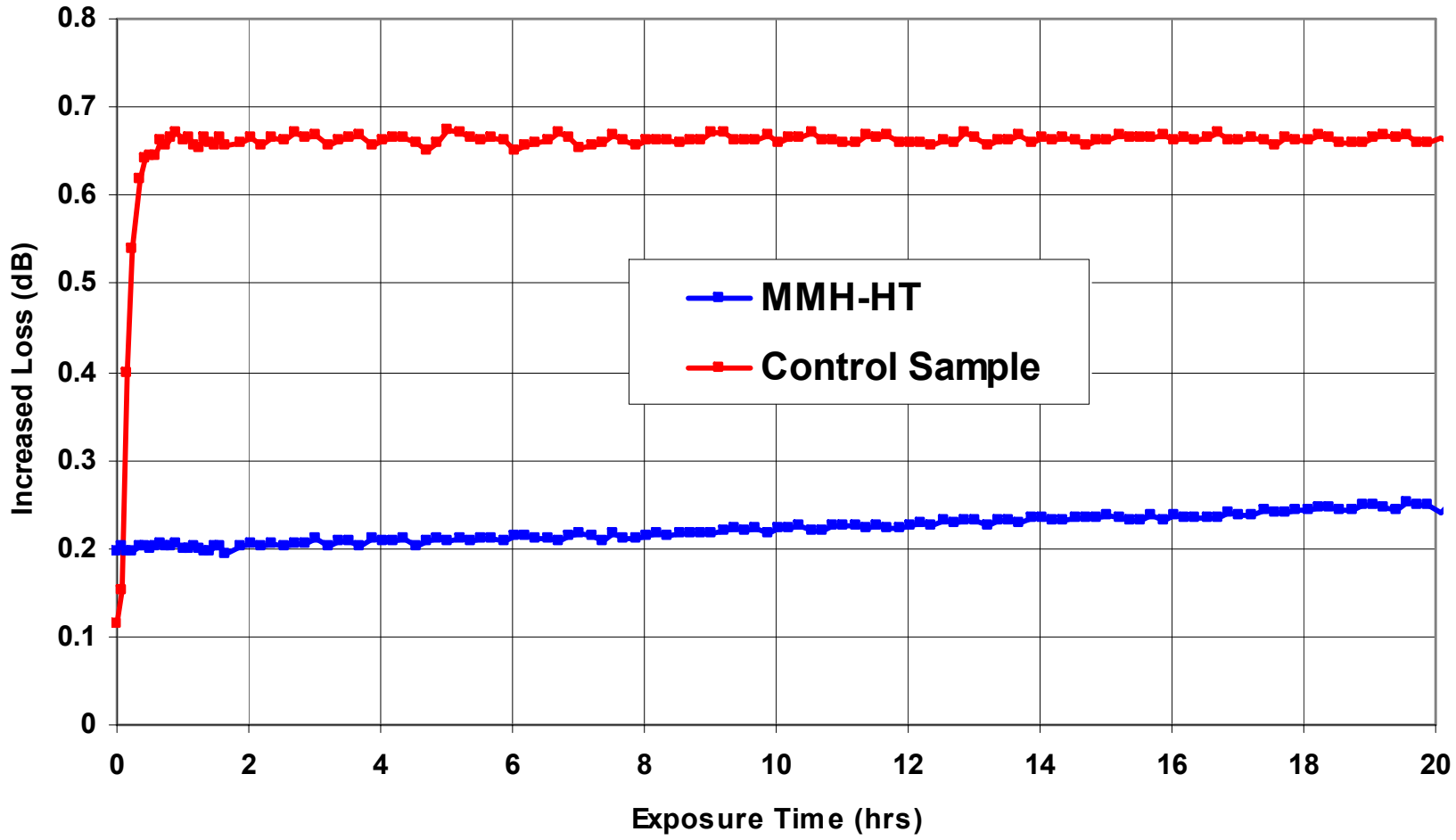


Carbon/polyimide coated fibers

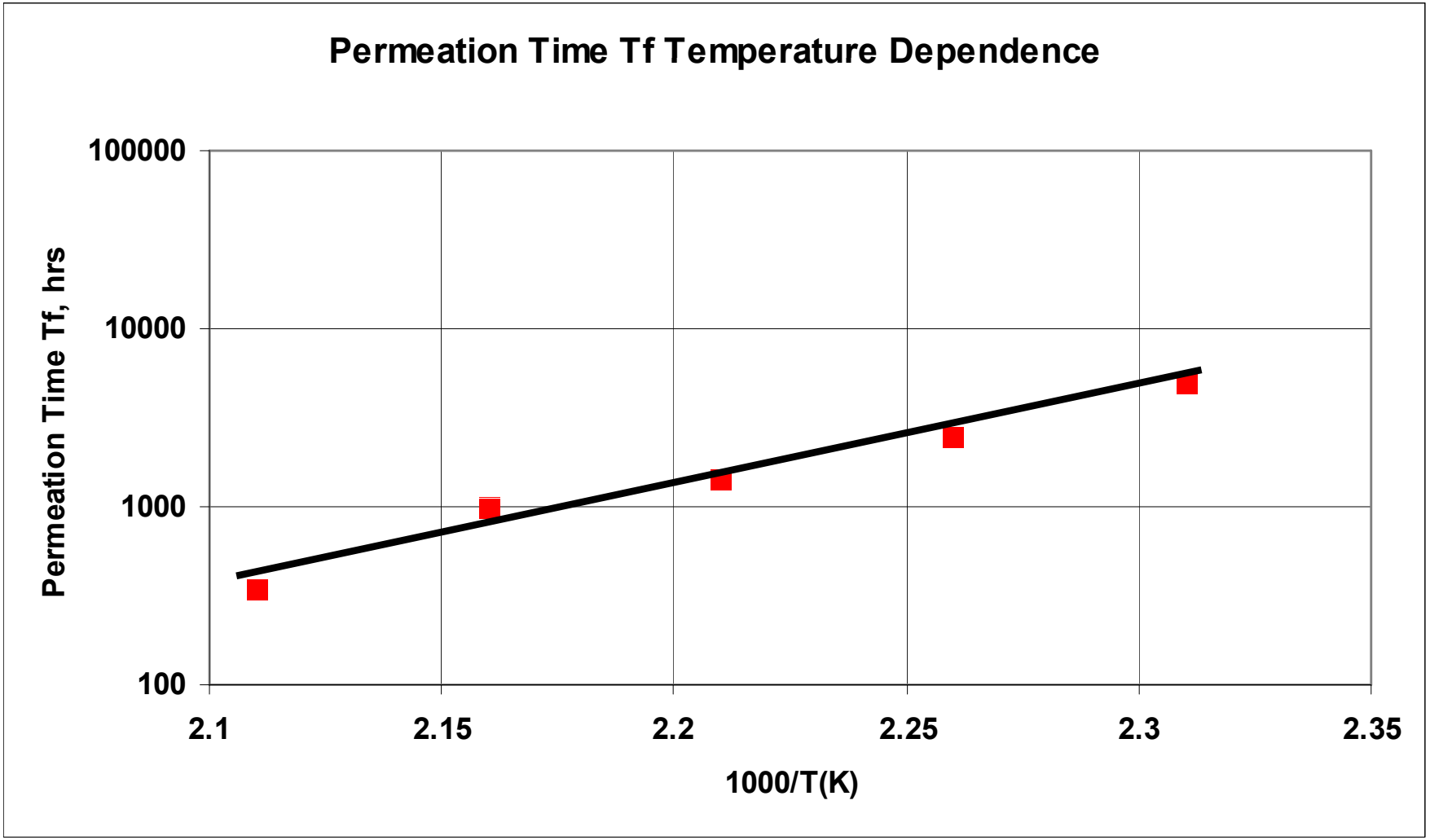
- **Hermetic coating:**
  - Amorphous carbon layer, 50nm thickness
  - Hydrogen diffusion barrier
  - Corning's proprietary deposition technique
- **Applications:**
  - Oil/Gas industry
  - Sensing
  - Aerospace/Defense



