Online optical refractive index measurement in research reactor core

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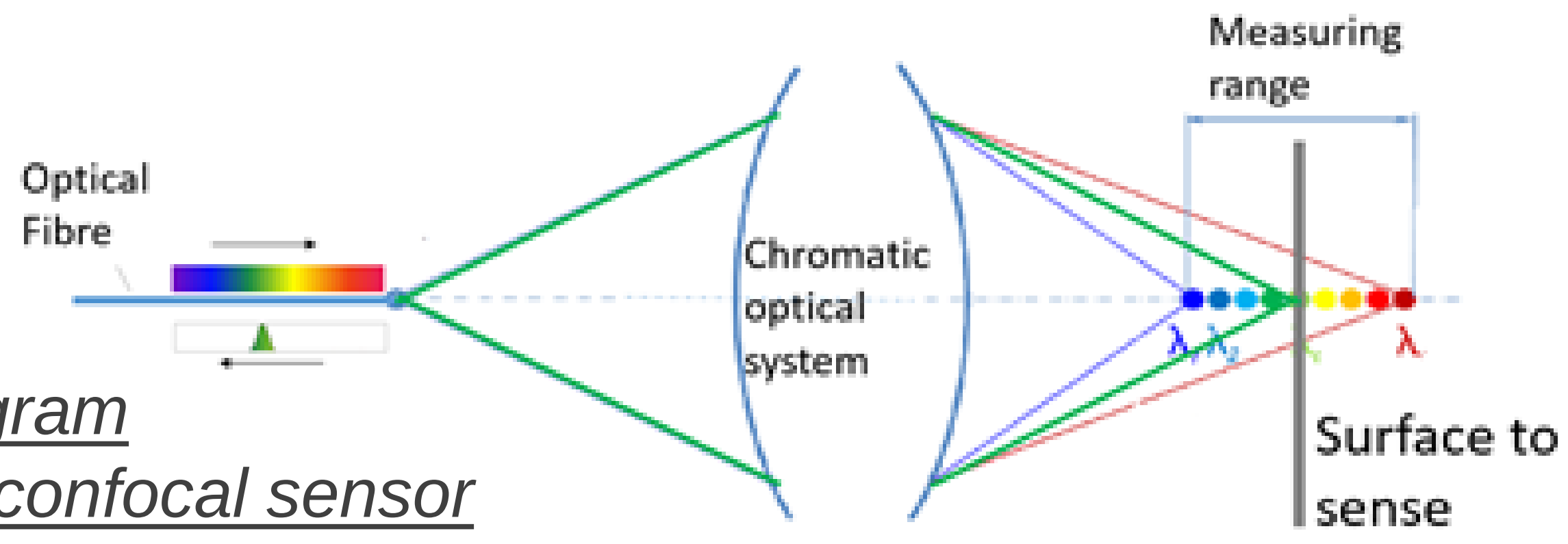
Context

There is a growing interest in **fiber optic measurements for applications in radiation environments**. They can monitor environmental parameters such as temperature, size, pressure, chemical composition, irradiation doses, and dose rates... Often, the developed systems imply no propagation of the light beam outside the fiber, but for some applications, **fiber optic is combined with an optical system** that focuses and/or collects the light beam. The question then arises not only about **the impact of the RIA** (Radiation-Induced Attenuation), but also of the **radiation-induced change of the refractive index** of the used glasses, which is a determining value for the optical function.

The chromatic confocal sensor

A development is on progress of a **non contact displacement sensor** able to operate under high neutron fluence (~10^{20} n.cm²) , high gamma dose (~GGy), and high temperature inside a research reactor.



