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Reflectometric temperature measurement using a „single-mode–multimode–single-mode" fiber optic structure

© A.Yu. Igumenov[1,2], I.V. Melnikov[1,3], A.A. Afanasiev[1], S.S. Popova[1], S.N. Lukinykh[2,4], I.A. Tambasov[5,6]

[1] Moscow Institute of Physics and Technology (National Research University), Dolgoprudny, Moscow Region, Russia
[2] T8 LLC, Moscow, Russia
[3] Sadovsky Institute of Geosphere Dynamics, Russian Academy of Sciences, Moscow, Russia
[4] Moscow State University, Moscow, Russia
[5] Kirensky Institute of Physics, Federal Research Center KSC SB, Russian Academy of Sciences, Krasnoyarsk, Russia
[6] LLC „Scientific and production company „Spetstechnauka", Krasnoyarsk, Russia
E-mail: igumenov.au@mipt.ru

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It is shown the „single-mode–multimode–single-mode" structure allows carrying out remote temperature measurement with optical time domain reflectometer. A multimode fiber length was 10 mm. We used the temperature range from 30 to 70°C and wavelengths of 1310 and 1550 nm. The total length of a single-mode fiber-optic line for reflectometric measurements was 20 km.

Keywords: fiber optics, fiber optic sensors, optical fiber reflectometry, multimode interference.

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Fiber single-mode–multimode–single-mode (SMS) structures have a wide range of applications in sensorics. These structures are sensitive to temperature, strain, and electromagnetic and chemical effects. Their sensing properties are underpinned by the self-imaging effect that may observed in multimode waveguides [1–6]. This effect opens up a new technological path to development of integrated photonic devices based on multimode interference (MMI) effects [7,8]. Among these devices are N-by-N splitters/couplers, asymmetric splitters for power control, polarization beam splitters, and devices based on biopolymer waveguides. As for fiber technology, the self-interference effect has been used at first for optimizing the signal transmission over fiber lines. More flexible functional optical all-fiber devices, such as tunable fiber lenses [9], band-pass filters [10], fiber lasers with a multimode section at the end of a single-mode fiber for reflection suppression [11–14], and a wide range of sensors and tunable lasers [15]. Fiber MMI devices have a wide range of applications in sensorics, since they are sensitive to the refraction index, temperature, displacement, and strain. These physical variables shape directly the spectral characteristic of an MMI device. It is also possible to measure mechanical (e.g., vibration and pressure), electromagnetic (e.g., voltage, current, and magnetic field), chemical (e.g., relative humidity and gas concentration), and optical (e.g., wavelength) variables [16].

The aim of the present study is to examine the feasibility of application of an SMS structure in remote temperature measurements with an optical reflectometer. The proposed technique is simple, cost-effective, and, in contrast to measurements with distributed temperature sensors utilizing phase-sensitive reflectometry [17,18] and fiber Bragg gratings [19,20], does not require complex data processing.

A standard single-mode fiber (SMF) structure containing a multimode fiber section was examined (see the diagram in Fig. 1, *a*). Fibers were fused coaxially (i.e., without any intentional lateral offset). A 50/125 μm OVS (Saransk) multimode fiber with a length of 10 mm and a G652D YOFC single-mode fiber were used.

Figure 1, *b* presents the experimental setup used for temperature measurements with a fiber temperature sensor. This setup comprises an SMS structure, optical fiber, radiation sources, optical power meters, and a Witeg WCR-P12 water bath. An Anritsu MT9085A portable optical time-domain reflectometer (OTDR), which provides an opportunity to measure the power loss at remote discontinuities in fiber communication lines, was used as a measurement device with a built-in radiation source. This OTDR measures the optical power of a light signal, which is returned by backward scattering at a certain point within a fiber, as a function of distance (Fig. 2). Radiation sources with wavelengths of 1310 and 1550 nm were used to measure the optical power of radiation propagating through SMS structures. An EXFO FOT 600 optical tester with the same wavelengths was used in addition to the OTDR. Two SMS structures of the same design were used in experiments: one was connected to the optical tester, while the other was connected to the reflectometer.

The relation between the water temperature and the power of radiation passing through the fiber sensor was established as a result of these experiments (Fig. 3). The power of radiation propagating through the SMS structure changes due to the heating-induced variation of length of

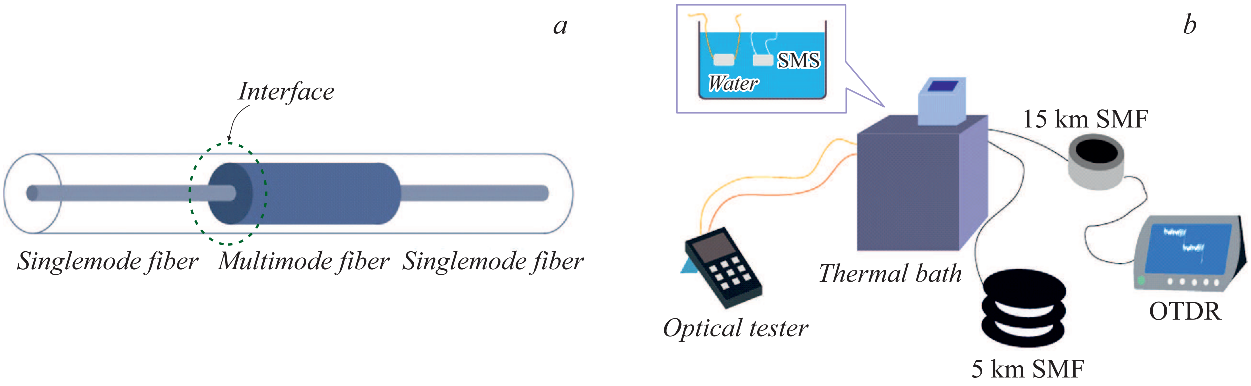

Figure 1. Diagram of the SMS structure (a) and diagram of the setup for measuring the water temperature (b).

