Optical Fiber Having a High Temperature Insensitivity and Centered on A Selected Temperature Range

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Abstract
A highly temperature-insensitive fiber is reported. Furthermore, a convenient method for selecting the temperature of minimum sensitivity, by controlling the B_2O_3 concentration in the core and monitoring it with 1550 nm attenuation, is presented.

Introduction. Optical fibers are often used in optical system components, such as fiber gratings, which may be subjected to fluctuations in temperature as large as -50 to +85 °C, but more commonly from 0 to +70 °C. Most optical fibers will have a different response depending upon the temperature to which they are subjected. This is due to a refractive index change in the glass induced by the temperature variation. For example, many components utilize fiber where gratings have been written, and the temperature difference may make the grating wavelength shift. This makes the grating inefficient at rejecting or passing the wavelength for which it was designed. This is especially true for long-period fiber gratings, which can have a temperature sensitivity of the center wavelength typically of around 0.5 nm/°C [1]. Thus, it is desirable to have a fiber which is highly temperature insensitive in order to have stable optical components.

Temperature sensitivity of fibers arise from the temperature sensitivity of its composition. For fibers to be temperature insensitive, the rate of change of index with temperature (dn/dT) of the core should equal that of the cladding. Correlations between temperature and refractive index are well known for the most commonly used dopants in silica-based fibers [2]. B_2O_3 and P_2O_5, for example, have indices which are more temperature sensitive than GeO_2 and SiO_2. Photosensitive fibers often include significant amounts of GeO_2 and B_2O_3 in the core. The temperature dependence of the refractive index of the core and cladding may be plotted as shown schematically in Figure 1. Knowing the temperature response of the refractive index, one can then plot the rate of change of index (dn/dT) versus temperature (Fig. 2).

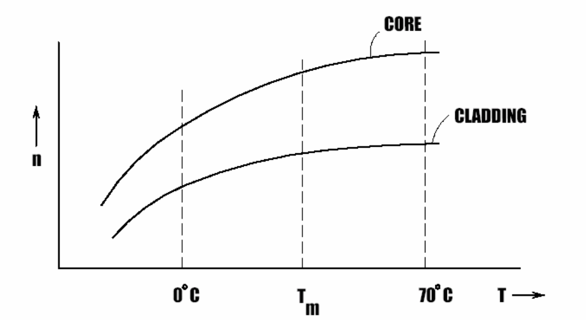

Figure 1. Index versus Temperature for Core and deposited cladding

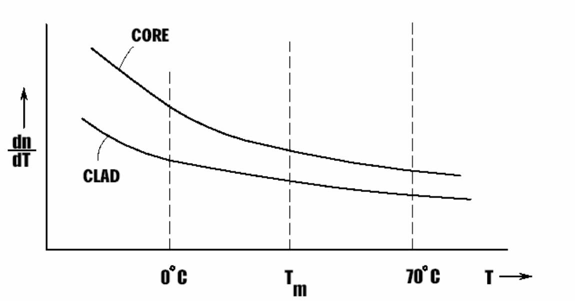

Figure 2. Rate of change of index versus Temperature, typical

Previous efforts at fabricating temperature insensitive fibers focused on formulating the composition of the core and cladding such that curves of dn/dT versus T for the core and cladding are identical. This yields a fiber which, by design, is temperature insensitive over all wavelength ranges. However, we have found that it is impractical to fabricate such a fiber using dopants commonly used in optical fiber manufacturing. Real life fibers tend to have varying temperature sensitivity over the operating range, with a minimum at a specific temperature. Temperature-insensitive fibers that have a temperature of minimum temperature sensitivity, T_m, at specific temperatures, such as 0 or 20 °C have been reported [1,3]. However, methods to control the minimum temperature and preferably select it to be at the center of the operating range have not been reported. Choosing the temperature of minimum sensitivity to be at the center of the operating range ensures the least variation of the operating wavelength over the extremes of the temperature range.

Experiments. As most optical components commonly operate in the range of 0 to +70 °C, we set out to investigate a photosensitive fiber with a T_m of 35°C. We designed a fiber where the $(dn/dT)_{core} \simeq (dn/dT)_{cladding}$ and the curves of dn/dT versus T for the core and cladding intersected within the operating temperature range, Fig. 3. The point at which the curves intersect would define the temperature of minimum (zero) sensitivity, T_m, as shown in Fig. 4. The fibers were designed to be photosensitive and as a direct consequence they had a composition of highly temperature sensitive components. The fibers were also designed to have an operating wavelength of approximately 1550 nm, where fibers using long period gratings are often employed. These particular fibers all had 125 micron cladding, core diameters of ~ 7 microns, cutoff wavelengths between 1250 and 1400 nm, and mode field diameters (MFD) at 1550 nm of ~ 7.5 microns.

