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DESIGNING OF SIMPLE INTERFEROMETRIC TEMPERATURE SENSOR THROUGH THE USE OF BEND INDUCED LOSS IN SINGLE MODE FIBER

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ABSTRACT
Optical Loss in a bend induced over moded fiber has been measured as a function of temperature. It has been observed under close watch. The observations are explained on the basis of interference between the core-guided mode and whispering gallery (WG) modes by reflection at the buffer air interface. The experimental results were consistent with the optothermal properties of the fiber and buffer. The buffer caoting was formed with the residual stresses, which will modify the buffer refractive index practical techniques. It was explained for the measurement of the diameter and refractive index of the buffer coating of a monomode optical fiber. Bending loss in optical fibers has been of extensive study because of its adverse effect on power budget in telecommunications. However, here bend loss has been exploited to sample light guide by a fiber sensor without disturbing the fibers as to form local light detectors/sensors. It is also used as transduction mechanism in the optic fiber sensors to produce a displacement that causes a change in fiber bend radius, hence modulates the optical attenuation.The experimental study are made on oscillations of bend loss with temperature which arises from the temperature dependence of the phases of the core mode and whispering gallery mode. Our observations of the temperature dependence of bend loss suggest the possibility of designing high temperature sensitivity communication interferometric fiber optic sensor. The measured values which are in good aggrement with the theoretical values comfirms the suggestion. We therefore, recommend that this high temperature sensing of intererence induced by fiber bending gives rise to rightful possibility of designing simple rugged temperature intreferometric sensor for upgrading of our telecommunications.

KEYWORDS: Bend loss, whispering Gallery modes, Single mode fiber, power meter, Temperature sensor, Detector.

INTROCTION
Loss of single mode optical fibers is caused by (a) material absorption (b) Material scattering which mainly consists of Rayleigh scattering and (c) radiation Losses due to curvature[1]. In Single mode fibers the transmission loss arises from the fundamental mode to leaking core modes whenever there is a change in curvature of the fiber axis, *e.g.* from straight to curved or vice versa [2,3]. The pure bend loss results from the continual loss of guidance at the outer portion of the evanescent field of the fundamental mode[2,3]. The Loss of guidance is due to the phase velocity of the outer part of the evanescent field becoming equal to the speed of Light in the cladding. The smaller the radius of the bend the greater the fraction of evanescent field affected and hence greater the percentage of light lost at the bend[14]. However, not all the light leaving the fundamental mode by the above methods is permanently lost, as some can reenter by coupling from the leaky core and cladding modes to the fundamentals[4,5]. Most theories assume an infinite cladding and thus predict a monotonic dependence loss on bend radius and length[6]. Oscillations in bend loss with bend radius[7], Length[5] and wavelength[8] were observed. These observations are explained using an interference model. The fiber cladding [or buffer coating] to form a whispering Gallery (WG) mode[8] guides Light ejected from the core by the bend. The requirement is that refractive index of the buffer is slightly higher than that of the cladding. Light which is ejected from the core of an optical fiber by a bend and enters the cladding[5-7] or buffer[9] of the fiber, may be coupled back into the core guide to modify the bend Loss. The whispering gallery mode recouples with core guided mode with a relative phase, which is dependent on the fiber geometry, bend radius and illuminating wavelength. The buffer properties must therefore be taken into account when predicting bend loss or designing fiber optical components such as Local Light detector[8] in which bend is deliberately introduced to the fiber and to do this, optical properties of the buffer must be know. Majority of the buffer material of the monomode optical fibers is a type of UV-Cured acrylate[12], the optical properties of which may change because of the coating process during which a monomer bulk material is polymerized, to form a mixture of monomer and polymer components whose refractive index will depend on the degree of polymerization. In addition, the buffer coating may be formed with residual stresses, which will also modify the buffer refractive index practical techniques were explained for the measurement of the diameter and refractive index of the buffer coating of a monomode optical fiber[13]. Bending Loss in optical fibers has been studied extensively, chiefly because of its adverse effect on power budget in telecommunications [15]. However, bend loss has been exploited to sample Light guided by a fiber without interrupting the fiber, to form local light detectors. Bend loss is also used as transduction mechanism in some type

of fiber optic sensors, for example where the measurand produces a displacement that causes a change in fiber bend radius and hence modulates the optical attenuation.