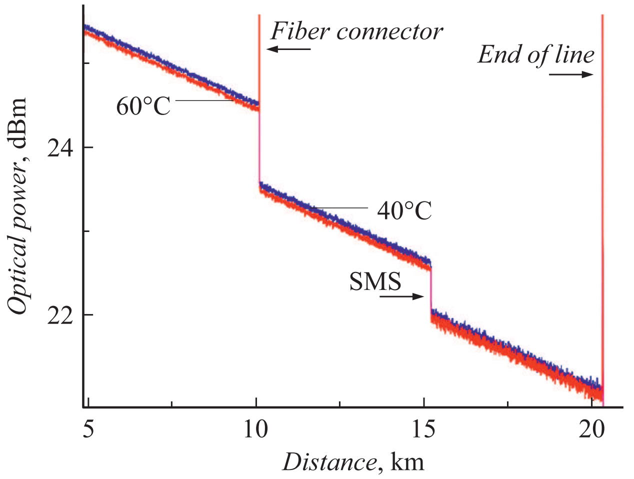

Figure 2. OTDR trace of the 15 km SMF–SMS–5 km SMF line. The wavelength was 1550 nm, and the pulse duration was 20 ns.

the multimode fiber section, which causes a shift of the maxima and minima of multimode interference. The power of radiation entering the single-mode fiber aperture changes accordingly. These dependences may be approximated by linear functions with determination coefficient $R^2 = 0.99$. The obtained mathematical dependence allows one to determine the water temperature based on the measured optical power loss in the SMS structure with a relative error no greater than 4.5% within the range from 30 to 70°C.

A prototype fiber detection system based on an SMS structure was proposed. The sensor has a simple structure, is built from readily available components, features a simple measurement principle, is insensitive to electromagnetic and radio-frequency interference, and responds accurately to the variation of key parameters of the medium for a very long period of time. The obtained experimental data provide an opportunity to establish a relation between

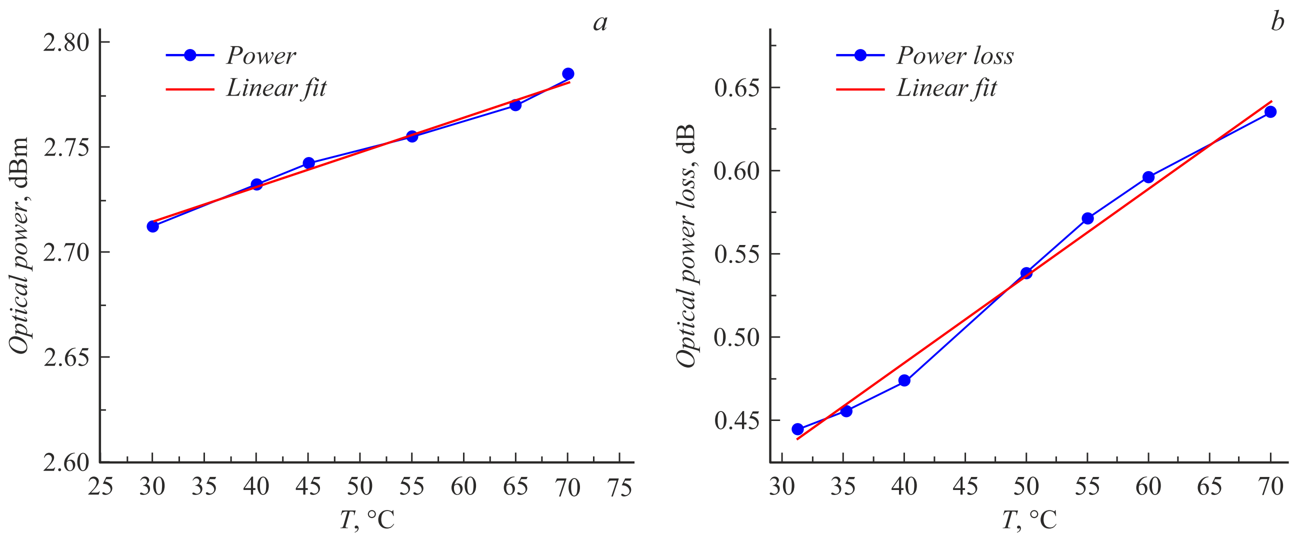

Figure 3. a — Dependence of the optical power on the thermostat temperature; the wavelength was 1550 nm; measurements were performed with an optical tester. b — Dependence of the optical power loss on the thermostat temperature; the wavelength was 1310 nm; measurements were performed with an optical reflectometer.

the water temperature and the output signal of the fiber temperature sensor. Using the mathematical dependence, one may determine the water temperature within the range from 30 to 70°C by measuring the optical power loss in the SMS structure. An OTDR allows one to perform remote measurements with the SMS structure introduced into a long fiber line.

Conflict of interest

The authors declare that they have no conflict of interest.

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