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Demonstration of the frequency modulation of optical signals with a high frequency deviation parameter

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***Abstract*. A new type of an integrated optical modulator for the frequency coding of optical signals is developed and fabricated. The modulator operation is based on the original technology of the electric control of a Bragg grating. The frequency modulation of an optical signal with the frequency deviation of 25 GHz is demonstrated experimentally. The modular was used to transfer the ASCII code through an optical fibre.**

Keywords: *optical telecommunications, fibreoptic communication systems, modulation formats, integrated optics, electrooptical modulators.*

1. Introduction

A permanent increase in the transfer rate in optical telecommunication systems is accompanied by the growing distortions of digital signals, caused, in particular, by dispersion and nonlinear optical effects. It is known that coding formats of optical signals based on the frequency modulation have the better stability to signal distortions and the lowest sensitivity to nonlinear effects in an optical fibre [1]. Although the frequency modulation is widely used in wireless communication systems and radio communication, the studies of the frequency modulation of optical signals [frequency shift keying (FSK)] or modulation of the light wavelength are at the initial development stage, far from practical applications. This is explained first of all by the absence of the required components for producing high speed frequency modulation of optical signals.

The matter is that, to transfer a binary frequency-modulated signal with the minimal bit error rate (BER), the frequency deviation Δ should correspond to the 'minimum shift' criterion [2]

$$\Delta f = \pm \frac{kB}{2}, \qquad (1)$$

where k is an integer and B is the spectral width of the binary signal. Thus, the frequency deviation directly depends on the spectral width of the binary signal (bit frequency). At present much work is underway on increasing the data transfer rate in fibreoptic communication systems and passage to the 40 Gbit s^{-1} standard [3]. The high bit rate prescribes high requirements to the frequency deviation of the FSK signal. To provide the minimum frequency modulation at a bit rate of 40 Gbit s^{-1}, the frequency deviation should exceed 20 GHz.

At present the frequency modulation of optical signals is performed by modulating directly the pump current of a semiconductor laser [4]. For comparatively small variations of the frequency (~ 1 GHz), variations in the amplitude from bit to bit are insignificant. However, the realisation of formats with the high frequency deviation (above 10 GHz) will inevitably change the signal amplitude. The parasitic amplitude modulation produces noise upon detection of the frequency-modulated signal and reduces stability to nonlinear-optical effects and dispersion. Therefore, such modulators are inconvenient for obtaining frequency modulation with a high bit rate (more than 10 Gbit s^{-1}). Thus, to realise new modulation formats for optical signals based on the frequency coding, it is necessary to develop frequency modulators providing simultaneously a high bit rate and a high frequency deviation without the parasitic amplitude modulation.

2. Prototype for demonstrating the transmission of frequency-modulated optical signals

We propose to fabricate a modulator of optical signals by using the original technology of the electrooptical control of spectral characteristic of Bragg gratings [5]. A Bragg grating operates as a narrowband optical filter (spectrally selective mirror) reflecting light in a narrow spectral range with the central wavelength corresponding to the exact fulfilment of the Bragg condition. If the grating is formed in an electrooptical material, the central wavelength of Bragg reflection can be changed by the electrooptical method by applying an external electric field and changing the average refractive index. Detailed studies of the electrooptical control of Bragg gratings [5] showed that the central wavelength of the Bragg grating reflection could be tuned within ~ 0.6 nm in the telecommunication wavelength region between 1500 and 1600 nm, which corresponds to the central frequency deviation 75 GHz. The use of the electrooptical effect can provide high frequencies of controlling the central wavelength (up to 10 GHz and

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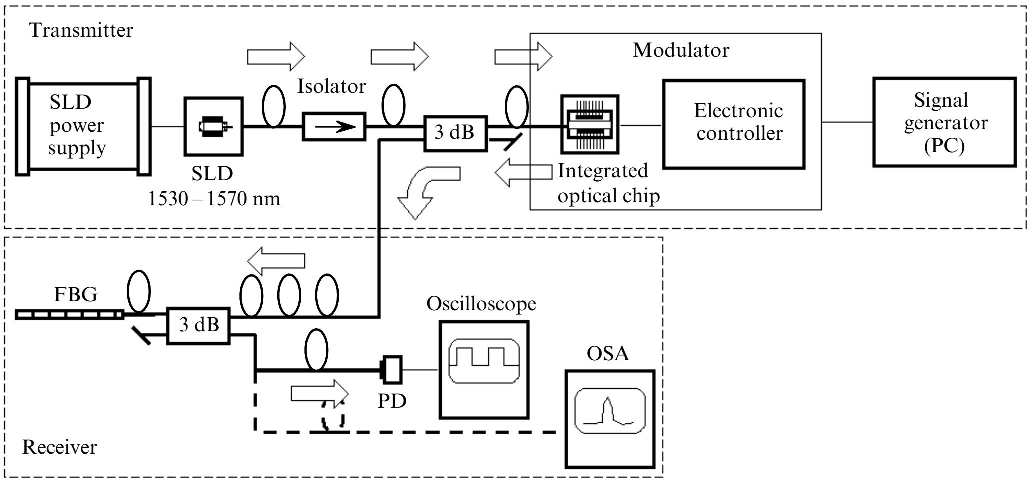

