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Development of a fiber-optic distributed acoustic sensing system for railway infrastructure condition monitoring

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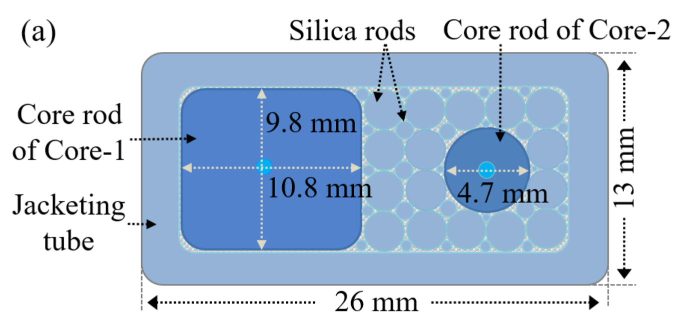
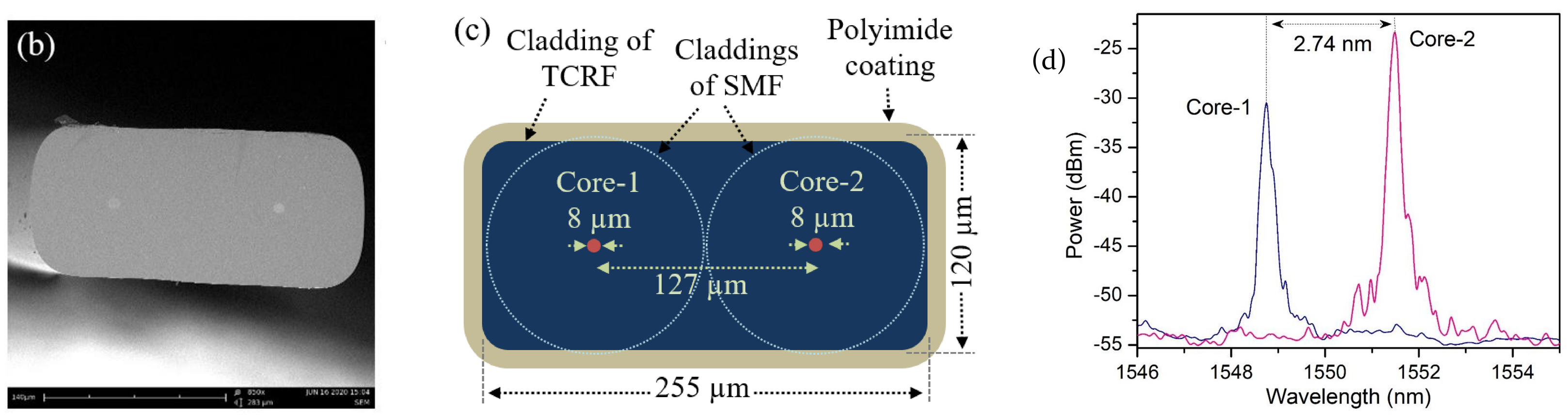
Development of two-core rectangular fiber

- Designed and built a novel rectangular optical fiber that can be easily attached onto rail tracks for simultaneous strain and vibration measurement and temperature compensation.
- A flat fiber consisting of two circular cores with different core deltas permits to measure two parameters with considerable difference in sensitivities between the two cores.
- Unlike conventional circular fiber, a fiber with a flat cladding can be used as a transport and sensing medium employing planar waveguide properties.
- The rectangular-cladding structure provides a large interfacing area, improving the physical contact between the flat-cladding and the substrate.

Fabrication of two-core rectangular fiber

- Using the stack-and-draw technique
- The refractive indices of Core-1 and Core-2 were 1.4476 and 1.4500, respectively.
- Two cores with a diameter of 8 µm and a rectangular cladding with dimensions of 120 µm×255 µm permit convenient splicing to conventional single mode fiber.