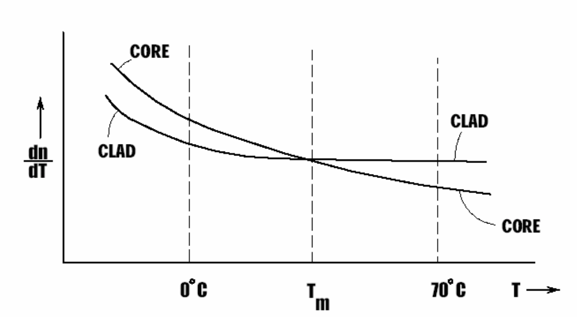

Figure 3. Rate of change of index versus Temperature, design

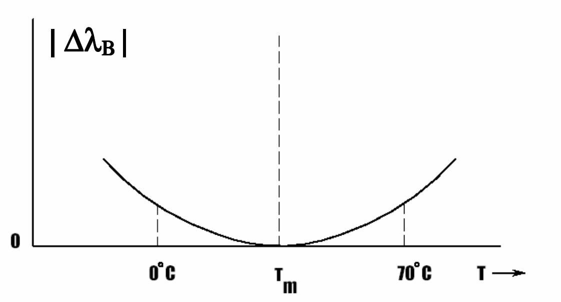

Figure 4. Resulting Fiber Bragg Grating Wavelength Shift, versus Temperature

As part of our investigation we fabricated multiple fibers via modified chemical vapor deposition (MCVD). The composition of these fibers is shown in Table 1. In all fibers, the deposited cladding composition was held constant because: 1) cladding compositions are often chosen based on index and to aid in splicing and 2) although phosphorus is highly temperature sensitive, the concentration in the cladding was very small and hence difficult to vary. The core was doped with GeO_2 and B_2O_3. Since B_2O_3 has a negative dn/dT and is nearly twice as sensitive as GeO_2, it was desirable to change boron rather than the germania concentration in the core because: 1) the dn/dT of the core could be reduced and made nearly equal to that of the cladding, and 2) only small changes in concentration were needed which didn't significantly affect optical properties such as cutoff and MFD.

Component	dn/dT x10^{-7} per K [2]	Core Composition	Deposited Cladding Composition
SiO_2	+102	Remainder	Remainder
GeO_2	+194	14.5% to 15.5%	0
P_2O_5	-922	0	1.4% to 1.5 %
F	Unknown	0	0.33%
B_2O_3	-350	3% to 10%	0

Table 1. Temperature Insensitive Fiber Compositions, in oxide wt%

The first fibers were drawn, had long-period grating written, and tested to determine the T_m. The resultant T_m values ranged from -30 to +230°C. In addition, each fiber was analyzed for composition using wavelength dispersive spectroscopy (WDS).

Analysis. In Fig. 5 the minimum temperature versus the boron content is plotted. We recognized that, for a given core composition, the minimum temperature can be targeted by tightly controlling the concentration of B_2O_3 in the core.

Clearly the most time consuming and expensive step in the process was performing composition analyses on the fibers. This adds significant time and expense to conducting the investigation. We realized that the presence of B_2O_3 results in increased attenuation via scattering at wavelengths above 1450 nm and that the fibers employed in this study had sufficient B_2O_3 concentrations. The variations in this attenuation could be monitored using standard fiber test equipment (Photon Kinetics Model PK2500). Consequently, we found that it was possible to determine the boron concentration in the core quickly and inexpensively through monitoring the fiber attenuation at 1550 nm. We could then correlate the T_m of a given fiber against the 1550 nm attenuation (Fig.6). This provided a very useful tool in providing quick and accurate feedback and allowed fibers having a T_m of 35 ^oC to be repeatedly fabricated.

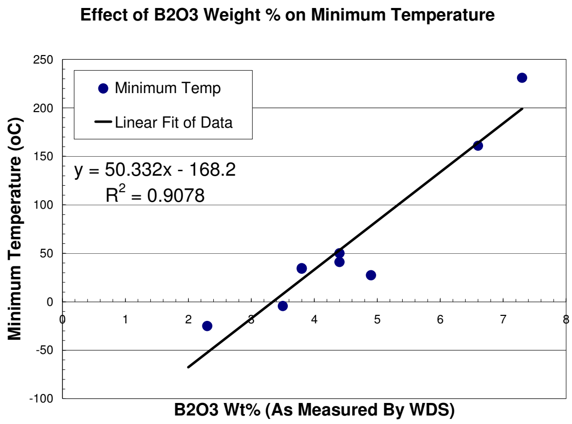

Figure 5. Effect of B_2O_3 on T_m.

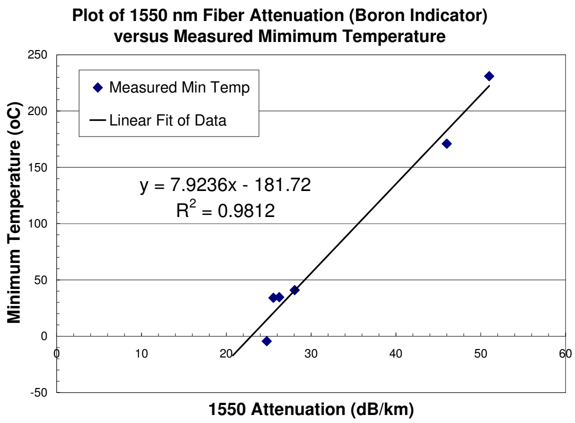

Figure 6. 1550 Attenuation vs. T_m

During our investigation, fibers often varied slightly from lot to lot. By monitoring the attenuation at 1550 nm, fibers that have a different temperature minimum can be readily identified.

It is known that the T_m of each fiber is affected slightly by the grating period and the exact grating writing technique employed. These fibers were tested on gratings made using various techniques, and although the T_m was slightly different, the relative ranking of the fibers was still based on the boron content and it would be readily possible to design a fiber optimized for each grating writing technique.

Conclusion. We have fabricated a photosensitive fiber that is temperature insensitive over a usable range of 0 to +70^{o}C. Furthermore, we were able to choose the temperature of minimum sensitivity, T_m, at around 35^{o}C, the mid-point of a commonly required operation temperature range. We have also devised a method of controlling T_m by varying the amount of boron in the core. Furthermore, we show how one can easily monitor the boron content, and hence T_m, by measuring the fiber's attenuation at 1550 nm. Alternative applications, such as optical temperature sensors, require the fiber to be highly temperature sensitive [4]. In such cases, one would make a fiber with a minimum temperature very far from the operating temperature, using the principles shown above.

References.

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