Fiber-optic bend sensor based on a section of double-cladding fiber

O.V. Ivanov \(^1,2\), I.V. Zlodeev \(^2\)

\(^1\) Ulyanovsk Branch of Kotel’nikov Institute of Radio Engineering and Electronics of RAS
48, Goncharova str., Ulyanovsk 432011, Russia
\(^2\) Ulyanovsk State University
42, L. Tolstogo str., Ulyanovsk 432017, Russia
Tel.: +7-906-1425694    Fax: +7-8422-442996    E-mail: olegivv@yandex.ru

Abstract

A fiber-optic structure based on a section of a double-clad fiber with depressed inner cladding is investigated for bend sensing. The structure is formed by splicing a section of SM630 fiber between two standard fibers SMF-28. The operation principle relies on the sensitivity of cladding modes that are induced at a splice of fibers having different refractive index profiles. The transmission spectra of the structure demonstrate a shift of dips to long wavelengths with increasing curvature of the fiber. The sensitivities of the spectral dips to the bend curvature are measured. A fiber-optics scheme with two light sources is proposed for bend sensing.

Keywords: Fiber-optic sensor, fiber mode, cladding mode, bend sensor

1. Introduction

The development of fiber optics components based on the use of cladding modes has become an important contribution to the progress in fiber sensing technology [1]. The cladding modes can be excited at some non-resonant defect in the fiber structure such as a misaligned splicing point, a nonadiabatic taper, or a splice of the standard fiber with a fiber having strongly different core [2]. A combination of two defects, for example a long-period fiber grating and a misaligned splicing point, with a section of fiber between them can be used for obtaining interference of two modes. Such structures find applications for sensing of strain, temperature, curvature, and inclination [3–5].

Recently, we proposed a new structure which is formed by splicing a section of depressed inner cladding fiber SM630 between standard SMF-28 fibers [6] (see Fig. 1). At splices between the two fibers, cladding modes are excited and interfere. The measured transmission spectrum of the structure features two broad dips. In this paper, the sensitivity of the proposed structure to bending is investigated. We measure the sensitivity of spectral dips to bending and use it for creating a bend sensor.

![Fig. 1. Scheme of light propagation in the fiber structure.](image)

2. Structure with double cladding fiber

Using a conventional fusion splicer, the standard SMF-28 fiber is spliced with SM630 fiber from 3M Specialty Optical Fiber. The fiber is cleaved to obtain a section of length \(L\),
which is spliced again with the standard fiber. The light from a broadband source is launched into the input standard fiber, and the output fiber is connected to an optical spectrum analyzer.

SM630 fiber has a small core ($r_c = 1.8 \mu\text{m}$, $\Delta = 0.325\%$, $\text{NA} = 0.12$, $\lambda_{\text{cutoff}} = 612\text{ nm}$) and an inner depressed cladding ($r_{inn} = 25 \mu\text{m}$, $n_{cl} - n_{inn} = 0.0043$, $r_{cl} = 62.5 \mu\text{m}$). This fiber is designed for single-mode operation at 630 nm. In this work, the spectral characteristics of the structure are investigated in the range 1100–1700 nm, at which the core of the SM630 fiber is a weak waveguide.

The fiber structure was fixed along an arc for bending measurements. The typical length of the section of SM630 fiber was from 5 to 30 cm. The polymer coating of the section of SM630 fiber was removed and was covered with black paint to remove higher order modes that can propagate in the fiber cladding.

At the first splice, the fundamental mode of the standard fiber is transformed into the modes of SM630 fiber (see Fig. 1). From the first splice, modes propagate to the second splice, some of them being absorbed or scattered at the fiber surface. At the second splice, the modes enter the standard fiber with different phase shifts, are partially transformed into its fundamental mode, and interfere. Some part of light is transformed into cladding modes of the standard fiber and is lost.

3. **Bend sensitivity of the structure**

For analyzing the sensitivity of the structure to bending deformation, we measured the evolution of the transmission spectra upon increasing fiber curvature. The spectrum exhibits a clear main dip at wavelength 1185 nm. When the fiber is bent, this dip shifts to longer wavelengths and its amplitude increases (Fig. 2). For curvature radii less than 10 cm, a new dip appears in the short wavelength range.

![Fig. 2. Evolution of spectra of the structure of length 22.5 cm upon changes of curvature radius from infinity to 7 cm.](image)

Figure 3 demonstrates the dependencies of wavelengths of the two dips on fiber curvature. It is seen from the figure that the dependencies are close to linear and the slopes of the corresponding approximating straight lines almost coincide. By changing orientation of the fiber we have shown that the direction of bending has no effect of the transmission spectrum of the structure.
We suppose that the shift of dip wavelength is caused by a change in the propagation constant of the cladding mode in the bent fiber. When the fiber is bent, the refractive index profile is inhomogeneously changed. This change is related to geometric modification of the waveguide and photoelastic effect. The amplitude of this change is proportional to the distance from the fiber center; therefore, it is small in the core region and maximal at the fiber surface. As a result, cladding mode profiles are displaced and their propagation constants are changed.

The shift of spectral dips of the structure under bending allowed us to design a sensor. We developed an interrogation scheme with two light sources with different wavelengths coupled to the same fiber and a photodetector. The bending is measured by division of detected signals from the two sources.
4. Conclusion
Using sensitivity of the investigated structure to bending we have developed a scheme of fiber optic sensor based on two light sources with different working wavelengths. The curvature of the fiber was measured by comparison between the signal at the resonance wavelength and the reference signal.

References