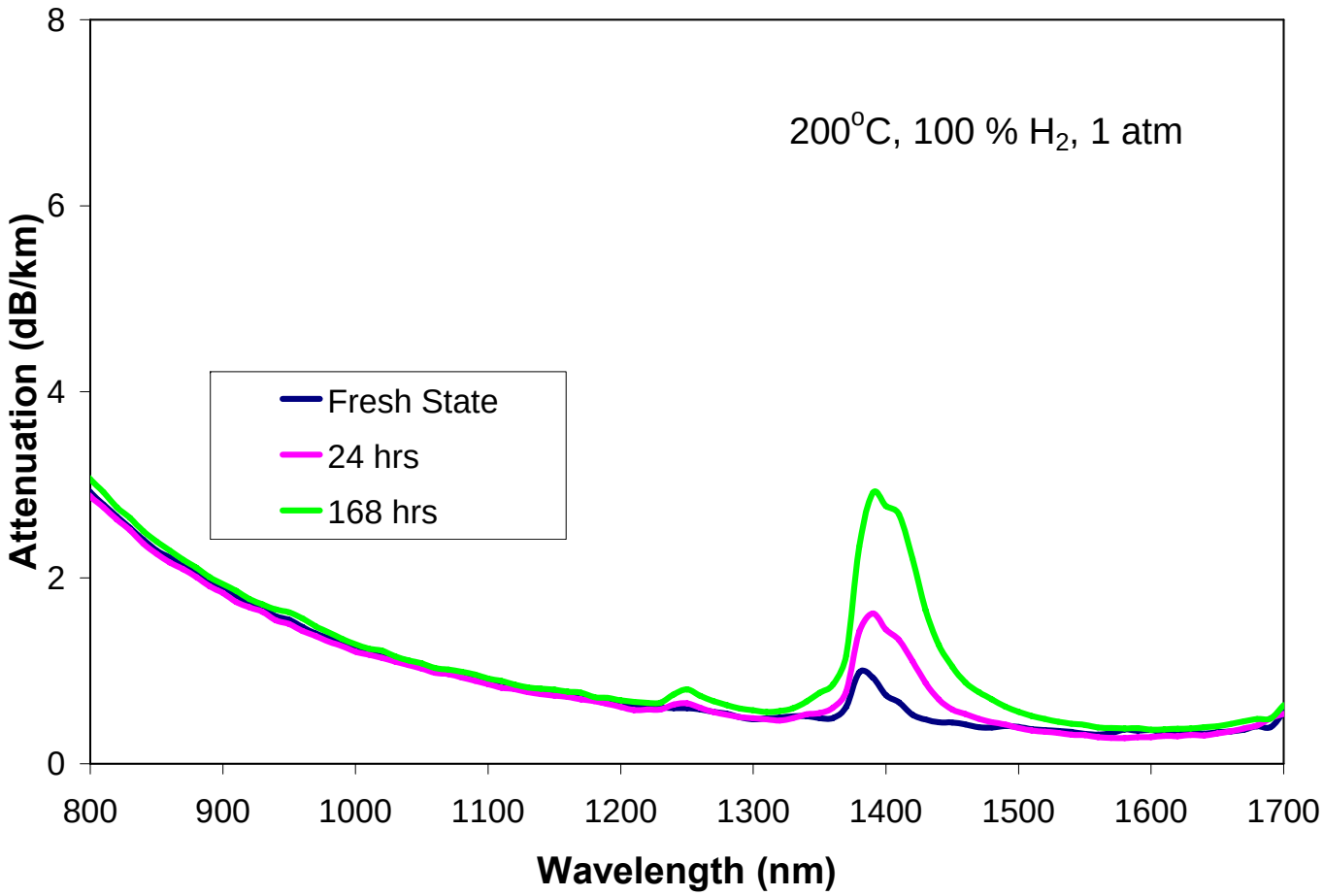
Carbon hermetic coating stability test for MMH-HT fiber sample at 200C and 400psi hydrogen pressure



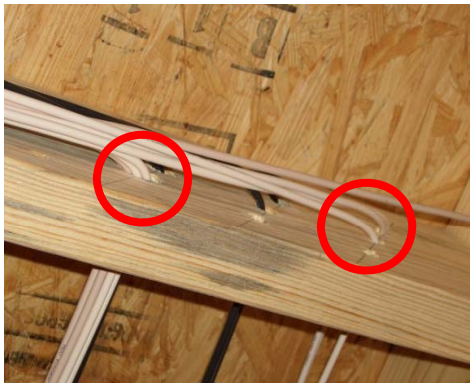
Carbon coating permeation time temperature dependence (160C – 200C)



