Effects of metallic coatings on the thermal sensitivity of optical fiber sensors at cryogenic temperature

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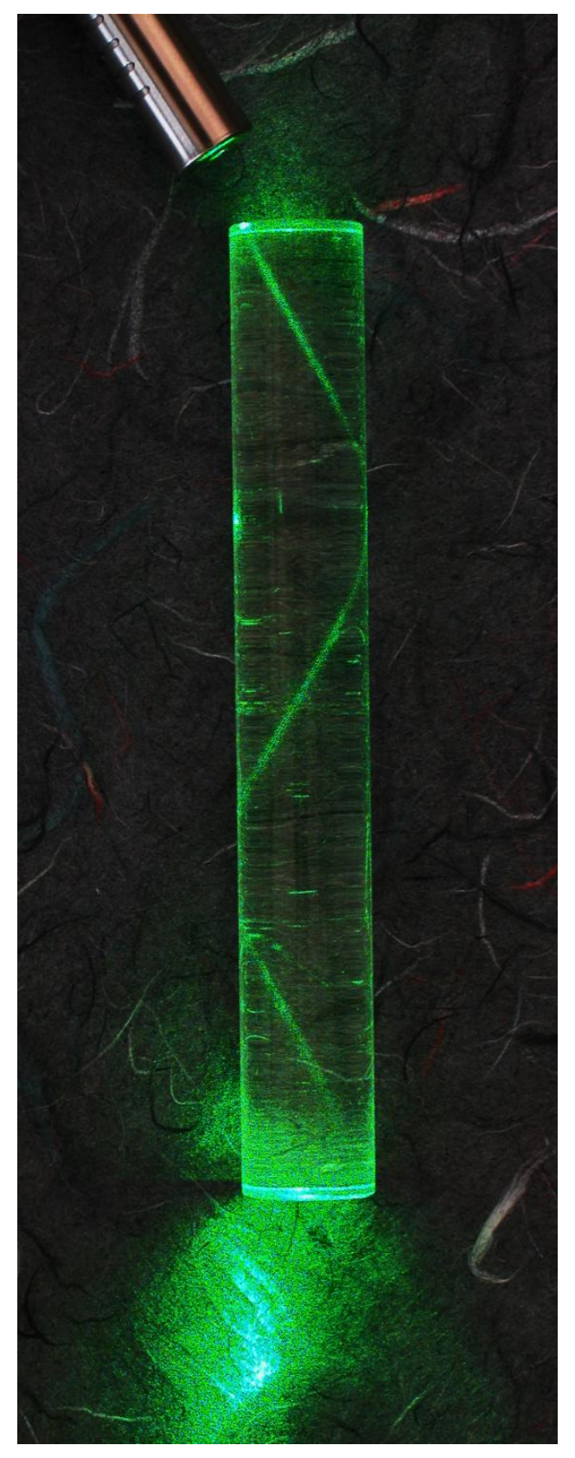
Overview

A promising new application for optical fiber sensors is in monitoring superconducting magnets which are, inevitably, operated at cryogenic temperature.



Rayleigh scattering interrogated optical fibers are distributed sensors of temperature and strain with high spatial resolution.

The measurement is based on the defects that are naturally occurring during fiber manufacturing

Standard, telecommunication grade optical fibers are the sensing element of the system – no need for specialty fibers or gratings.

Main drawback:
The thermal sensitivity of optical fibers is significantly reduced at cryogenic temperatures

Research Goals
Developing a coating technique to manufacturing long length coating on optical fibers
Develop coatings that increase the thermal sensitivity of Rayleigh interrogated optical fibers at cryogenic temperatures

The main ideas behind the project
At cryogenic temperatures, thermal expansion is the only mechanism for thermal sensitivity

Engineering the overall thermal expansion of the fiber so that it is maximized at low temperatures will maximize the thermal sensitivity.

The overall thermal expansion of the fiber assembly can be increased by providing the fiber with a combination of coating layers with high thermal expansion coefficients and high modulus.

A combination of polymers and low temperature metals seem the best choice.

