Spun Fiber For Current Sensors

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Introduction

Fiber optic current sensors (FOCS), otherwise known as optical current transformers (OCT), are the main industrial application of spun optical fibers. To support the FOCS / OCT industry, the following Fibercore Technote has been written to provide focused information about Fibercore's SHB1250 Spun HiBi fiber and SLB1250 Spun LoBi fiber, with relevance to the current sensor industry.

The basic principle of FOCS and OCTs is to measure polarization rotation due to the Faraday effect. The Faraday effect is the rotation of the polarization state of light, β, when it passes through a magnetic field, B, induced by an electrical current. The larger the electric current, the greater the magnetic field and hence the larger the polarization rotation.

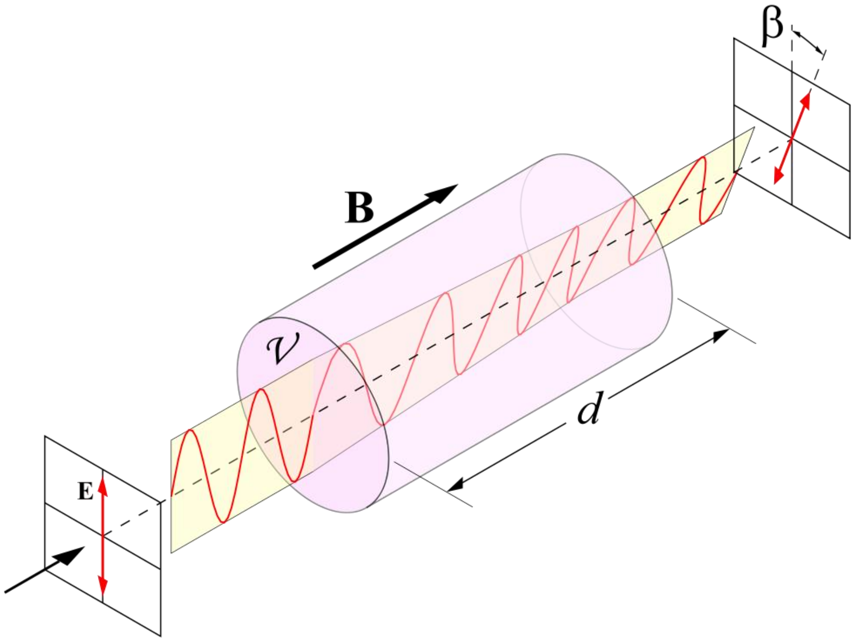

Figure 1: *Polarization rotation as linearly polarized light passes through a material with a Verdet constant, V, and a distance, d. The polarization rotation, β, is proportional to the magnetic field, B.[1]*

FOCS offer significant advantages over traditional current sensing technologies; the sensor element is naturally decoupled from the voltage line, there is minimal electrical interference on the signal line, they offer extremely fast response times with high measurement accuracy, the size and weight of the sensors is reduced in comparison with existing technologies and they do not explode during catastrophic failure, unlike oil-filled electrical insulation towers.

Fibercore Limited have developed a range of optical fibers designed specifically for use in FOCS. This includes the sensor element fibers **Spun HiBi SHB1250** and **Spun LoBi SLB1250** fibers, as well as supporting component fibers such as **HB-Z ZING™ polarizing fibers**, **HB, HB-T** and **HB-G delay coil fibers** and **quarter wave plate fibers** and erbium doped **IsoGain** and **MetroGain** fibers.

Wavelength

The Verdet constant is proportional to $1/\lambda^2$ so to achieve higher current sensing sensitivities, it is recommended to use shorter wavelengths. Fibercore's SHB1250 and SLB1250 are designed for use at 1310nm to give a higher Verdet constant than at 1550nm, whilst also enabling the use of standard low cost telecoms components, such as light sources and fiber couplers and utilizing the 1300nm low attenuation window.