MMH-HT fiber spectral attenuation: hydrogen aging at 200C

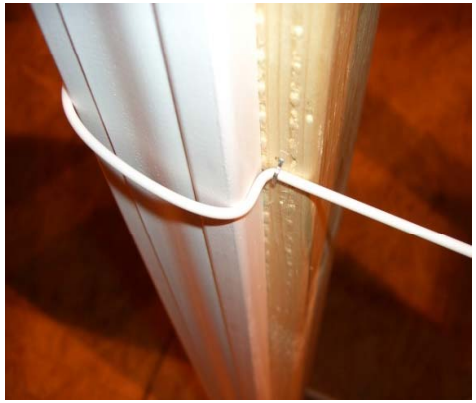


Corning bend insensitive fibers

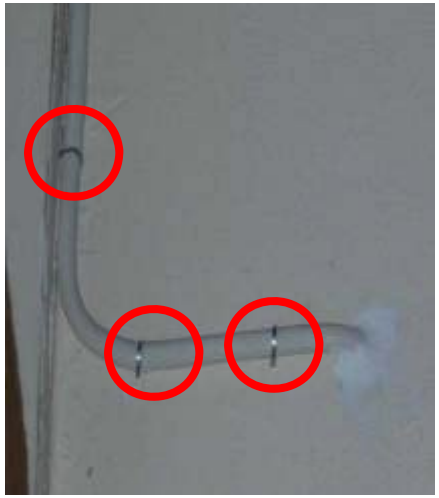


Tight Bends

Staples



Cable Tension



Corning® ClearCurve® single-mode fiber portfolio

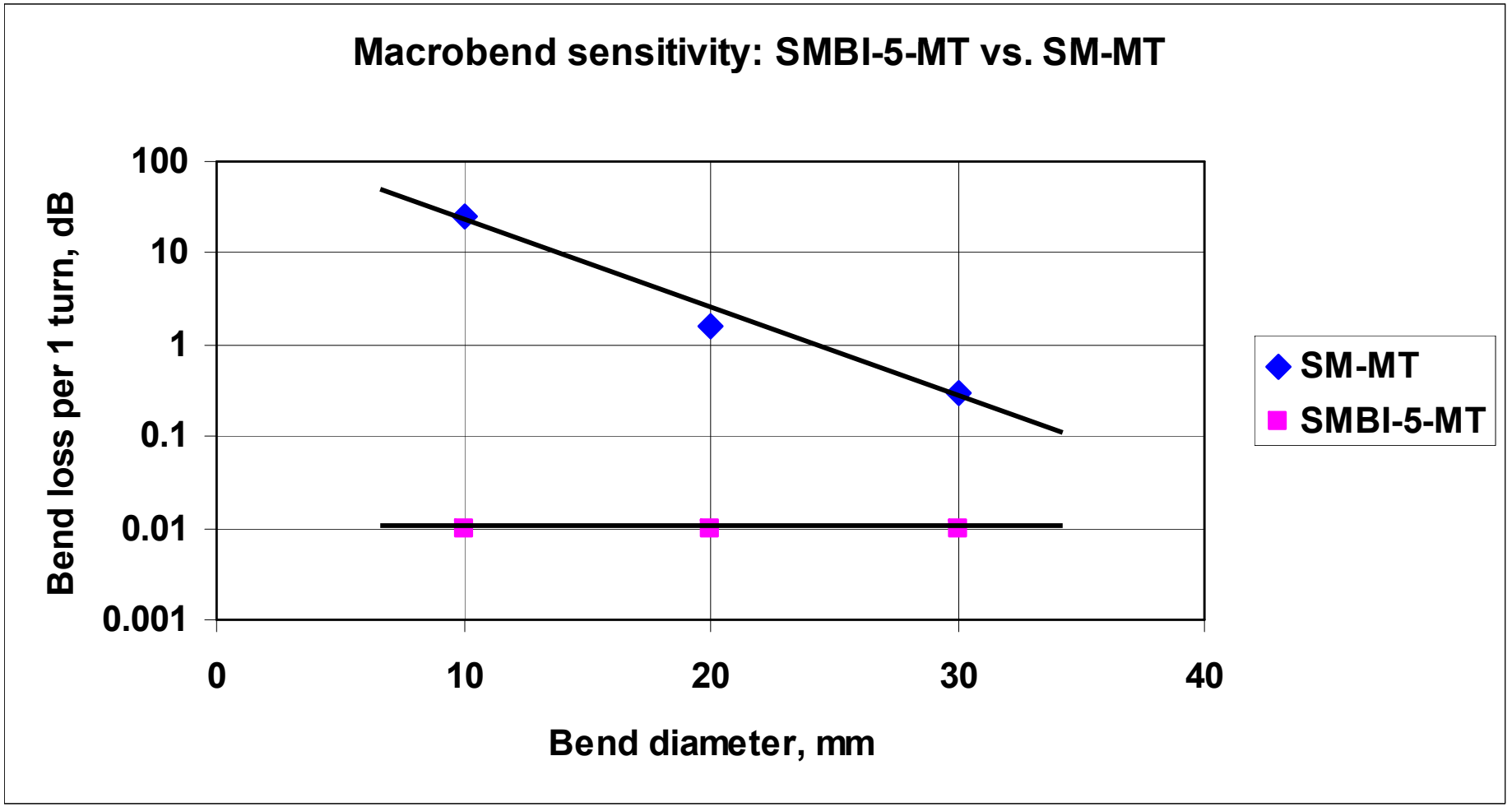
Product	Application	ITU-T	Radius	Corning Spec
ClearCurve® ZBL SMF – Ultra low bend loss	• Virtually no bend-loss • Very low loss in extreme (5mm) bend environments • Enables smaller components	Exceeds G.657. A3*/B3	5 mm	< 0.10 dB/turn
			7.5 mm	< 0.05 dB/turn
ClearCurve® LBL SMF – Low bend loss	• Appropriate for a broader range of applications where some level of loss is acceptable	Exceeds G.657. A2/B2	7.5 mm	< 0.4 dB/turn
ClearCurve® XB SMF – Enhanced bend capability	• Improved performance vs. standard single-mode fiber • Enables a broader range of design options and deployment flexibility	Exceeds G.657. A1	10 mm	< 0.50 dB/turn