Rayleigh backscattering interrogated optical fibers Measurement principle

- Telecommunication grade optical fibers used as distributed sensors of temperature and strain
- Thermal sensitivity due to two contributions: changes in fiber dimension (thermal expansion) and change in refractive index (thermo-optic)

$$\frac{\Delta\lambda}{\lambda} = (\alpha + \xi)\Delta T$$

$$\alpha = \frac{1}{L}\frac{\partial L}{\partial T} \qquad \xi = \frac{1}{n}\frac{\partial n}{\partial T}$$

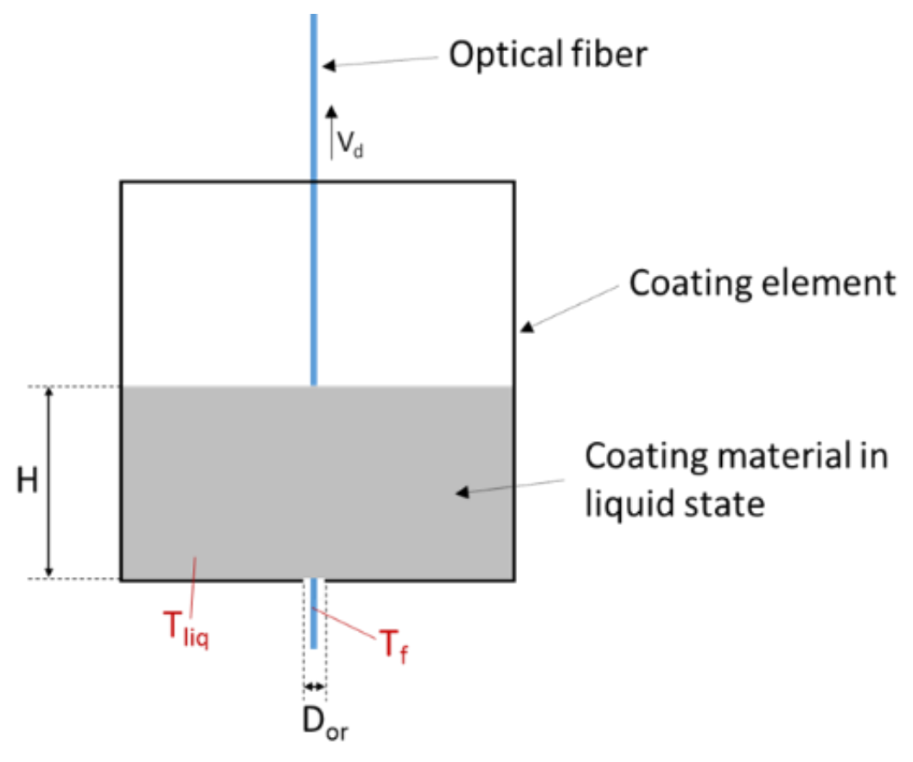
- Decreases with temperature and overall small because of the silica cladding
- Can be engineered

- Decreases with temperature and approaches zero at 4.2 K
- Cannot be engineered

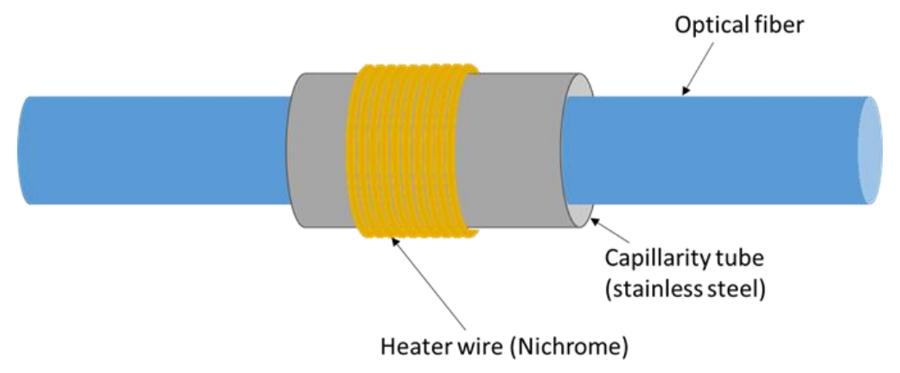
At cryogenic temperatures, the contribution of the thermo-optic coefficient is minimal and thermal expansion is the main mechanism responsible for the sensitivity