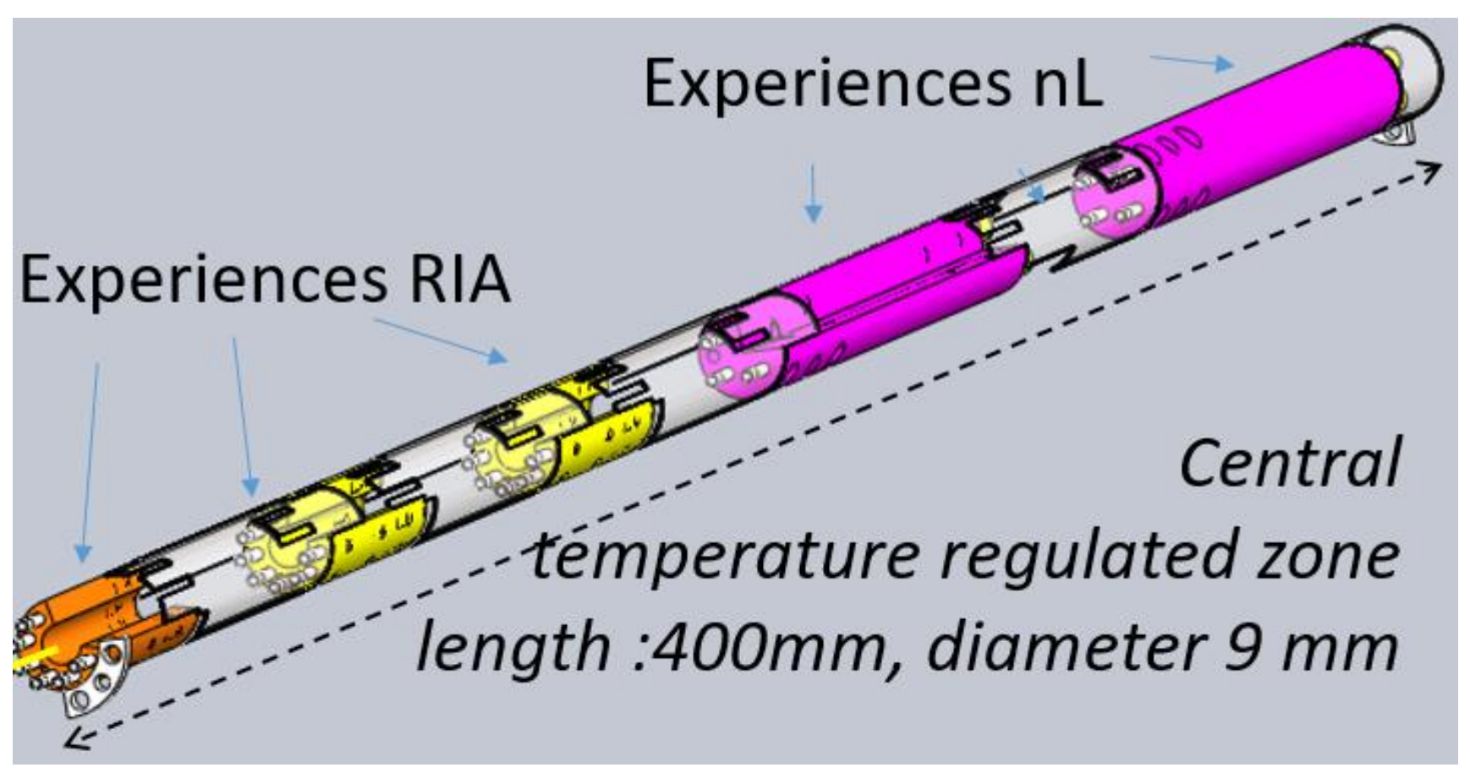
Schematic diagram of a chromatic confocal sensor

Work presentation by my colleague AGOYAN Marion
#04-161 Confocal chromatic sensor for displacement monitoring in research reactor (June 24th 2021)

The TESCA (Test in capsule) irradiation

This works requires to better know the **behavior of glasses under radiations**. CEA is preparing an irradiation in the BR2 reactor of SCK.CEN (Belgium). We will test several fiber-optic sensors, and also some **glasses good candidates to be integrated in an hardened chromatic confocal sensor.**

Except for silica, whose behavior under radiation is better known**, other rad-hard glasses have only been tested under low gamma flux (~ few MGy).**