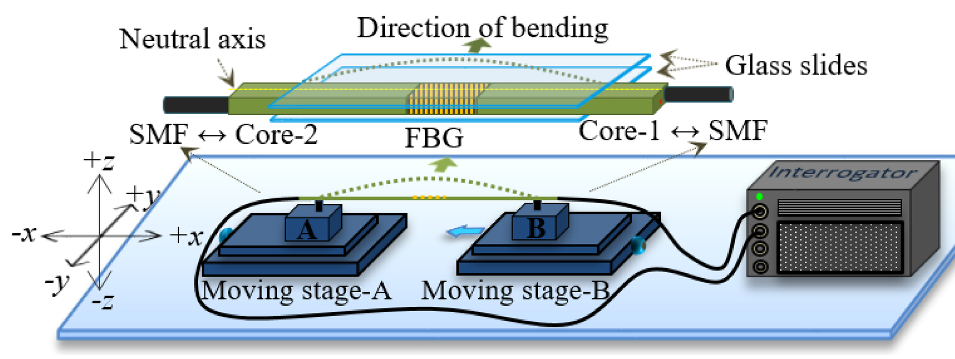




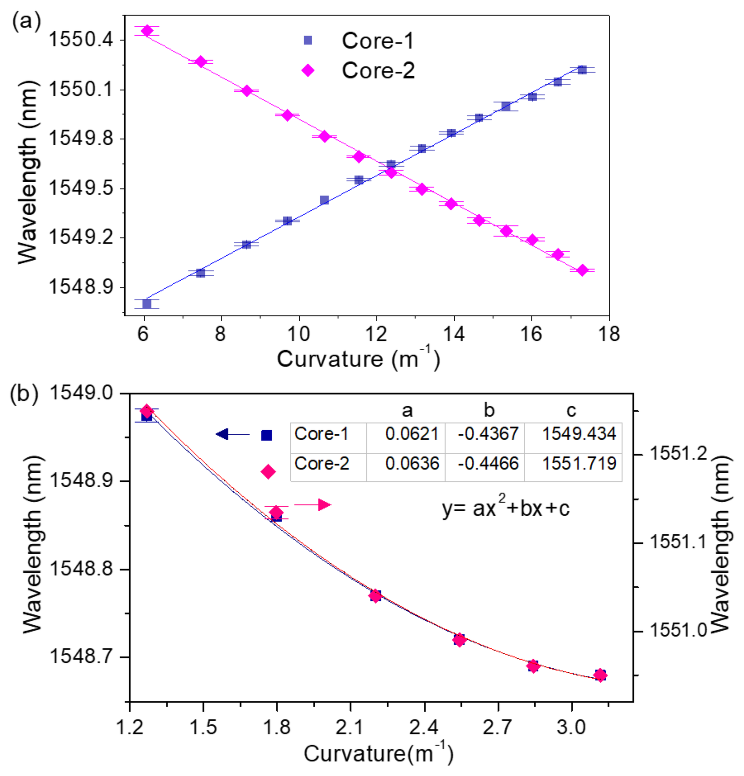
(a) Cross-sectional image of the two-core rectangular fiber preform. Cross-section of two-core rectangular fiber (b) captured by SEM and (c) comparison with respect to the dimensions of SMF. (d) Reflection spectrum profiles of the FBGs inscribed in two-core rectangular fiber.

Curvature, strain and temperature sensing

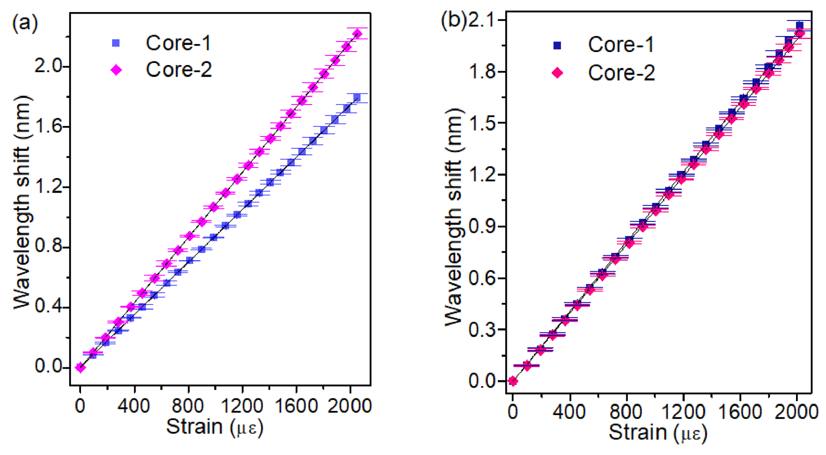
	Bending strain (pm/µε)	Curvature (pm/m^{-1})	Temperature (pm/°C)
Core-1	0.87±(4.8×10^{-4})	126±1.8	10.05±0.17
Core-2	1.08±(2.6×10^{-4})	−128±2.0	10.40±0.19