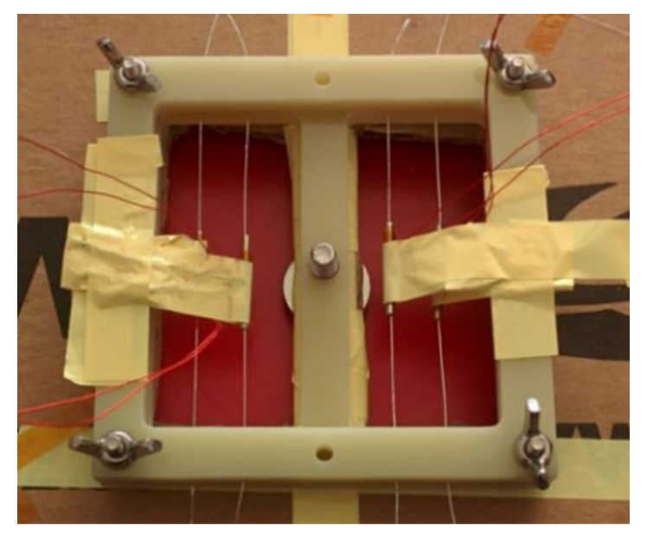
Experimental setup

- Fiber is drawn through a coating element containing the melt of the coating material – compatible with long length, continuous deposition



- Each fiber is equipped with a heater to release a thermal perturbation and placed in a holder
- All samples subject to same conditions and same input power
- Thus, the higher the spectral shift, the higher the sensitivity