Corning elevated temperature specialty fibers

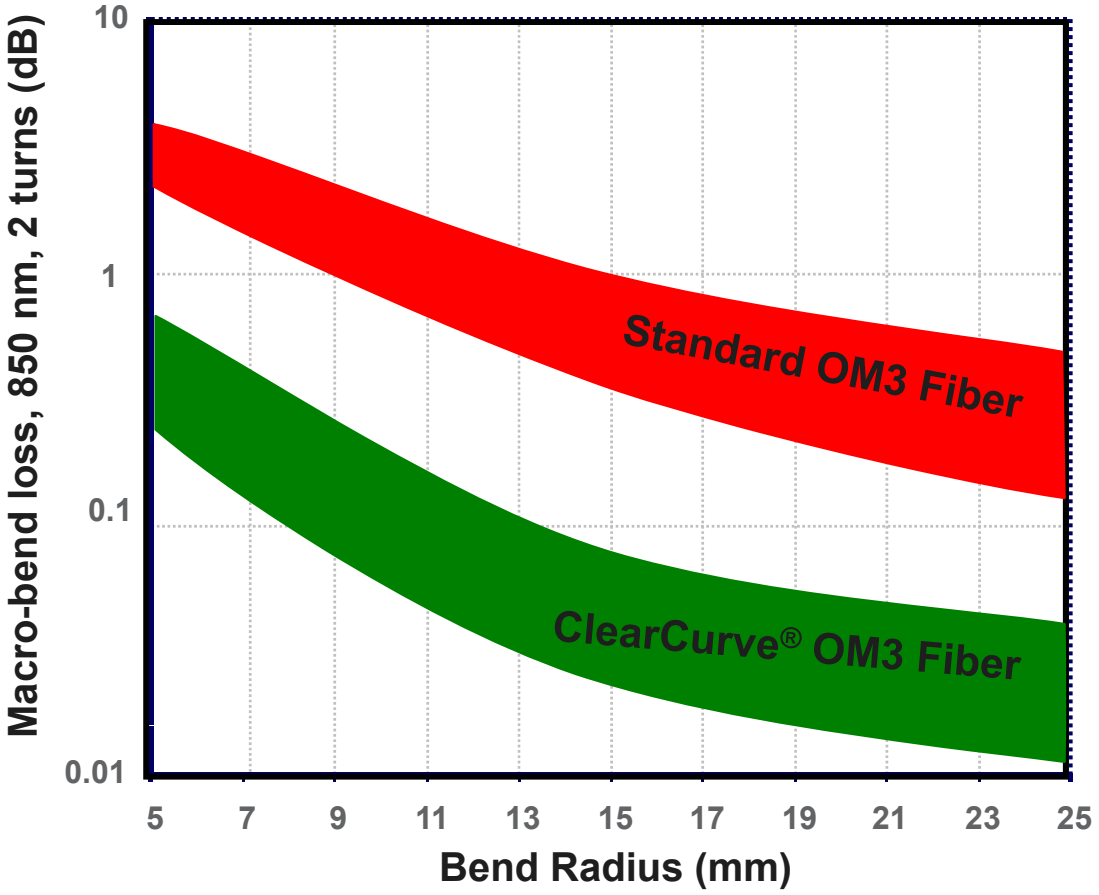
- Elevated temperature optical fibers
  - Mid temperature acrylate coating: single or dual coat (coating diameter of 200 or 245 micron)
    - SM-MT, SMH-MT, MM-MT, MMH-MT
  - Polyimide coating (coating diameter of 155 micron)
    - SM-HT, SMH-HT, MM-HT, MMH-HT

- ClearCurve® optical fiber family glass design
  - Bend insensitive single-mode fibers (coating diameter of 200 or 245 micron)
    - SMBI-5-MT, SMBI-7.5-MT, SMBI-10-MT
    - Same with Hermetic coating
  - Bend insensitive multimode fibers (50/125 µm, NA=0.20, GI)
    - MMBI-MT, MMBIH-MT