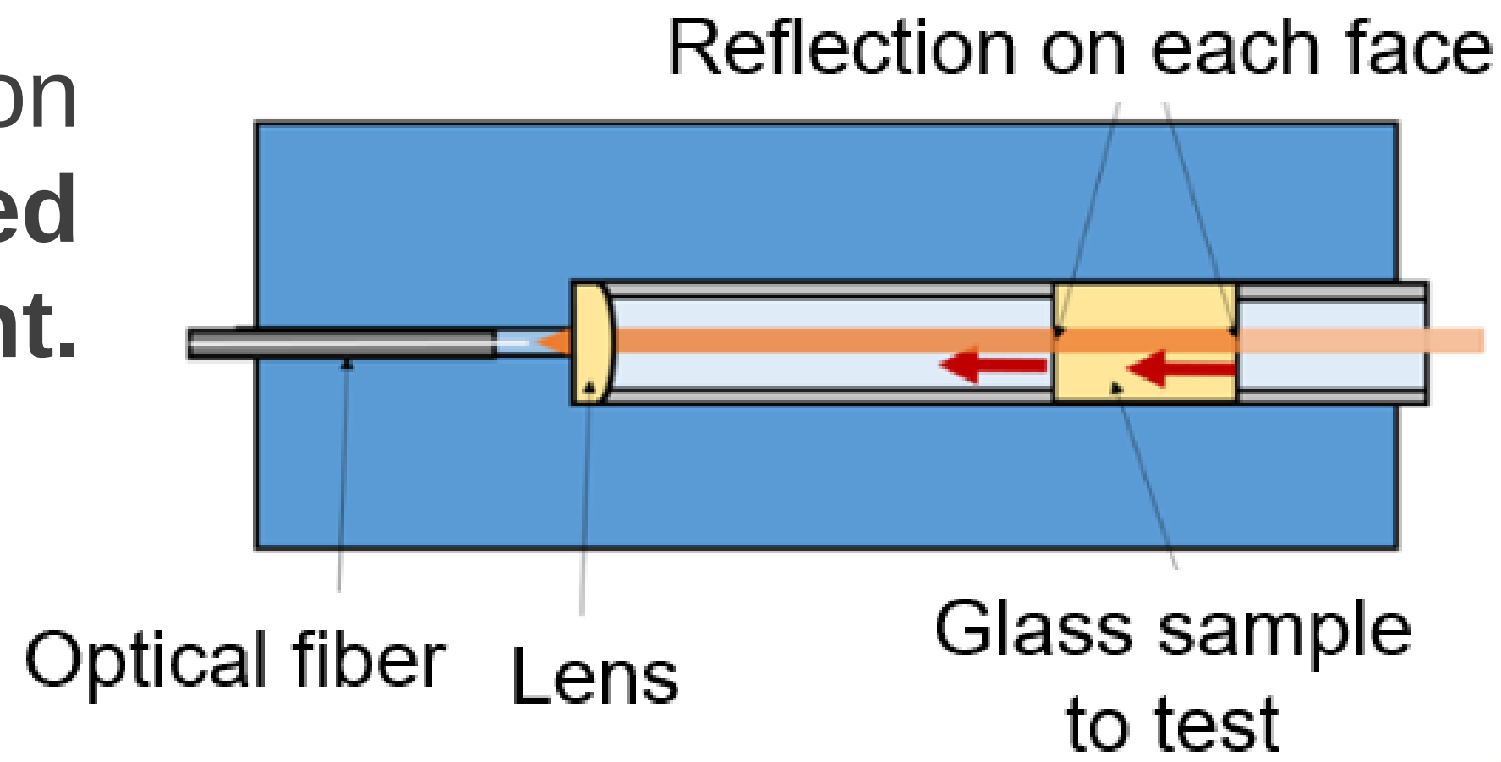


View of the TESCA assembly dedicated to online measurement on glasses

Online measurement of the variation of the optical length and refractive index in TESCA

The first objective is to measure the refractive index change by white light **interferometry**. But high neutron fluence is known to produce also density change leading to compaction in a silica bulk material. **The targeted online measurement of refractive index (n) therefore becomes an optical length (n_* L) measurement.** We are also preparing **pre and post-irradiation of glass samples** to decorrelate variations of n and L.

The **n and L variations** of silica for example under high fluence – 10^{19} n/cm² (E>1MeV) and several GGy in gamma – is in the range of **some 10^{-3}.** The expected accuracy of the measurement is ~ 10^{-4}