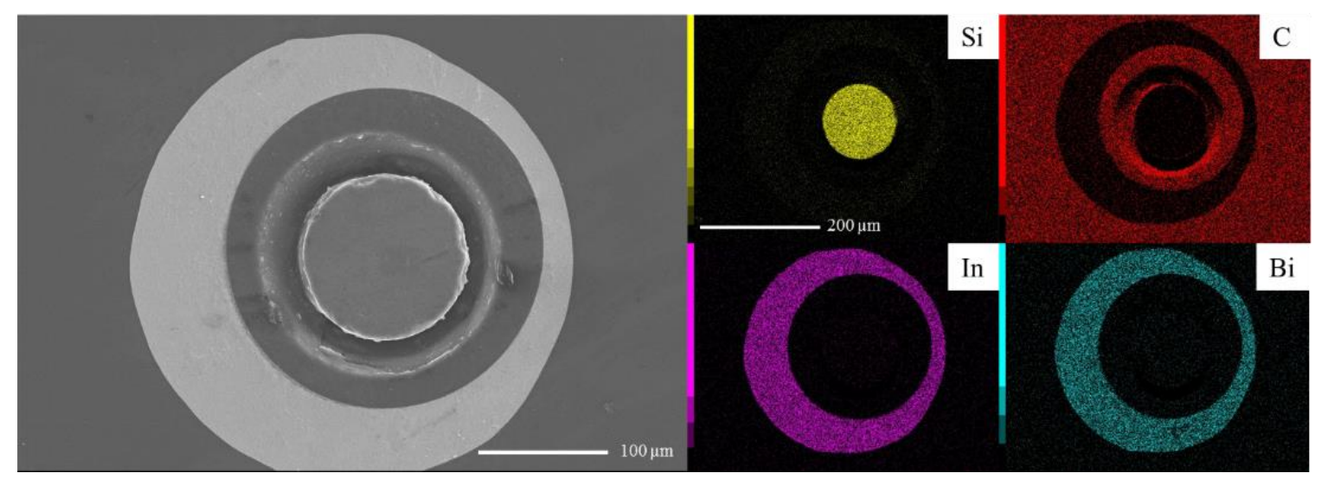


Results

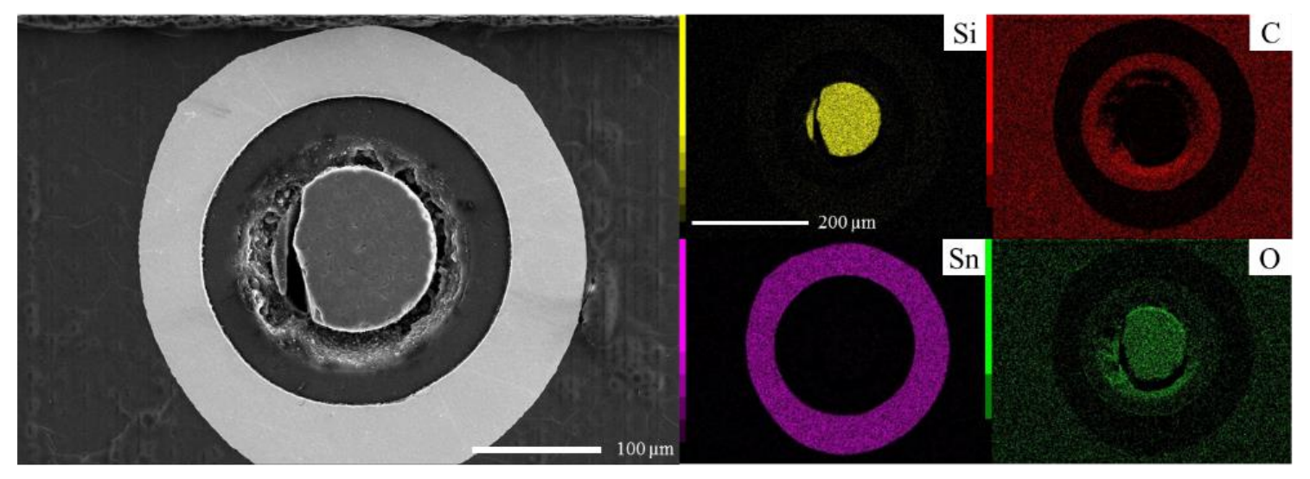
SEM micrographs and EDS maps showing a cross section of optical fiber coated with the different materials studied

All optical fibers are single-mode, conventional, telecommunication grade with a 125 μm silica cladding

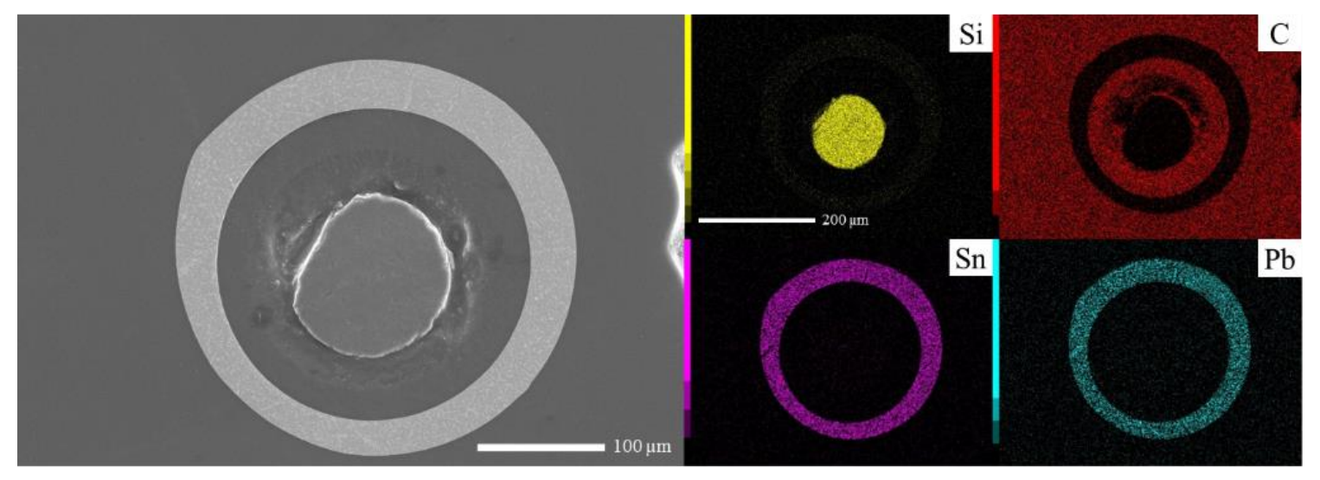
Acrylate primary coating; InBi secondary