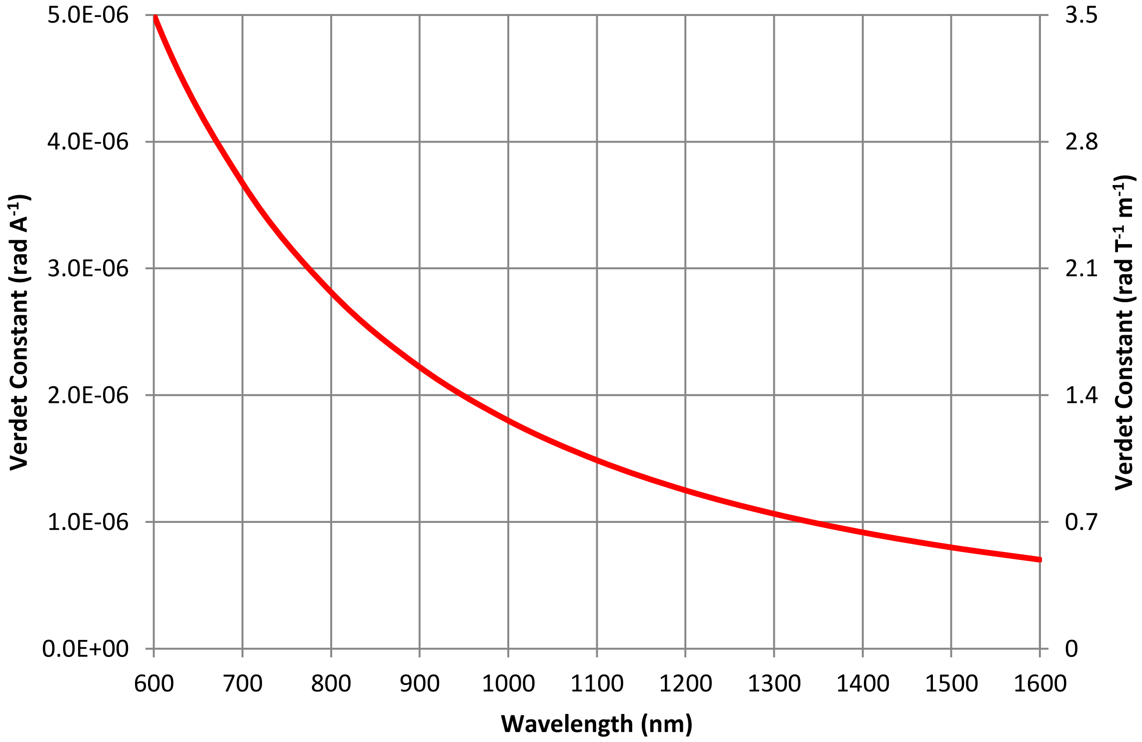

Figure 2: *Variation in Verdet constant with wavelength for a silica core fiber [2].*

Shorter wavelengths give a higher Verdet constant

Fiber Length

The sensitivity of a fiber optic current sensor is linearly proportional to the number of coils of fiber wrapped around the current conductor. If a longer length of fiber is used, more coils can be achieved, giving a higher sensitivity. In a coil, the Faraday phase shift, φ, is proportional to:

$$\varphi \propto V \cdot N \cdot I$$

where V is the Verdet Constant, N the number of coils and I the current flowing through the conductor. Published work uses various lengths of fiber, including 16m [3] and 19m [4] of spun HiBi fiber. To increase the sensitivity, a reflector may be used at the end of the sensor fiber to give a double-pass, achieving double the Faraday shift.