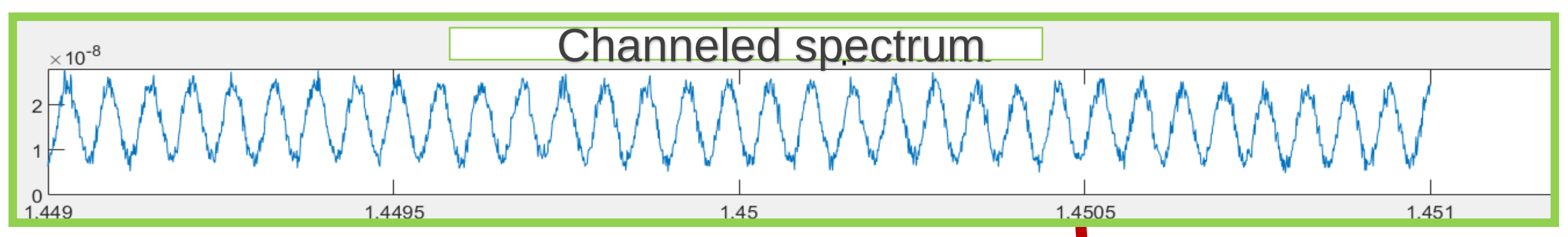


Schematic diagram of n_* L on line measurement

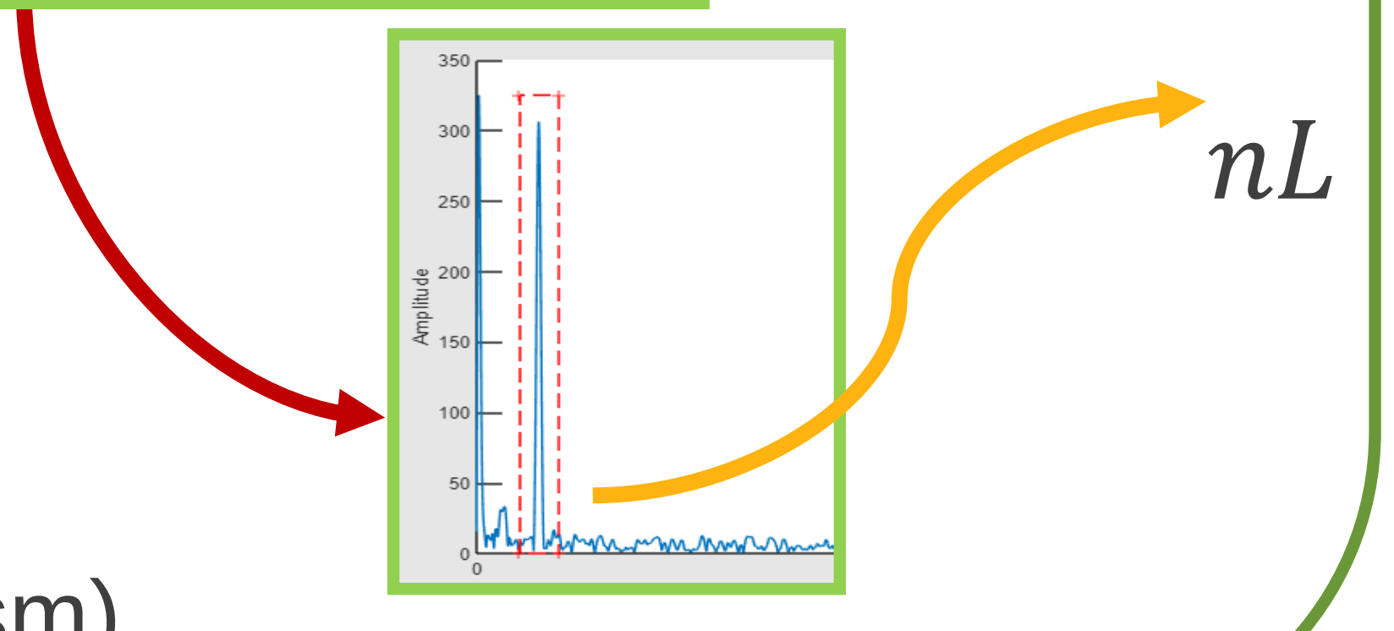
How do we get the value of optical path ?

The measurement system monitor the **channeled spectrum** describing the intensity given by the interference between reflection on each face of the sample.

$$I(\lambda,T) = I_0\left[a + bcos\left(2\pi\left(\frac{2(n(\lambda,T)*L(T))}{\lambda}\right)\right)\right]$$