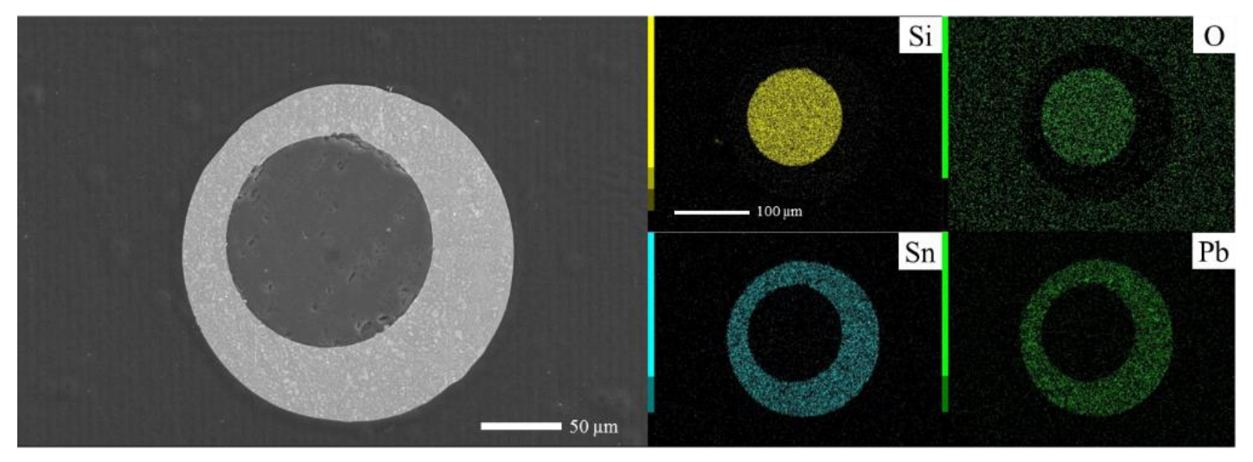
Acrylate primary coating; Sn secondary



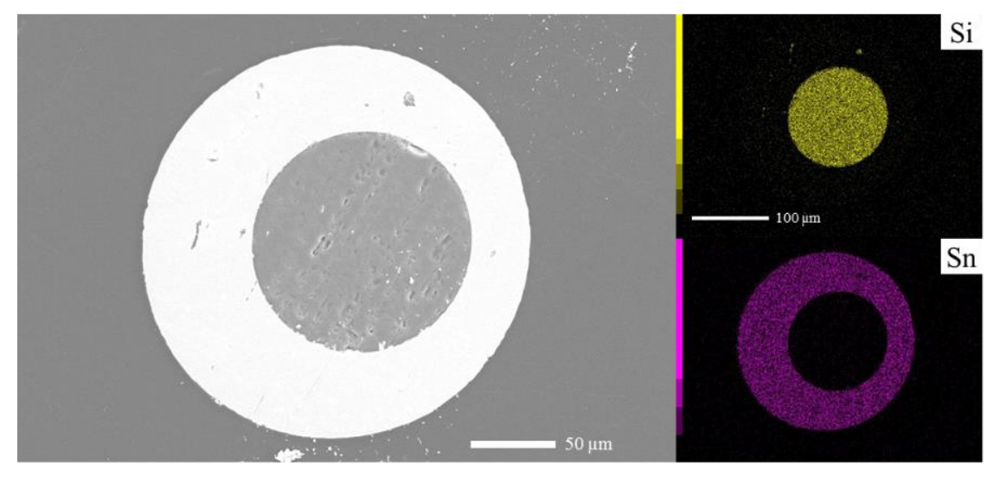
Acrylate primary coating; PbSnAg secondary