The higher the number of fiber coils, the greater the Faraday shift

Coiling

The Faraday rotation per unit length, f, is dependent on the coil diameter, D, of the fiber, the current, I, being passed through the conductor and the wavelength of operation, such that:

$$f \propto \frac{I}{\lambda^2 D}$$

Therefore it is advantageous to use a coil of fiber with a small diameter to achieve a high level of Faraday rotation. However, as a fiber is bent, the bend induced birefringence increases, reducing the maximum sensitivity of the fiber. Lamming *et Al.*[4] define the maximum sensitivity of the fiber when bent, S_B, as:

$$S_B = \frac{L_B^2 / L'^2_P}{1 + L_B^2 / L'^2_P}$$

Where L'_p is the elliptical beat length of the fiber and L_B is the unspun linear beat length. Because the fiber also has an inherent sensitivity level, based on the spin pitch and natural birefringence, the total sensitivity of the fiber, S_T, is given by:

$$S_T = S \times S_B$$

Where S is the inherent sensitivity of the fiber.
Using the equation for S_T, a graph may be drawn showing the total sensitivity of spun HiBi fiber and spun LoBi fiber as the coil diameter is reduced, as shown in Figure 3. Spun HiBi fibers allow the fiber to be coiled into smaller coil diameters than the spun LoBi fiber. However, because the fiber has an inherent birefringence, the maximum sensitivity is around 90% rather than the 100% maximum sensitivity from the spun LoBi fiber.

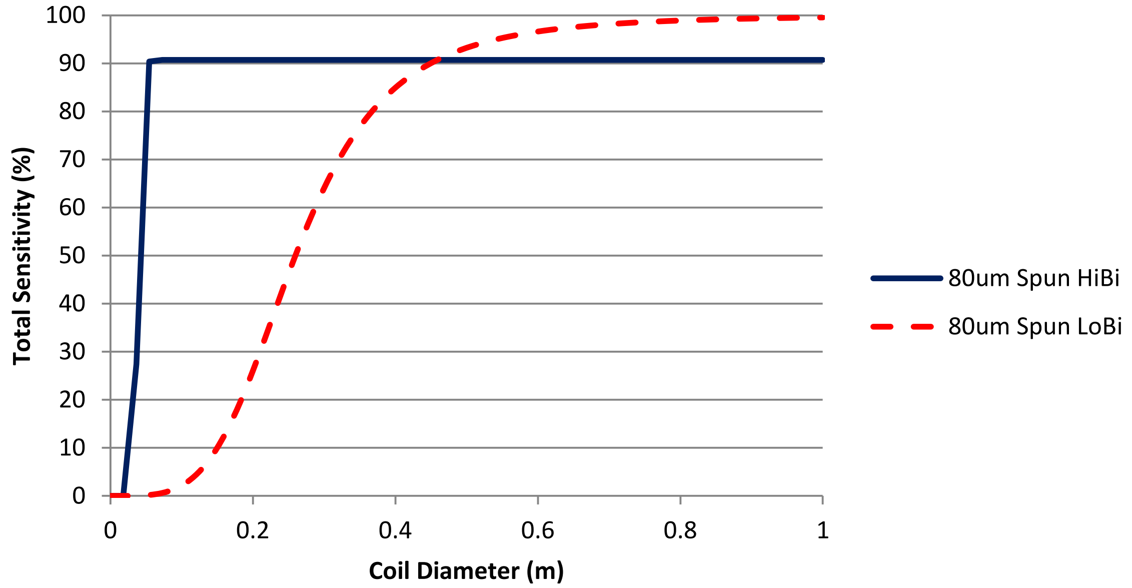

Figure 3: *Theoretical comparison of the sensitivities achieved using an 80µm cladding diameter spun HiBi fiber and an 80µm cladding diameter spun LoBi fiber.*

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SHB1250 Spun HiBi fiber can give a higher sensitivity in smaller coil diameters (<0.5m) than SLB1250 spun LoBi fiber

In large coil diameters (>0.5m), SLB1250 spun LoBi fibers can give a higher sensitivity than SHB1250 spun HiBi fiber

Fiber Diameter

The stress within a coiled fiber is relative to the fiber cladding diameter and the coil diameter. The larger the cladding diameter, the higher the stress across the fiber. Subsequently this effects the sensitivity of the spun LoBi and spun HiBi fibers as shown in Figure 4 and Figure 5.