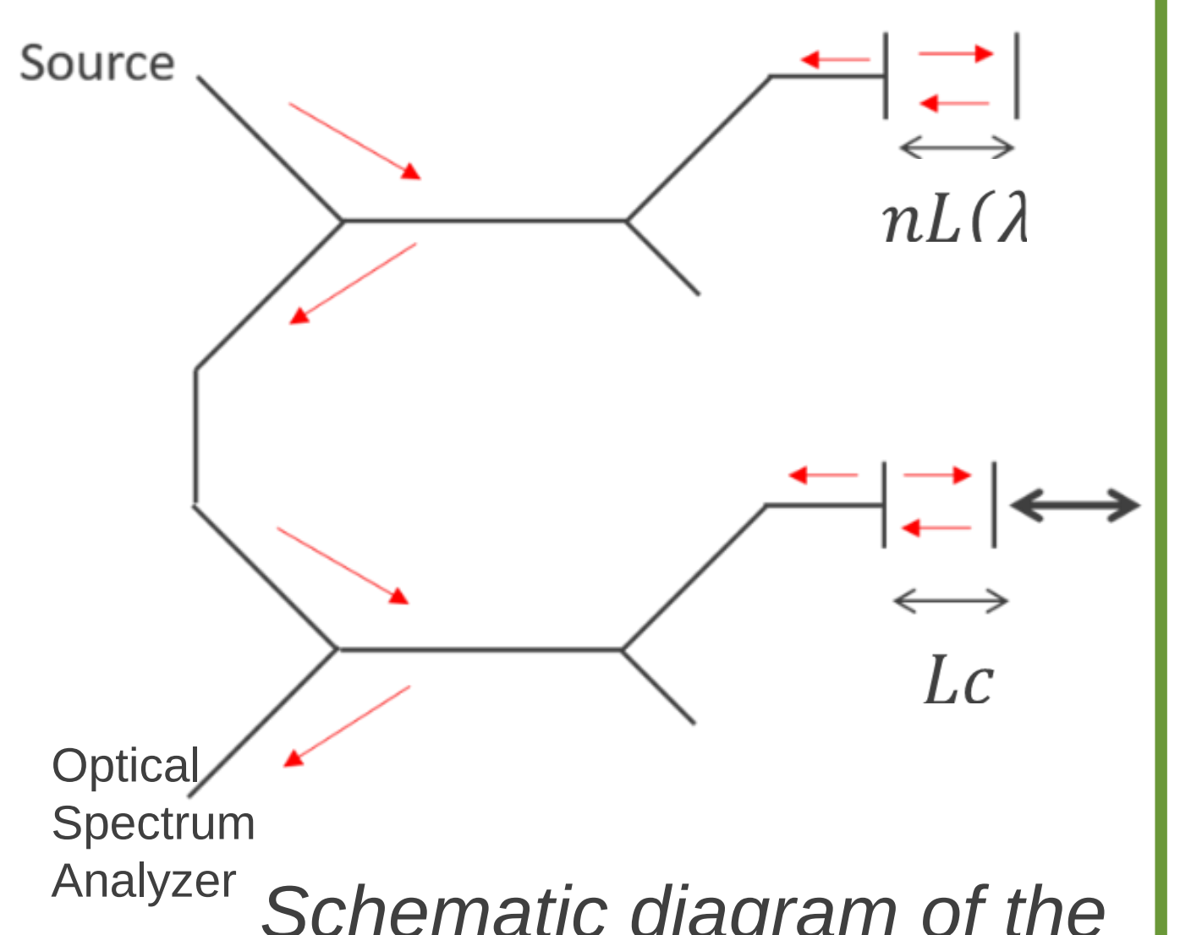
We then apply a FFT on I(σ) with σ = 1/λ. The absissa of the peak corresponds to the **value of n_*L** after a correction required by the fact that n varies with λ (chromatism).



Using a double interferometer to increase the precision

We use 2 **interferometers in series.** The first one is our nL measurement system and the second one is a cavity not far from n_*L. The resulting channeled spectrum corrrespond to:

$$I(\lambda,T) = I_0\left[a + bcos\left(2\pi\left(\frac{2(n(\lambda,T)*L(T) - \mathbf{Lc})}{\lambda}\right)\right)\right]$$

