Picometer resolution profilometer for hollow-core fiber surface roughness characterization

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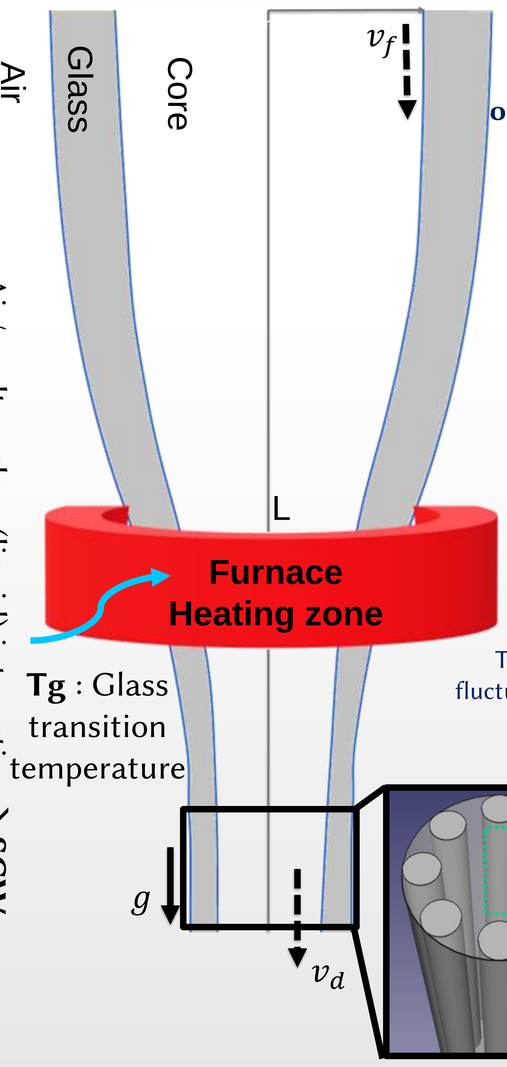
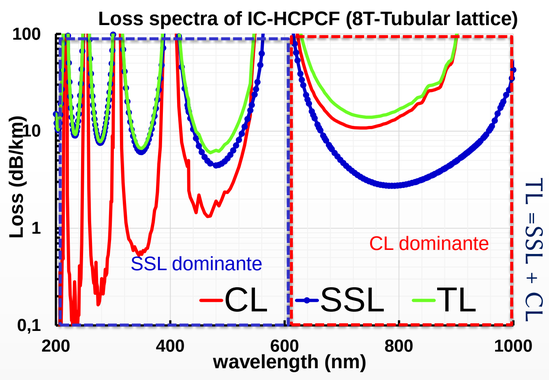
***Abstract:** We build a picometer-sensitivity optical surface-profiler based on polarization-interferometry. The profilometer is design to measure surface roughness profiles of HCPCF. Two HCPCF categories with different fabrication processes were characterized. We observe that for HCPCFs fabricated the new process exhibit a reduction of rms core-surface roughness rms by a factor of close to 3 relative to the surface capillary wave thermodynamic limit, and thus explaining the record loss achieved in the VIS-UV range achieved with these fibers.*

What is the thermodynamic induced Surface capillary waves on HCPCF ?



Tg : Glass transition temperature

Today the performance of the transmission of hollow fibers is limited by the surface scattering loss (SSL) induced by the surface roughness (SR) [1].



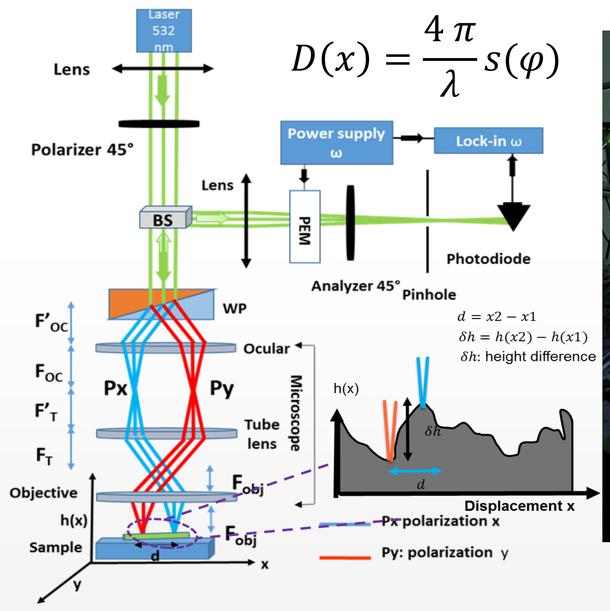
Surface roughness during the fiber fabrication