Bend loss: SM-MT vs. SMBI-5-MT

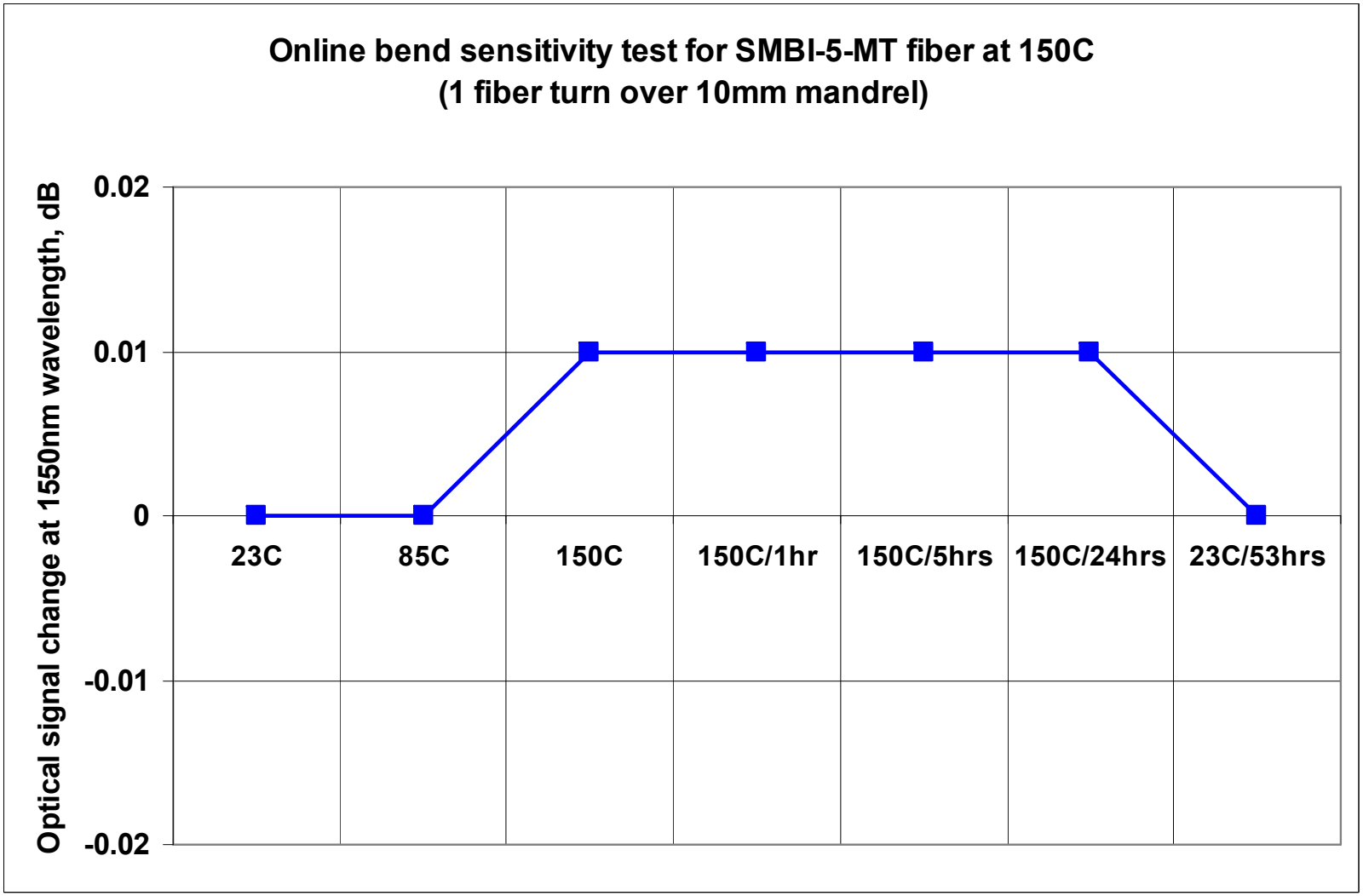


Bend insensitive multimode fibers

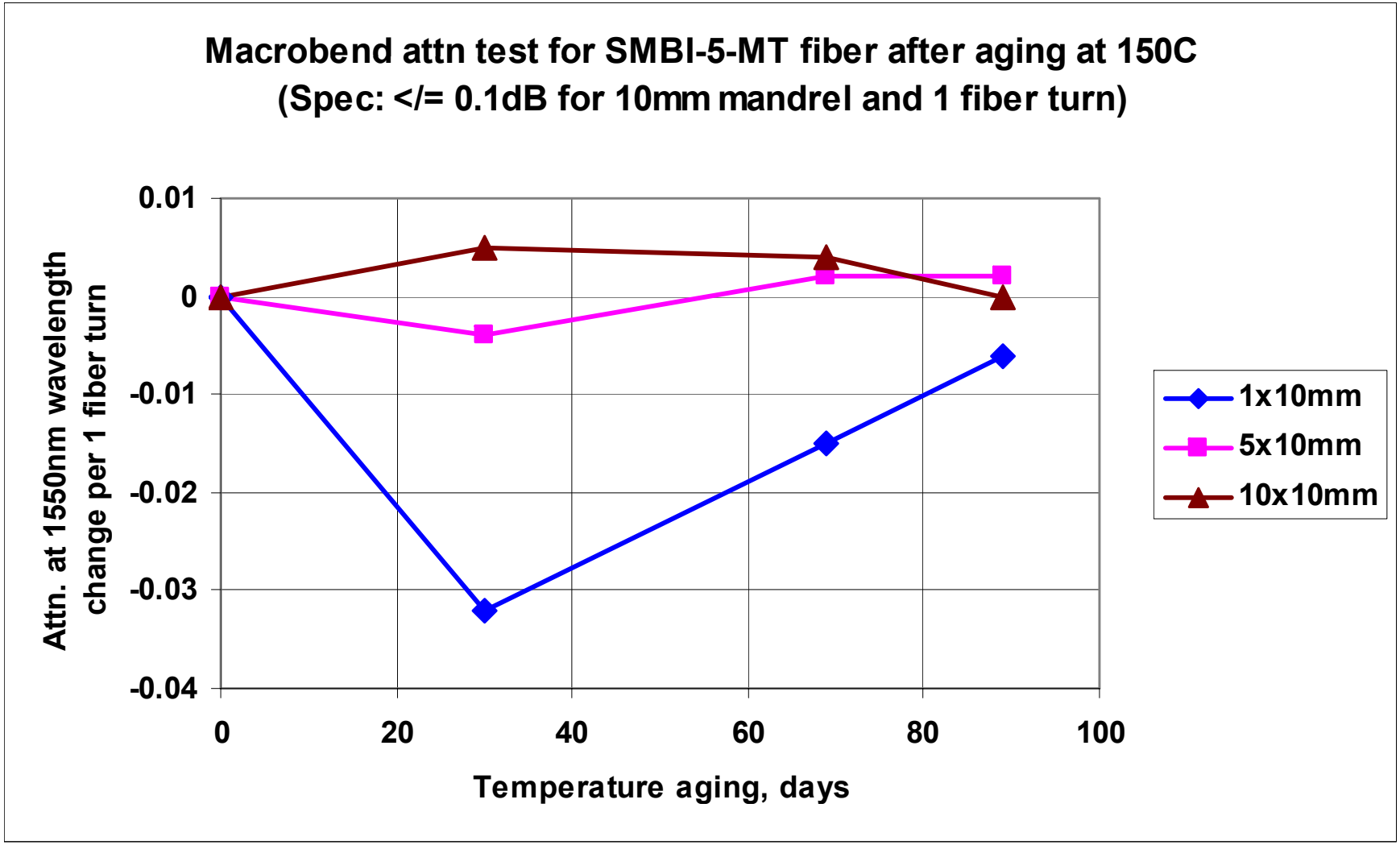


- Up to 10x better bend performance compared to standard 50 µm MMF
- **Macrobend attn spec: ≤ 0.2dB for bend radius 7.5mm and 2 fiber turns (850nm)**
- **Bandwidth OM2/OM3/OM4 capability**
- May be spliced/connectorized to conventional 50/125 fibers with commercially available equipment