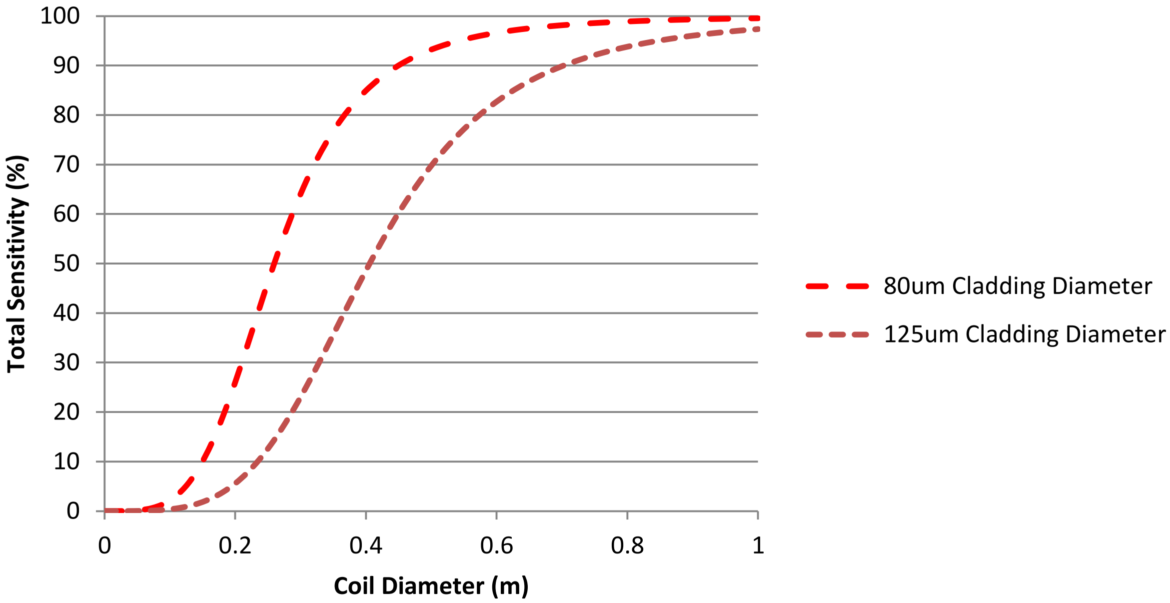

Figure 4: *Spun LoBi fiber sensitivity variation with coil diameter and cladding diameter.*

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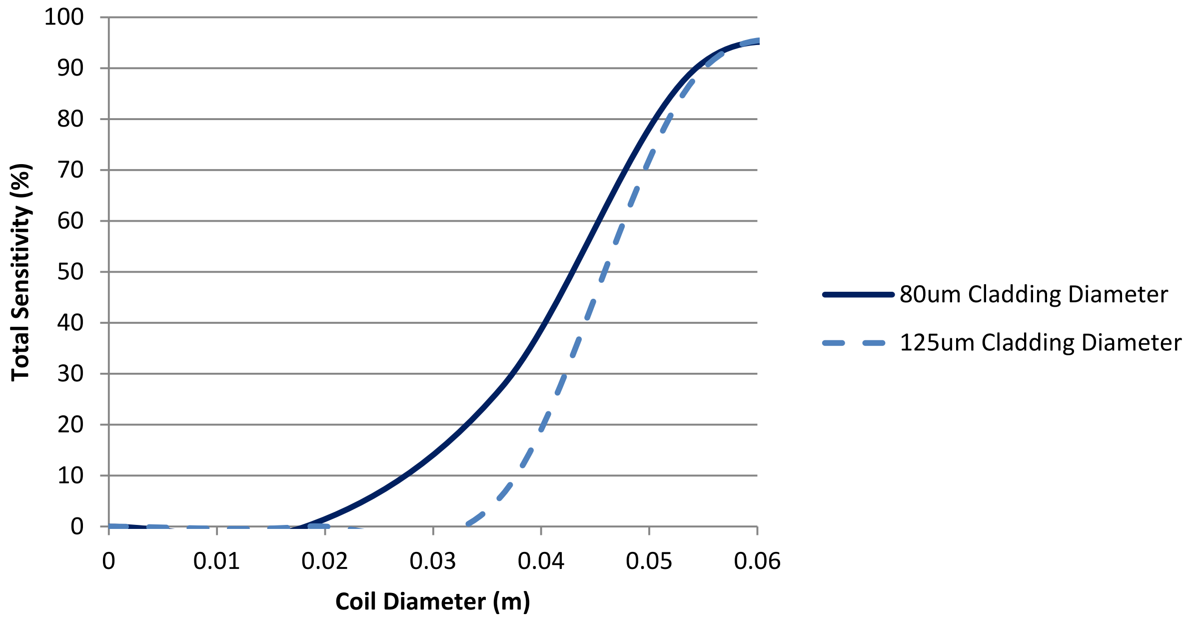