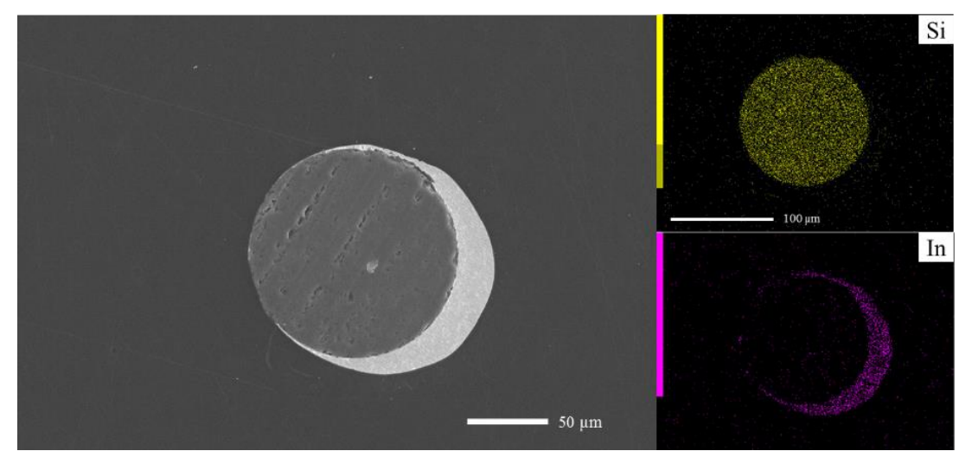
Single coating of PbBiAg on SiO_2 cladding