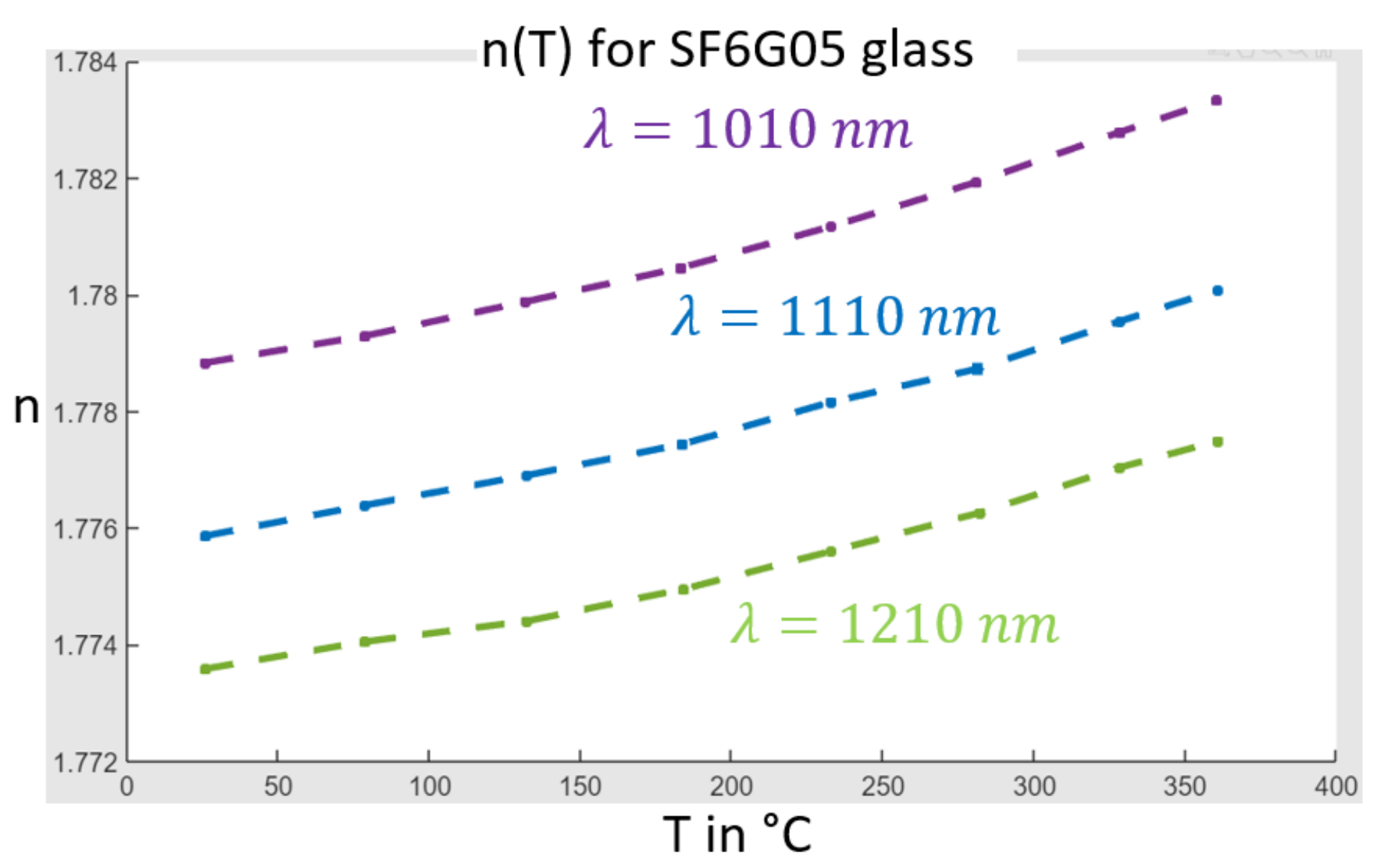


Schematic diagram of the double interferometer

With this new system, we have access to the value: *n_* L - Lc. That roughly permits to **increase the accuracy** in the ratio: n*L/(n*L-Lc).*

Refractive index

In order to **test the robustness of our measuring device, and to collect data not available in the literature,** we made measurements of the $n*L$ variations up to 350°C on various glasses. By dividing the results by $L(T)^{(1)}$, we get *n(T)*.
For example, with **SF6G05 glass**, we obtained:



(1): relative error ≤ 10-3

Conclusions

- In order to develop a rad-hard confocal chromatic sensor, **data on the behavior of glasses under radiation** are expected to result from the **TESCA irradiation** (2022, in the BR2 research reactor).
- We have developed a **smart miniature device** in order to measure **by interferometry the variations of the optical path n * L of some glass samples** under radiation environment. This device will be set in the research reactor's core for **online measurements**.
- The robustness of the device has been tested by measuring the n_*L variations with temperature, giving access to **n(T) up to 350°C**, data which are non available up to now in the literature for most of glasses.
- Work is in progress to **consolidate the accuracy**.

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