Most of the oscillations in the bend loss could form the basis of a number of applications, which include: (a) Using the rapid rise in the loss to sense changes in the radius of an object to which, the fiber is attenuated and (b) minimizing the bend loss in single mode optical communication links by designing fibers to give synchronized coupling from the whispering gallery mode to the fundamental mode at the operating wavelength and bend radius to be used. Recent experimental and theoretical work shows that bend loss is a strong function of wavelength. The strong wavelength dependence of loss is also a complicating factor in the design of intensity modulated fiber optic sensor. The general form is an increase of loss with wavelenght 1.2 to 1.6µm[10] with higher loss at smaller bend radii. In this work, the experimental study made on oscillations of bend loss with temperature, which arises from the temperature dependence of the phase of the core mode and whispering gallery mode coupling for He-Ne of wavelength in the visible region. Our observations of the temperature dependence of bend loss suggest the possibility of designing high temperature sensitive communication interferometric fiber optic sensor.

THEORY

Whenever fiber forms a bend, whispering gallery (WG) modes is created[8], propagated in the cladding or buffer, which can interfere with the guided core mode to produce oscillations in bend loss depending on bend geometry or light wavelength. The formation of such whispering gallery modes creates an interferometer within the fiber one arm (length L_1), being within the core and other L_2 primarily within buffer.

The thermal sensitivity of an optical path may be expressed as[10]:

$$\frac{Ld\phi}{LdT} = \frac{2\pi\,\Delta\quad({}^{n}\alpha + \beta)}{\lambda}$$

Where α is the thermal expansion coefficient, β is the thermo-optic coefficient, ℓ is the length and $d\Phi$ is the temperature coefficient of optical phase. The path length L_1 and L_2 will have temperature induced phase shifts of $\Delta\Phi_1$and $\Delta\Phi_1$ respectively, and the relative phase change ΔØ will be given by

$$\Delta\Phi = \frac{2\pi\,\Delta T}{\lambda}\{ L2\,(n_2\,\alpha_2 + \beta_2) - L_1\,(n_1\,\alpha_1 + \beta_1)\}$$

This phase shift will lead to observed oscillations of bend loss as the relative phase of the whispering gallery and core modes change with temperature.

EXPERIMENT

The fiber bend induced by making mandrels of different radii, bent portion dipped in the paraffin oil bath (for controlling temperature). A polarized He-Ne source used for Launching of wavelength 632. 8nm, output power 5mw and beam diameter 0.75 + or – 0.0 5nm. Readings of power transmitted through the fiber were made using photo detector (818-SL New port model, range 400-1100nm). The detector was a power meter (1815-c, New port model, operating environment < 70% relative humidity non condensing 18° (-28°C). Temperature induced bend loss were observed. For bend loss measurement, a zero bend reference power level (*i.e.* with the fiber straight) was measured. The bend arc and length were increased to desired value and dipped into paraffin oil bath, which was heated from ambient temperature to higher values (not greater than 85 °C above, which buffer coating would suffer degradation). The power levels were noted with respect to temperature. The process was repeated for different bend radii. The calculated losses are in dB-m.