Single coating of Sn on SiO_2 cladding

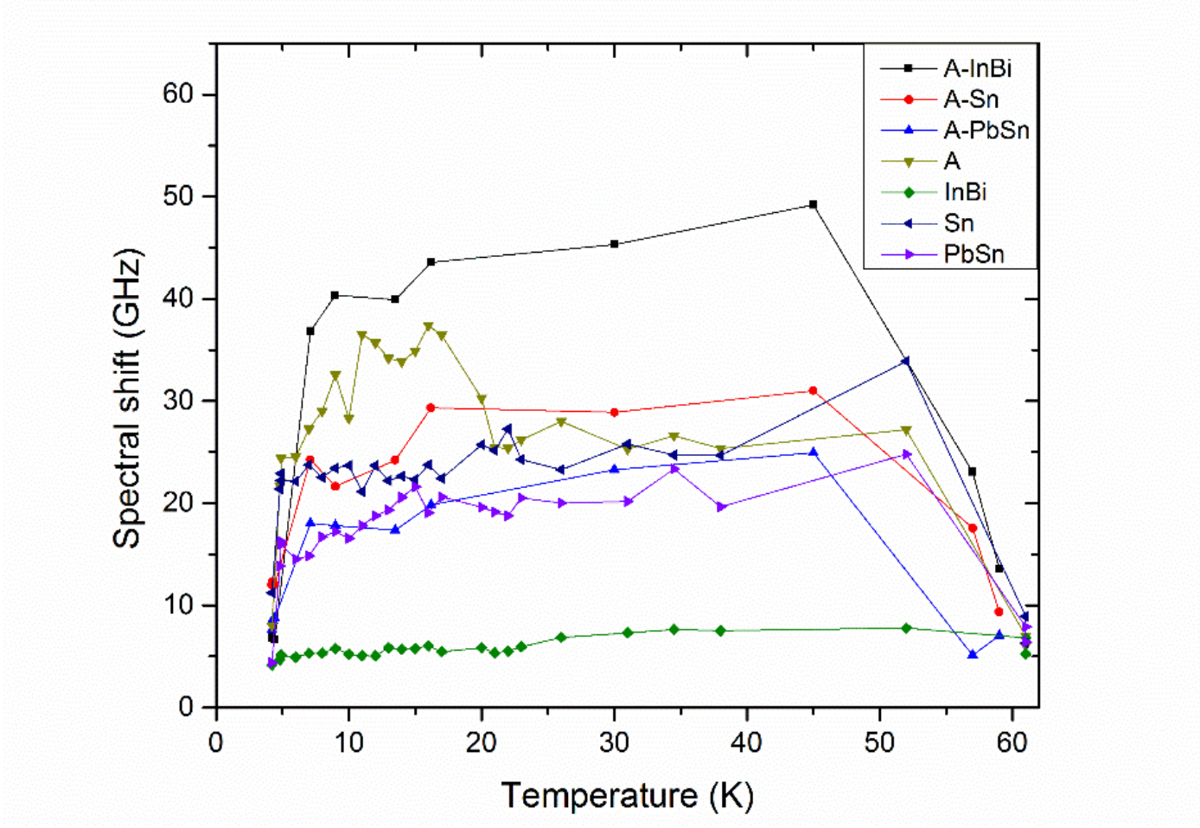


Single coating of InBi on SiO_2 cladding

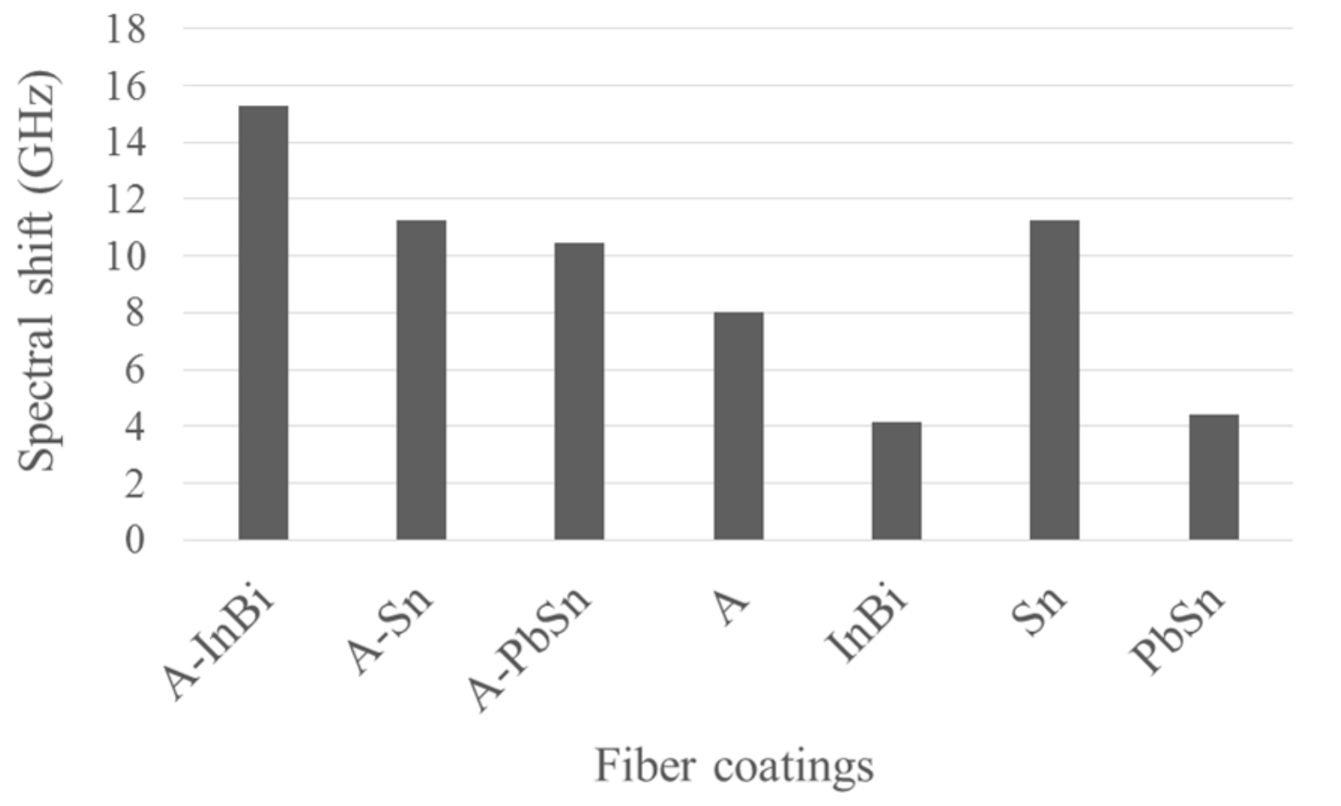


All samples have satisfactory bonding at the interfaces, except for the single InBi layer.