Thermodynamic fluctuations of the glass interface ➡ Frozen surface capillary waves (SCW) ➡ Surface roughness (SR)

- Thermodynamical process : $E_c \approx \sqrt{K_B T}$
- RMS roughness for silica: $\sigma \approx \sqrt{K_B T_G/\gamma} \approx 0.4$ nm [2]

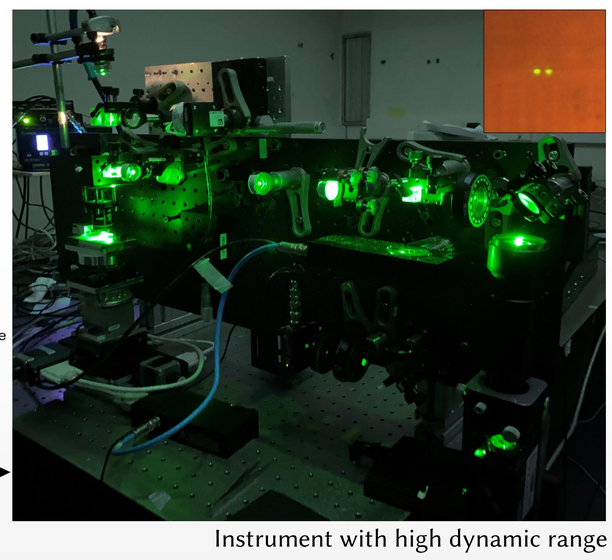
Optical profilometer

Measuring the difference of height by measuring the phase shift between the two beams reflected on the sample [3].

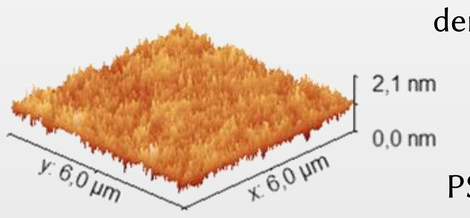


$$D(x) = \frac{4\pi}{\lambda} s(\varphi)$$

$d = x2 - x1$
$\delta h = h(x2) - h(x1)$
δh: height difference



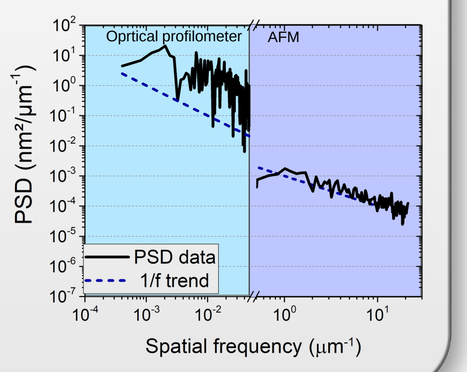
Instrument with high dynamic range



Power spectral density (PSD) is one way to explain roughness.

PSD of the SCW :