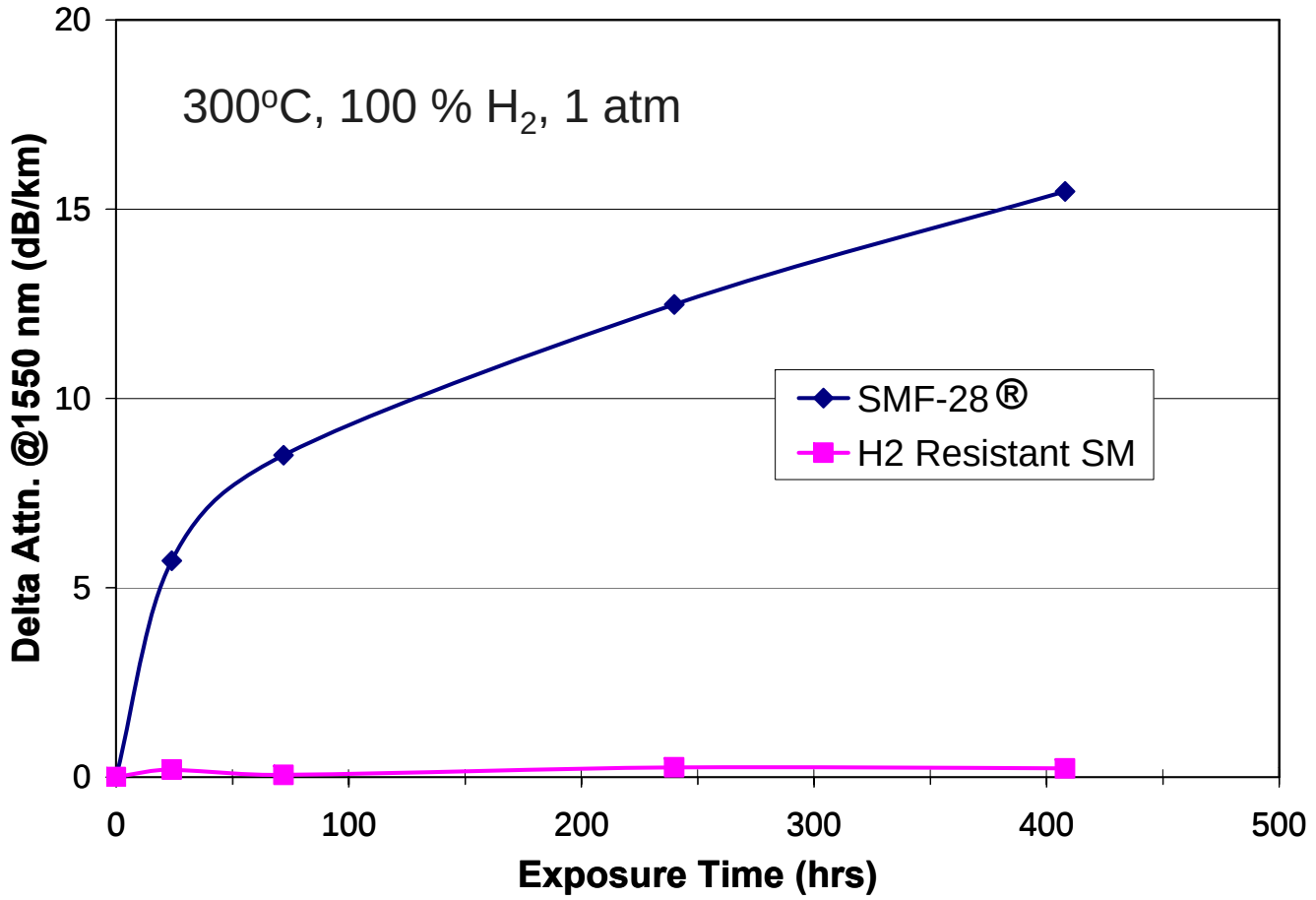
Online bend sensitivity test for SMBI-5-MT fiber at 150C (1 fiber turn over 10mm mandrel)



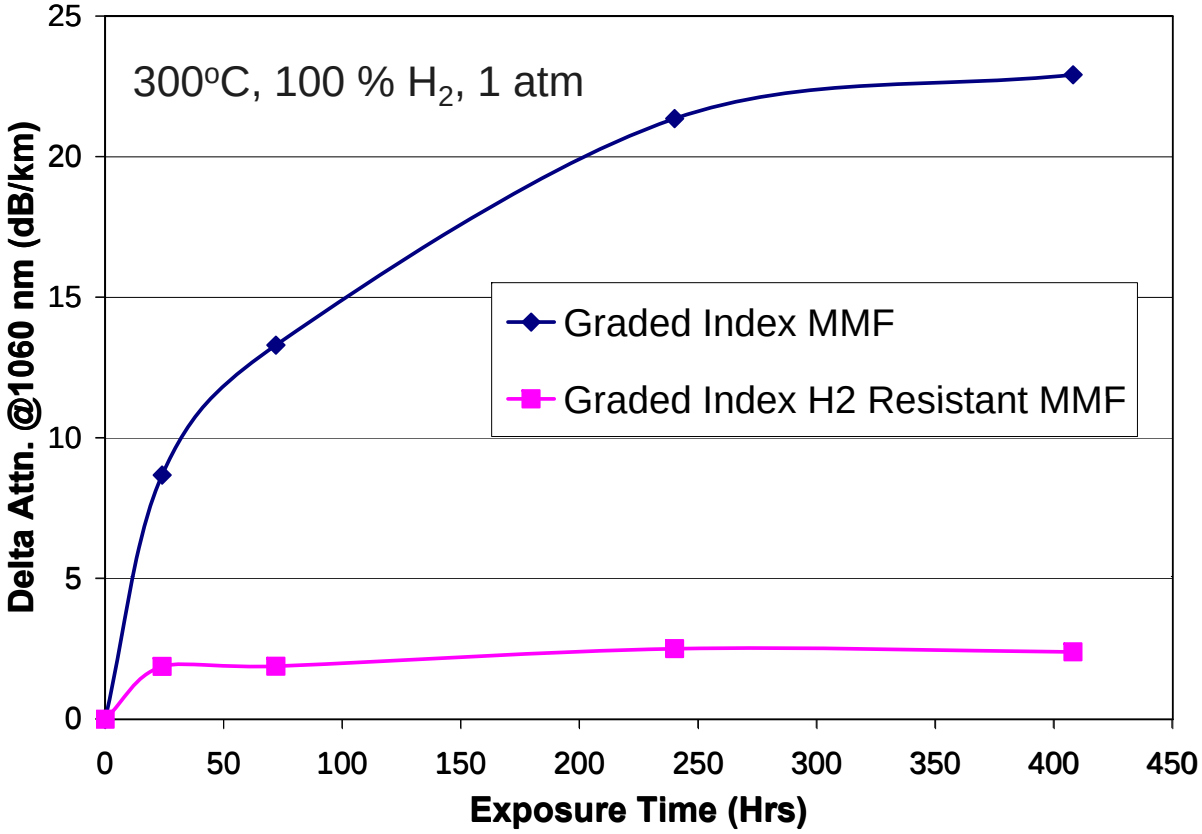
Bend sensitivity test for SMBI-5-MT fiber after aging at 150C