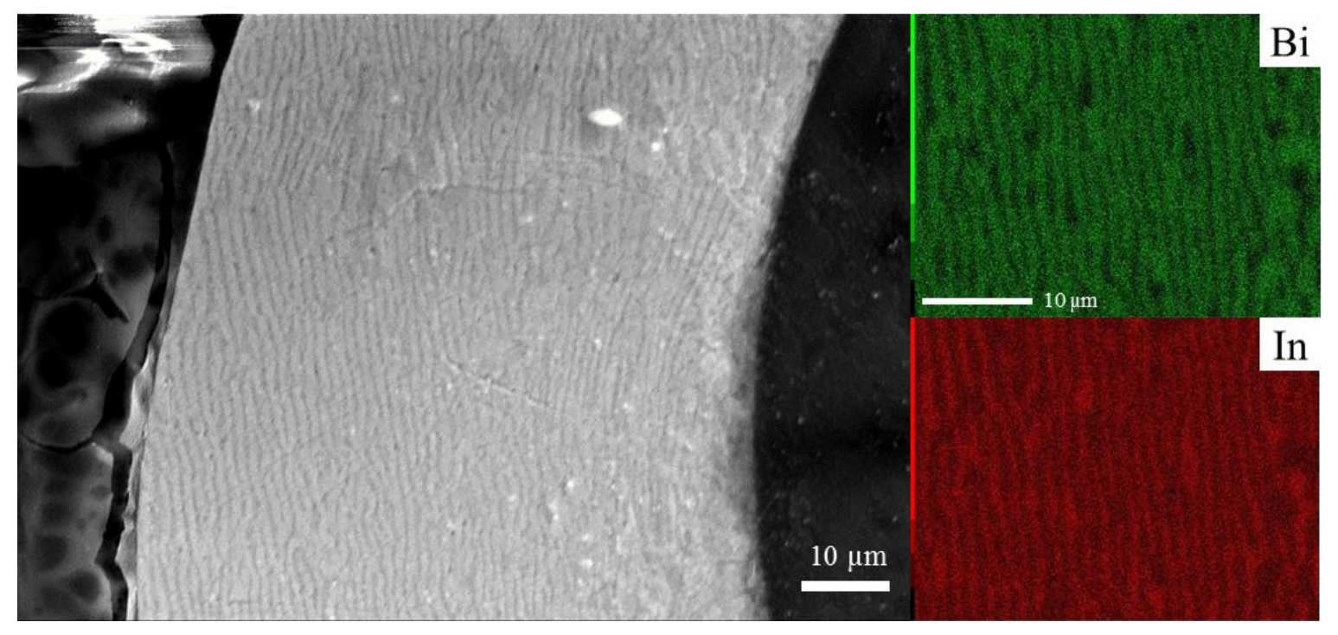
The concentricity and uniformity of the coating can be improved.



Thermal sensitivity of all samples as a function of temperature



Thermal sensitivity of all samples at 4.2 K, averaged over 5 measurements



High magnification SEM micrograph and EDS maps showing the lamellar microstructure of the InBi solidified from the melt.

Conclusions

- A melt coating process has been developed and used to deposit metallic coatings on optical fibers
- Each sample has been characterized for bonding and coating quality
- Thermal sensitivity has been measured at 4.2 K and as a function of temperature
- The combination of an acrylate and InBi coatings yielded the highest sensitivity
- All coatings follow the same temperature behavior: the sensitivity increases soon after 5 K and it then decreases again around 60 K

References

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- M. B. Reid and M. Ozcan, "Temperature dependence of fiber optic Bragg gratings at low temperatures," Opt. Eng. 37(1), 237–240 (1998).

Next steps

- Extend the study to other primary coating materials and smaller cladding sizes
- Improving the coating uniformity and concentricity
- Scaling up to long length manufacturing
- Characterization of samples in terms of mechanical properties and fatigue