$$S_z(f) \approx \frac{K_B T_g}{4\pi\gamma f}$$

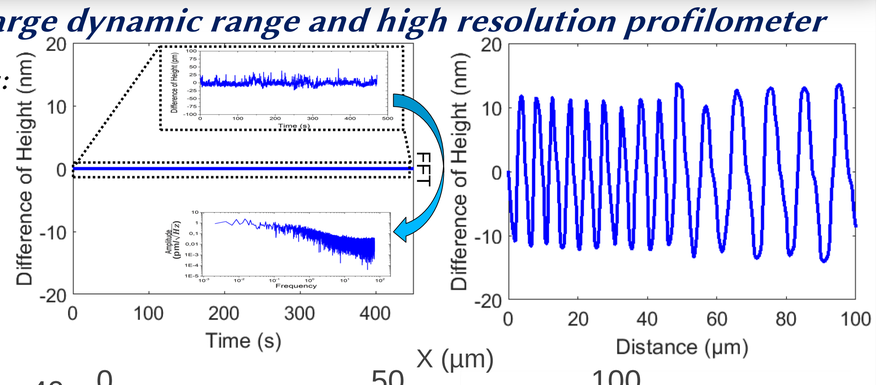


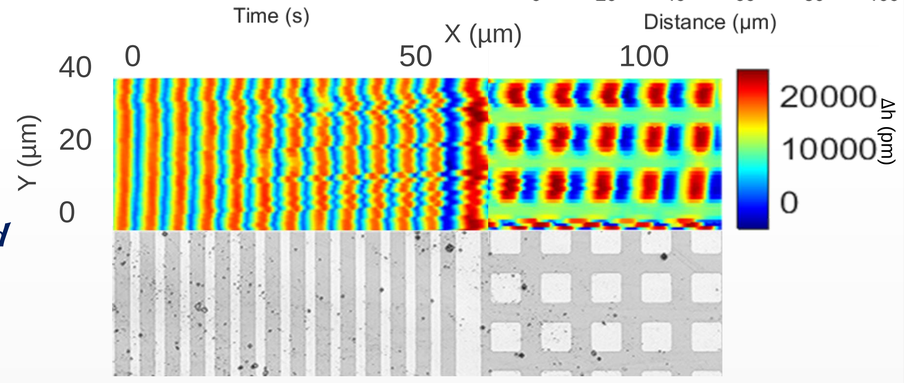
Sensitivity, resolution and dynamics of the surface profiler

1. Height and scan large dynamic range and high resolution profilometer

Instrument specifications:

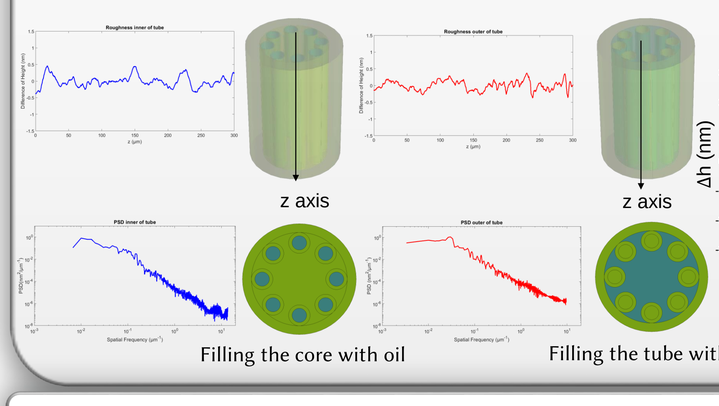
- **Minimum RMS value (sensitivity): *(2pm/√Hz)***
- ***Maximum measured calibrated height: 100 nm***
- ***Maximum measured "calibrated" scan with 7pm sensitivty: 1 cm.***
- ***Reproductibilty : within 10 pm***



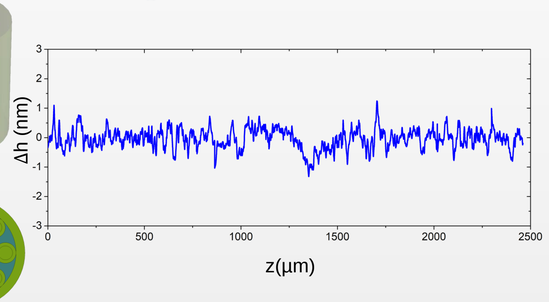


2. Ability to build a 2D profile

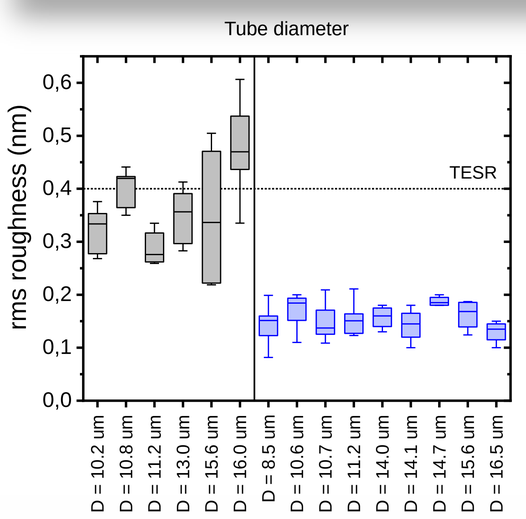
3. Ability to distinguish two surfaces 600 nm apart