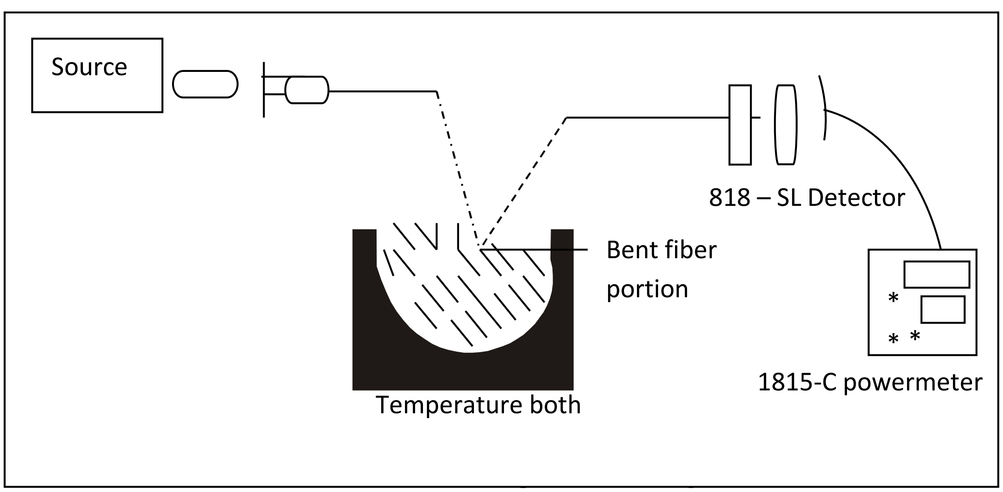

TABLE 1: Fiber Properties

	Core	Cladding	Buffer
Refractive Index (n)	1.448	1.444	1.53
Radius	9hm	125hm	400hm
Thermal Expansivity (α)	5 x $10^{-7}k^{-1}$	5 x $10^{-7}k^{-1}$	20 x $10^{-5}k^{-1}$
Thermo – optic coefficient (β)	1.9 x $10^{-5}k^{-1}$	19 x $10^{-5}k^{-1}$	-23 x10^{-5}

TABLE 2: Calculations of ΔT spacing

Bent Radius	180° angle		360° angle	
	Calculated	Observed	calculated	Observed
0.5cm	9.95k	7.8561k	5.49k	7.6754k
1.0cm	18.90k	8.5100k	9.85k	8.76400k

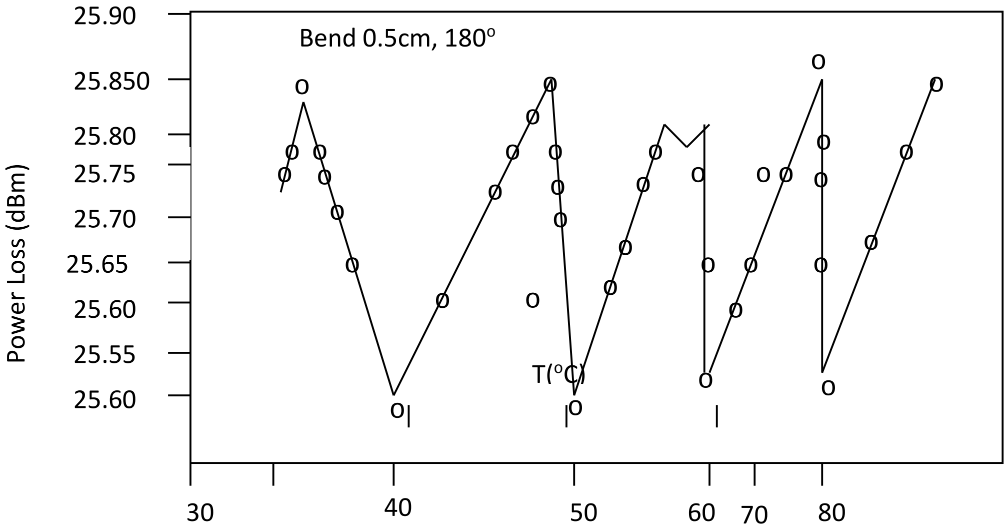

FIGURE 2: Temperature dependent bend loss for 0.5cm, 180 bend optical fiber.

