FBG-sensors interrogation with coherent optical frequency-domain reflectometer based on self-sweeping fiber laser

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Optical reflectometry is a key technology for distributed measurements of physical quantities along optical lines using dependencies of scattered in an optical fiber radiation parameters (e.g., the polarization, intensity, and optical frequency) on the physical parameters of external actions (the temperature or strain) [1]. Time- and frequency-domain reflectometry are distinguished from each other according to their principles of operation. The principle of coherent optical reflectometry in the frequency-domain (optical frequency-domain reflectometry, OFDR, for short) operation is based on spectral analysis of an interference signal produced by mixing of probe and scattered radiation. This analysis can be carried out with continuous wave (CW) tunable probe radiation. In this case, spatial coordinates of reflectors located along the tested line are proportional to the frequency coordinates of maxima in a Fourier spectrum of the interference signal measured during the tuning of the probe radiation.

Implementation of a self-sweeping fiber laser as the key element of the OFDR is proposed in [2]. In this type of laser, the optical frequency tunes due to internal processes in the laser active fiber without using any actively tuned elements. One important feature of this laser is generation of a sequence of coherent microsecond pulses with spectral width of less than 1 MHz and with strict discreteness of the optical frequency tuning. The possibility of attaining a spatial sampling of ~200 μm and reflectance sensitivity as high as –85 dB/mm at a test line length of ~9 m was demonstrated in [2]. In this paper we present the first results of implementation of the OFDR based on a self-sweeping fiber laser for sensor applications.

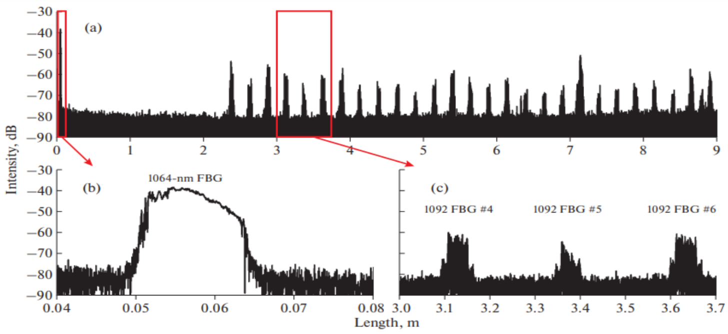

Fig.1. A reflectogram of the sensing line in different scales.

The optical scheme of the OFDR is based on a Mach–Zehnder interferometer formed by three couplers. One of the interferometer arms contained a FBG array sensor. The FBG array consisted of a set of 28 FBGs with reflection peak maxima centered approximately at the same wavelength of 1092 nm and one FBG at wavelength of ~1064 nm. Only in the later case reflection spectrum of the FBG falls into the tuning range of the self-sweeping laser. For this reason, we will further divide all FBGs into the resonant FBG (at 1064 nm) and the non resonant FBGs (at 1092 nm). Owing to the linear relationship between the optical frequency and the pulse number, the spectral dependence of the normalized amplitude of the interference signal can be obtained based on the relative pulse number [2]. A reflectogram, i.e., the longitudinal distribution of reflectors along the fiber sensing line, was obtained by applying the fast Fourier transform to the dependence of the normalized interference signal on the optical frequency (Fig.1). One can see that the reflectogram consists of numerous peaks and each peak corresponds to its own FBG. Figure 1a shows that the amplitude of the reflection signal from the resonant FBG is higher as compared with nonresonant ones.

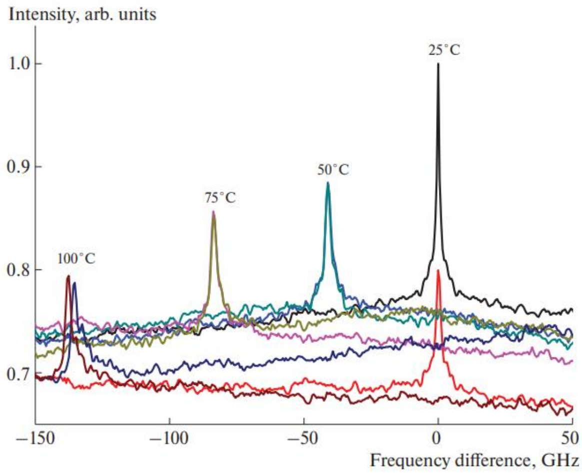

Fig. 2. Correlation functions for reflection spectra of a non-resonant FBG at room temperature (25°C) and when heated.

To demonstrate applicability of the system for sensing, one of the non-resonant FBGs is placed into a thermostat with temperature control from room to 100°C. A correlation function of the FBG reflection spectra at room temperature (25°C) and in the heated state is analyzed in the experiments. An offset of the correlation peak maximum can originate both from the heating and from fluctuations of starting optical frequency of the sweeping laser. To eliminate the latter contribution, the offset was taken into account by considering similar correlation peak of a reference FBG kept at room temperature. Fig. 2 shows the offset of the narrow correlation peak towards lower frequencies during heating of a nonresonant FBG. The offset of the correlation peak is related to temperature according to the linear law with a slope of 1.83 GHz/°C (0.73 nm/100°C).

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References

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