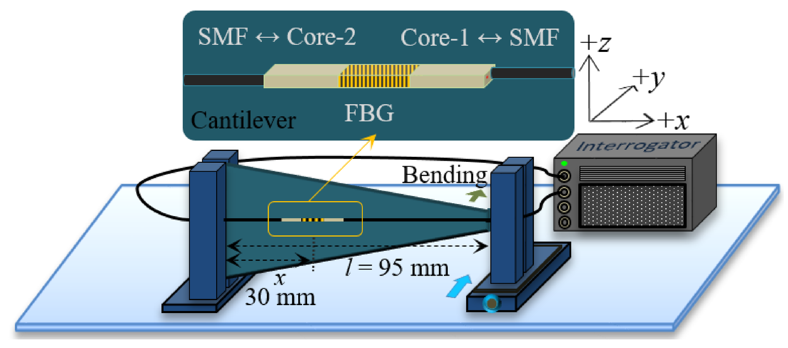
Schematic setup for measuring curvature responses when 255-µm sides of the two-core rectangular fiber was bent.



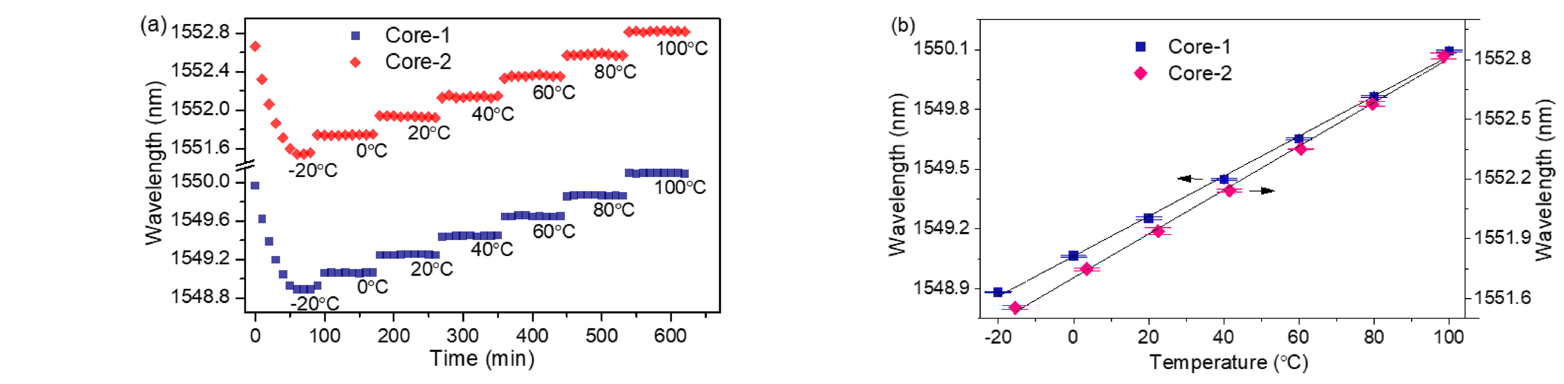
Wavelength responses of the sensor as a function of applied curvature by bending (a) 255-µm sides and (b) 120-µm sides of two-core rectangular fiber.



Bragg wavelength shifts of Core-1 and Core-2 of two-core rectangular fiber corresponding to (a) bend-induced strains and (b) axial strains.



Schematic setup for measuring strain responses of two-core rectangular fiber.



(a) Characterization of the thermal stability of the sensor and (b) wavelength responses of the sensor as a function of temperature changes.

Distributed sensing system for railway infrastructure

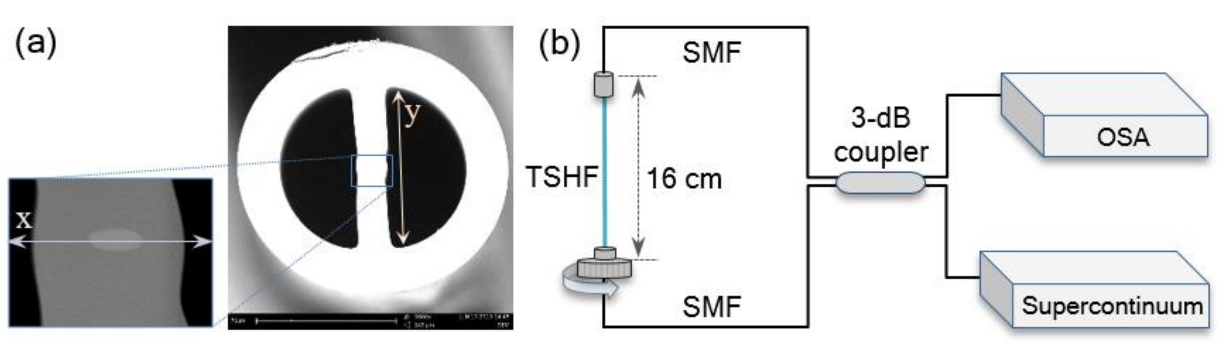
- The two cores can be attached onto railway tracks under identical conditions which is important when a long length of fiber is used for distributed sensing.
- The fiber can be easily placed in a desired orientation without any fiber twists in distributed sensing.
- The sensor can be implemented in structural health monitoring in high-speed railway systems where the FBG sensors are installed in different structures for various sensing purposes such as to detect train dynamic load, axle counting, wheel imbalance weighting and train identification.