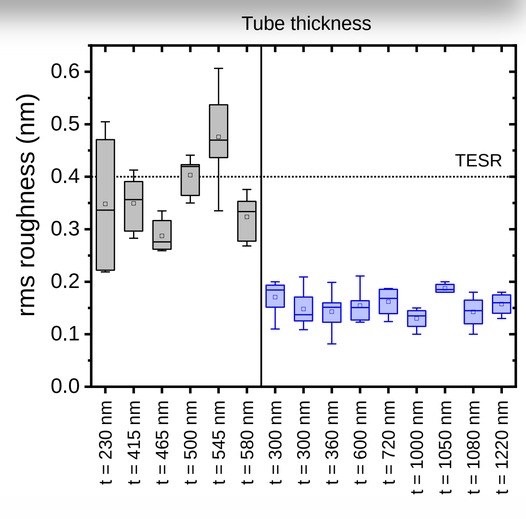


4. High dynamic range roughness on Z-axis (>2.5 mm)

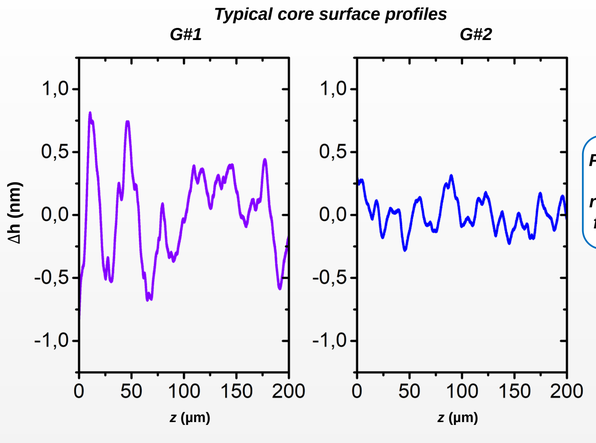


HCPCF surface roughness measurments

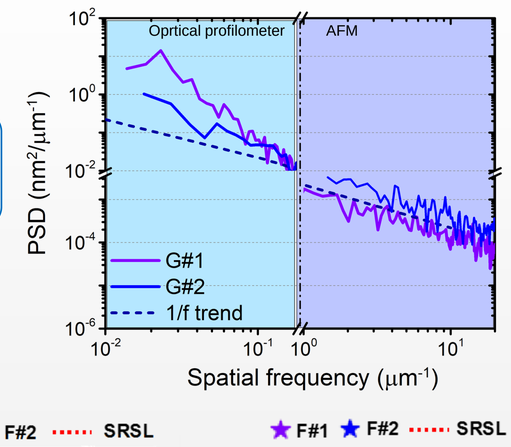


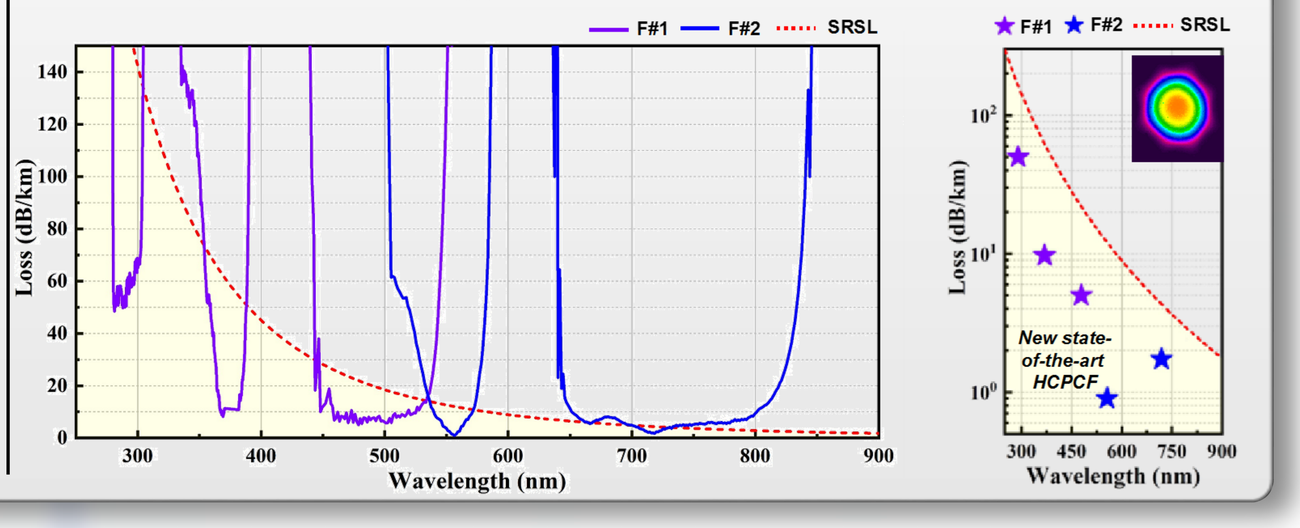


Typical core surface profiles



Peak-to-peak roughness reduced by a factor ~3 [4]





References

[1] B Debord et al., MDPI - fiber, paper review, Vol. 7, No 16, 2019.
[2] P. J. Roberts et al., Optics Express Vol. 13, No 13, 2005.
[3] P Gleyzes et al., J. Opt J. Opt. Vol. 25, No 4, 1994.
[4] J Osorio et al., ArXiv: 2207.110990, 2022.