Hydrogen resistant SM-HT fiber vs. SM-HT fiber



Hydrogen resistant MM-HT fiber vs. MM-HT fiber



Hydrogen resistant MMF has graded index profile

Bandwidth
(MHz*km)

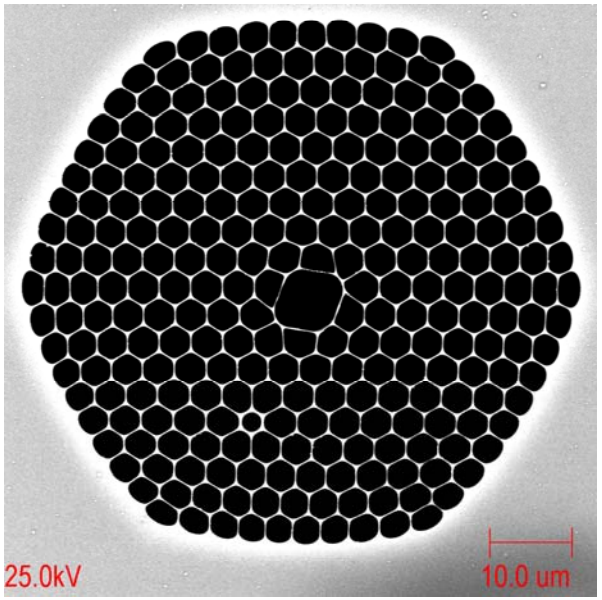
	850nm	1300nm
Step Index	<20	<20
Hydrogen Resistant	**1170**	**850**

PM photonic band gap fiber (PBGF)

- **Air core guiding, pure silica PM fiber**

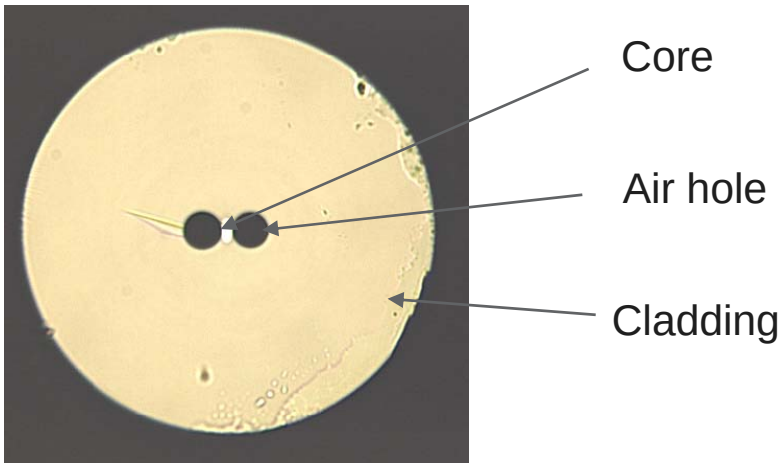
<u>Functionality/Value</u>:

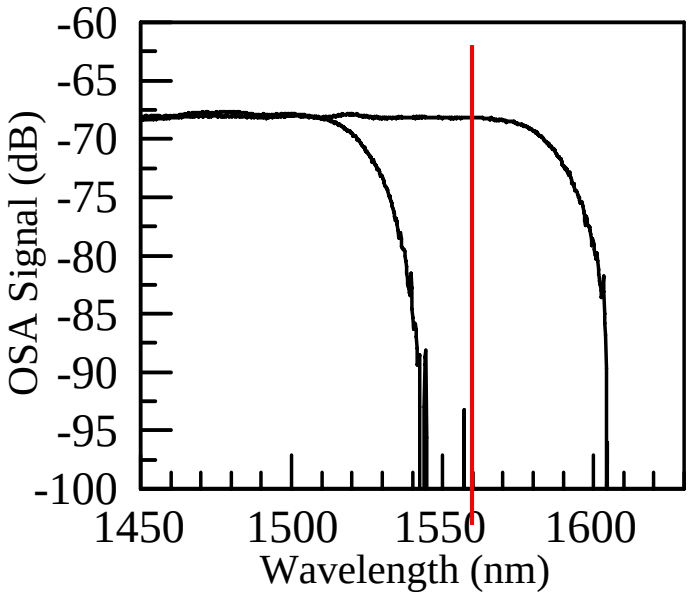
- **World's largest birefringence, $\delta n = 2.5 \times 10^{-2}$**
- **Ultimate radiation resistance**
- **Low non-linearities (1000x lower than SMF)**
- **Exceptionally low macro-bend loss (100x lower)**