Development of two semicircular-hole fiber

- A new type of optical fiber which contains an elliptical core and two large semicircular-holes was developed to determine strain and temperature perturbations and distinguish the direction of torsion.
- Since the slow axis of the fiber core is orthogonal to the two semicircular-holes, the separation of adjacent dips in the interference pattern increases with respect to the angle of twist.
- A twist sensitivity of 5.01 nm/° was recorded which is over five orders in magnitude higher than similar reported sensors using various microstructured optical fibers in a Sagnac loop.

Fabrication of two semicircular-hole fiber

- Fabricated by the stack-and-draw method
- A cladding diameter is ~125 µm and thickness of the strut is ~15 µm.
- The dimensions of the elliptical core and the air-holes are 2.2×5.3 µm and 38×82 µm, respectively.

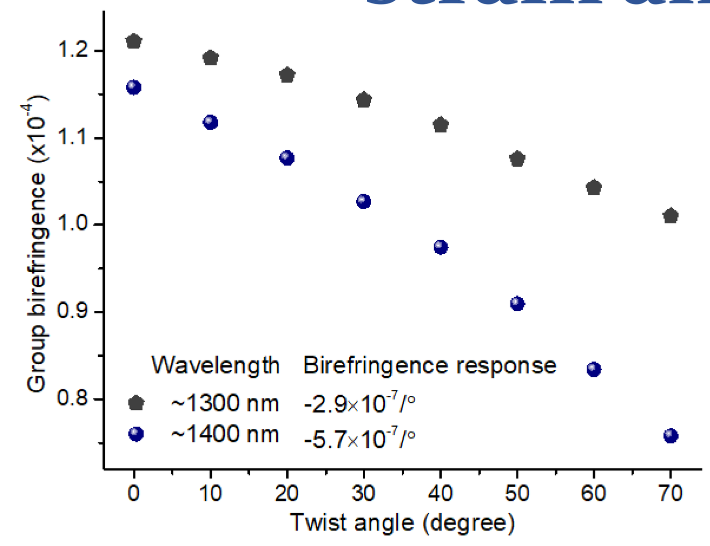


(a) The SEM image of the TSHF where x and y represent the slow axis of the elliptical core and the long axis of the air-hole, respectively, and (b) experimental setup of the SI-based twist sensor.

For railway infrastructure and smart-structural applications

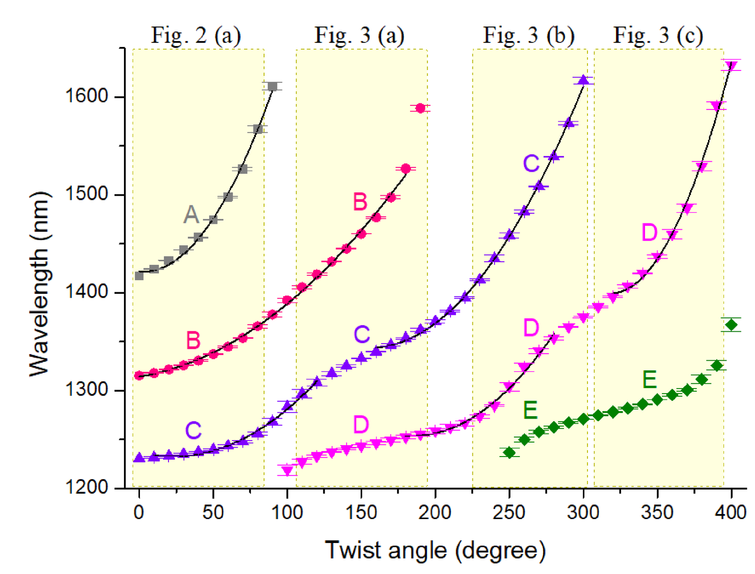
- Highly desirable for railway infrastructure condition monitoring due to its various advantages such as ease of fabrication, high sensitivity, and discrimination of torsion, temperature and strain as well as rotational direction discrimination
- The polyimide coating of the fiber helps to improve bonding characteristics between the test material and the optical fiber.
- The sensor is preferable for smart-structural applications where precision measurement is required especially for small twist angle regimes.