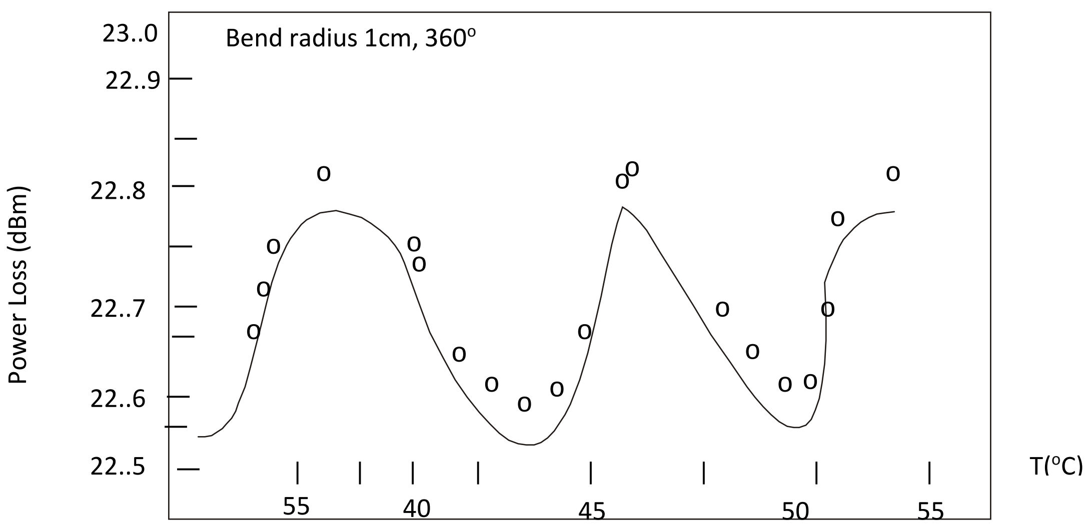

FIGURE 3. Temperature dependent bend loss for 1cm, 360 bend optical fiber

RESULTS & DISCUSSION

Bend loss as a function of temperature for the fiber of table 1 are present in fig. 2 and 3. Optical transmission through a bend of radii 0.5cm and 1cm and arc of lenght of 180° and 360° are studied. Temperature dependence bend loss characteristics for bend angle 180 and 360 degrees for a bent of 0.5cm and 1cm are also shown in fig.2 and 3 respectively. It is observed that loss oscillations are consistent with rise of temperature and loss is higher at larger bend angle i.e at 360° with a difference of 1 – dBm power. The same is true for other bend radius 1cm. Using fiber properties given in table 1, calculations are made for determining the spacing ΔT of the transmission peaks by equating the phase change of ΔΦ to 2π. It therefore, predicts that generation of whispering gallery modes at cladding modes at cladding/buffer increases, as the bend radius decreases in agreement with theoretical model. It is seen that, the calculated spacing for 0.5 cm bend radius, 360^o is $\Delta T = 8.95k$, while average peaks in figure 2 is 6.8661k. Experiment and theory thus agree within the experimental error and uncertainties associated within the data of table 1. It is also observed that ΔT spacing increases with increase in bent radius due to attenuating or damping of whispering gallery modes. It is also in good agreement with theoretical model.

Hence the general form is an increasing loss with temperature on which superimposed oscillations whose spacing increases with bent radius. It is seen from graphs, the temperature sensitivity raises to approximately 0.1 dB/K with a total variation of 1dB increase between maximum and minimum values.

CONCLUSION

The results of temperature dependence of the bend loss for single mode fiber of different bend radii and angles have been analyzed. It has been found that peaks appear in the bending losses due to the interference between the guided modes in the cladding and whispering gallery mode which is guided by reflection at buffer/air interface. Measured values are in good agreement with theoretical values. The bend loss in buffered single mode fiber shows oscillations with very low power loss and inconsistent for He-Ne laser of 632.8nm. It has been shown that whispering gallery modes propagating in the buffer coating of a monomode optical fiber, can lead to oscillations in the bending loss as a function of temperature. The period of oscillations varies as a function of the bend geometry and of the optical and physical properties of the buffer coating. The cladding mode is formed from the light leaving the fundamental mode due to the pure bend loss. The minima or troughs in the oscillations result from synchronized, *i.e.* in phase coupling of light from the whispering gallery mode to the fundamental mode and the peaks of oscillations corresponding to asynchronous, *i.e.* out of phase coupling. The bend radii in which synchronized coupling takes place are in good agreement with experiment. This temperature effects are clearly relevant to the design and operating of devices such as Local detectors in which a bend is deliberately introduced into a fiber. The temperature sensitivity in fig 2 to 3 is approximately 0.1db/k with total variation of 1db-m in intensity between maximum and minimum values. This high temperature sensing of interference induced by bending gives rise to possibility of designing of a simple rugged interferometric sensor.

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