Figure 5: *Spun HiBi fiber sensitivity variation with coil diameter and cladding diameter.*

80µm cladding diameter fibers can give a higher sensitivity than 125µm cladding diameter fibers in smaller diameter coils

Spinning vs Twisting

Spun fibers are spun, not twisted. They have the axial rotation locked into the fiber during the fiber drawing process. This means that there are no torsional stresses within the fiber. A twist is where after manufacturing the fiber, a mechanical twist is applied by applying torsion to the fiber, this induces a high level of internal stress within the fiber.

Historically, researchers have tried to twist standard telecoms fibers to create circular birefringence within the fiber [5] and overcome bend-induced birefringence. However, twisting fibers can cause reliability problems [6]. During thermal cycles, particularly in thermal-shock situations, the rapid change in the twist-induced torsional stresses can cause mechanical failure of the fiber.

Whilst the SLB1250 spun LoBi fiber can benefit from the twist process to average out the effect of coiling the fiber, it is difficult to create a process which will accurately and repeatedly put in the twist and guarantee high reliability over a wide range of temperatures. It is worth noting that if the twist is put in the opposite direction to the spin direction, then worse performance may be achieved as the applied twist effectively untwists the spin. Subsequently, the SHB1250 Spun HiBi fiber is designed to not require twisting, saving process time and improving reliability.

SHB1250 Spun HiBi fiber does not require twisting to overcome bend-induced birefringence

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Micro-Bends

Any pressure applied to the side of the fiber can cause micro-bends. Micro-bends cause a localized birefringence which can reduce the sensitivity of the fiber optic current sensor. Micro-bends can be caused by the packaging technique, for example if glue or tape is used on the fiber. Often the packaging technique can cause poor sensor performance, especially over temperature, where the glue or tape can expand and contract with temperature and therefore apply pressure to the fiber.

Fibercore's spun fibers have been designed with a coating package optimized for mechanical and thermal stability. This coating package has been thoroughly proven in the highly demanding aerospace industry where Fibercore supply tens of millions of meters of fiber, with this coating package, every year. The coating package design gives the best compromise between mechanical protection and usability, ensuring rugged performance whilst still being easy to strip and clean.

To overcome the problems of micro-bends it is advisable to use SHB1250 spun HiBi fiber where the natural birefringence will more easily overcome the micro-bend induced birefringence. Spun LoBi fiber is more prone to errors induced by micro-bends.

SHB1250 Spun HiBi fiber will optically resist micro-bend better than SLB1250 Spun LoBi fiber

Need more information? Check out:

- *Fibercore Factnote:* ***SHB1250 – Spun HiBi Fiber***
- *Fibercore Factnote:* ***SLB1250 – Spun LoBi Fiber***
- *Fibercore Appnote:* ***Fiber Optic Current Sensors (FOCS) and Optical Current Transformers (OCT)***
- *Fibercore White Paper:* ***Faraday Effect Current Sensors***

References

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[6] A.J. Barlow and D.N. Payne, "Polarisation Maintenance In Circularly Birefringent Fibers", Electronics Letters, vol. 17, no. 11, 388-389, 1981

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