Simultaneous discrimination of torsion, strain and temperature

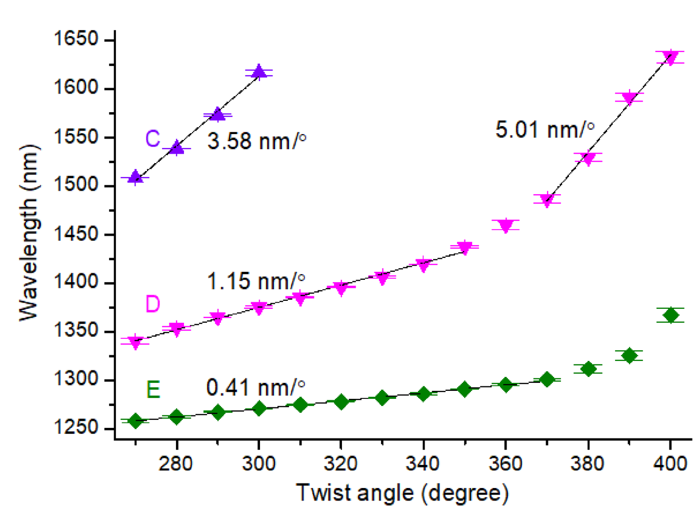


The dependence of group birefringence on the twist angle of the fiber.

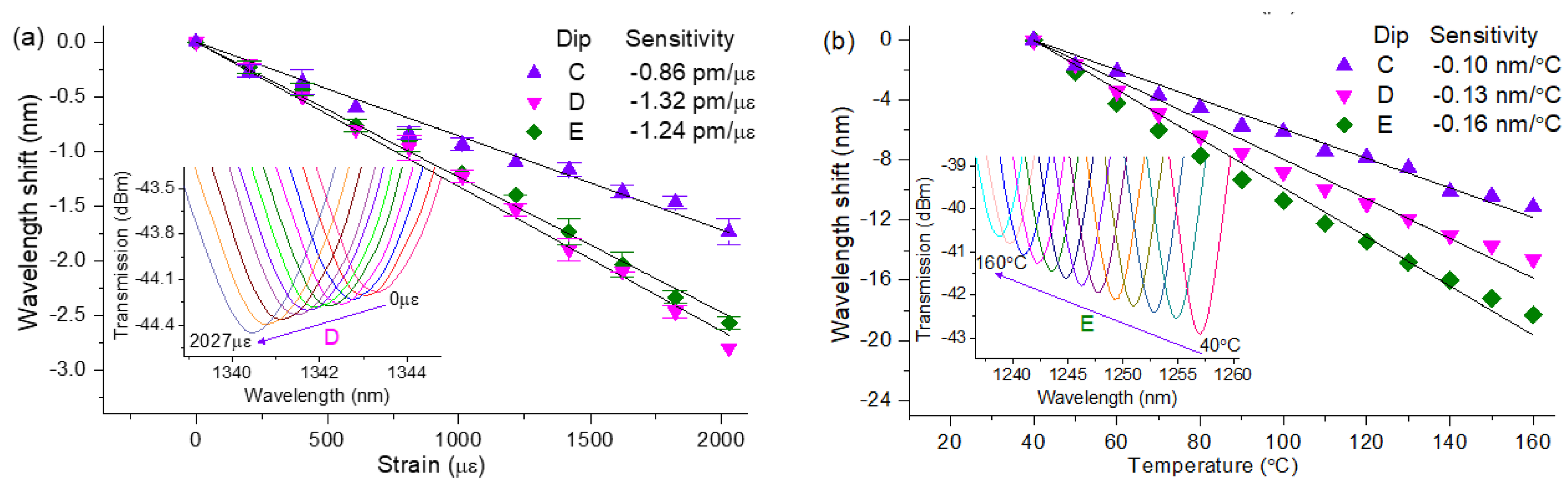
Dip	Torsion (nm/°)	Strain (pm/µε)	Temperature (nm/°C)
C	3.58	−0.86	−0.10
D	1.15	−1.32	−0.13
E	0.41	−1.24	−0.16



The relationship between the wavelength shift of the resonance dips and the applied twist angle.



The wavelength responses of dip C, D and E with respect to applied twist angles from 270°-400°. Straight lines represent the linear fits of the measured data.



(a) The strain-induced wavelength shift and (b) temperature response of the sensor at a twist angle of 270°. Straight lines are the linear fits of the measured data.