Corning single polarization fiber

Elliptical core/Dual air hole design





Air-assisted optical fibers: from millimeter to nanometer scale

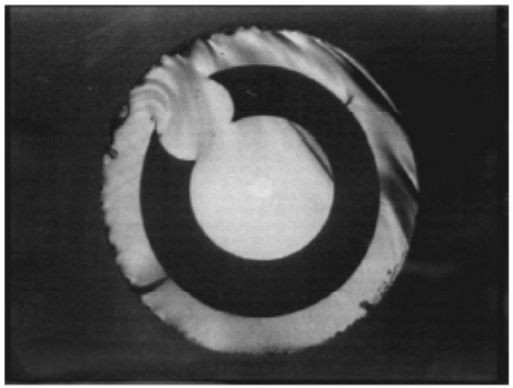
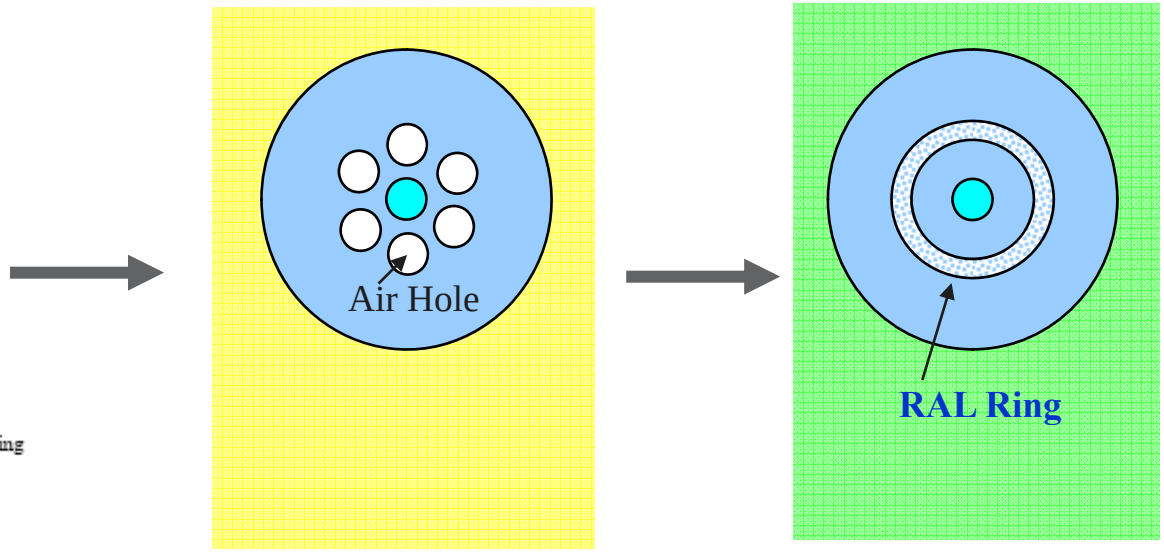
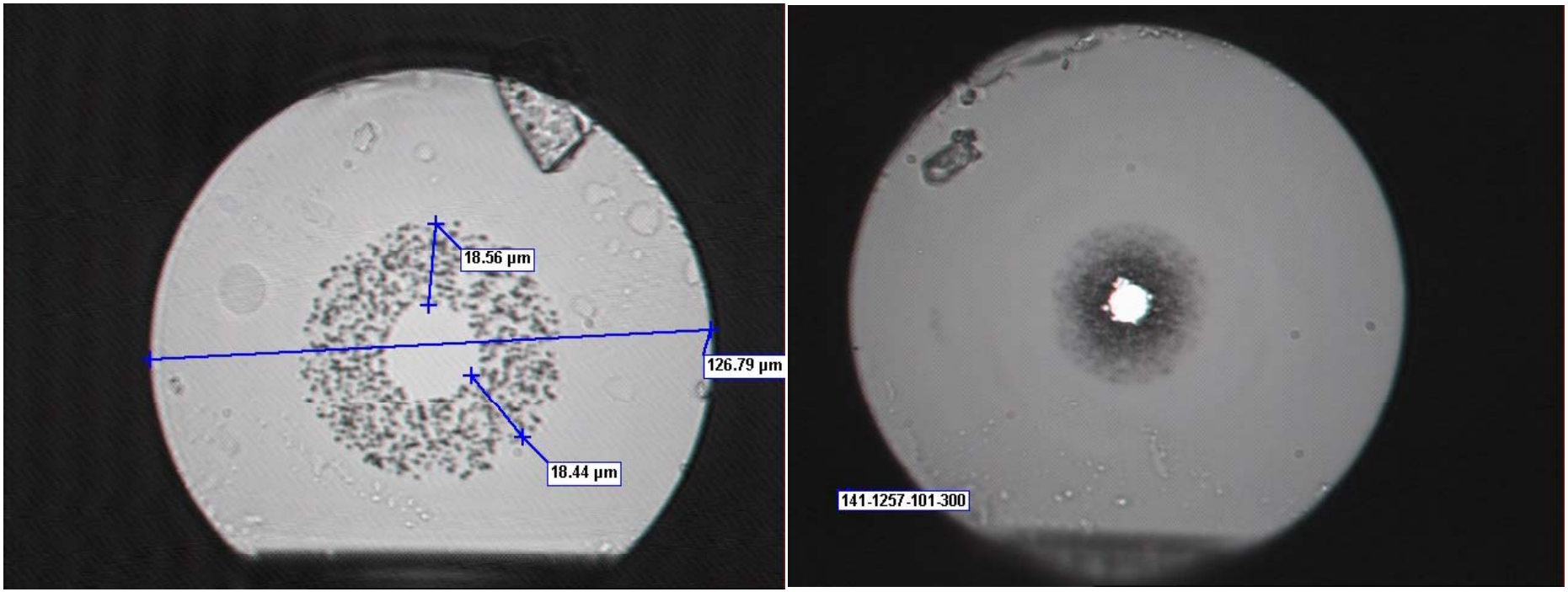


Fig. 2. Cross section of the fiber drawn from the silica–air double-cladding preform.



nanoStructures™ technology

Optical fibers with nanoStructures™ cladding



Corning Specialty Fiber's capabilities

- **Glass**
  - Capability to tune profile and composition to meet customer's needs
    - Profiles: single mode, graded index multimode, bend insensitive, SBS engineered, high power delivery, polarization maintaining, double clad, photonic crystal….
    - Composition: Ge, Al, B, F, P, Rare Earths, Ti…
  - Custom diameters from 50 to beyond 1000 μm

- **Coating**
  - Capability for multiple coating systems
    - Acrylates, Polyimide, Optical Polymers
    - Custom diameters from 100 to beyond 1000 μm
  - Hermetic Coating can be added to any fiber product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