Figure 1. Scheme of the experimental setup for demonstrating the transmission of a frequency-modulated optical signal: SLD : superluminescent diode; FBG: fibre Bragg grating; PD: photodetector; OSA: optical spectrum analyser.

higher), which makes this technology very promising for realisation of frequency modulation in optical telecommunication systems.

We developed and fabricated a prototype of a communication channel demonstrating the transfer of a frequency-modulated signal (Fig. 1), which consists of two basic units: a transmitter and a receiver.

The key element of the prototype is an integrated optical modulator based on a controllable Bragg grating. The modulator is shown in the scheme in the form of two separate units: an electronic controller and an integrated optical chip (controllable Bragg grating). The electronic controller was specially developed to generate signals to control the modulator and is connected with a PC via a standard RS-232 interface. To realise the user interface, a special software envelope operating in OS Windows was developed. A holographic Bragg grating formed in a channel optical waveguide on a $LiNbO_3$ substrate was used as an integrated optical chip. We fabricated several grating samples with the reflectance exceeding 95 % and the transmission-band FWHM of 0.2 nm. The original system of electrodes provided the versatile control of the spectral characteristic of the Bragg grating. Bragg gratings were joined with a single-mode optical fibre.

A superluminescent diode (SLD) with an electronic driver was used as a radiation source. The width of the SLD emission spectrum was 40 nm (1530 – 1570 nm) and the integrated output power was 5 mW. Optical radiation reflected from the modulator was coupled and coupled out through a fibre coupler with the beam splitting ratio of 3 dB (50 : 50).

A frequency-modulated binary optical signal was discriminated by using in the receiver a fibre Bragg grating (FBG) manufactured to order at the Fiber Optics Research Center, RAS. The fibre Bragg grating performed the transformation of the wavelength (frequency) modulation of light to the intensity modulation on the slope of its reflection band, which was detected with a photodetector and observed with an oscilloscope.

3. Experimental results

We demonstrated the transfer of a frequency-modulated signal by using the information signal of a standard 8-bit ASCII code transmitted from a PC to the electronic control unit by the integrated optical modulator via the RS-232 interface. The transmission rate of the signal was 19 200 bit s^{-1}. The transmission rate was limited by the electronic equipment available. An integrated optical modulator controlled by Bragg gratings can provide in principle modulation frequencies up to 10 GHz and higher.

The frequency deviation Δf of the frequency-modulated optical signal was adjusted by setting the values of the control electric field applied to the Bragg grating in the electronic controller of the modulator, which correspond to the states of the logical zero ($E_0 = -11.3$ V μm^{-1}) and logical unit ($E_1 = 6.5$ V μm^{-1}). Measurements of the optical spectrum of the signal for the two states of the frequency-modulated binary signal showed that the shift of the central wavelength for the given values of the control electric field was 0.2 nm. This is equivalent to the frequency deviation 25 GHz in the frequency scale (Fig. 2). The radiation power at the transmitter output was less than 10 %.

Thus, we have shown experimentally that the modulator of a new type provides a high frequency deviation required for the high-bit-rate transmission of signals (above 10 Gbit s^{-1}); in this case, the amplitude modulation of the signal is insignificant, which cannot be achieved in semiconductor lasers with directly modulated pump current.

Figure 3 shows oscillograms of the output signal of the photodetector after the discrimination of frequency-modulated signals on the Bragg grating. We performed the transmission of a random sequence of symbols of the 8-bit ASCII code and transmission of the abbreviation PTI. Upon the transmission of a random sequence of pulses, the so-called eye-diagram was observed on the oscilloscope. The observations of the eye-diagram showed good discrimination between the levels of the binary signal, which demonstrates the low BER level.

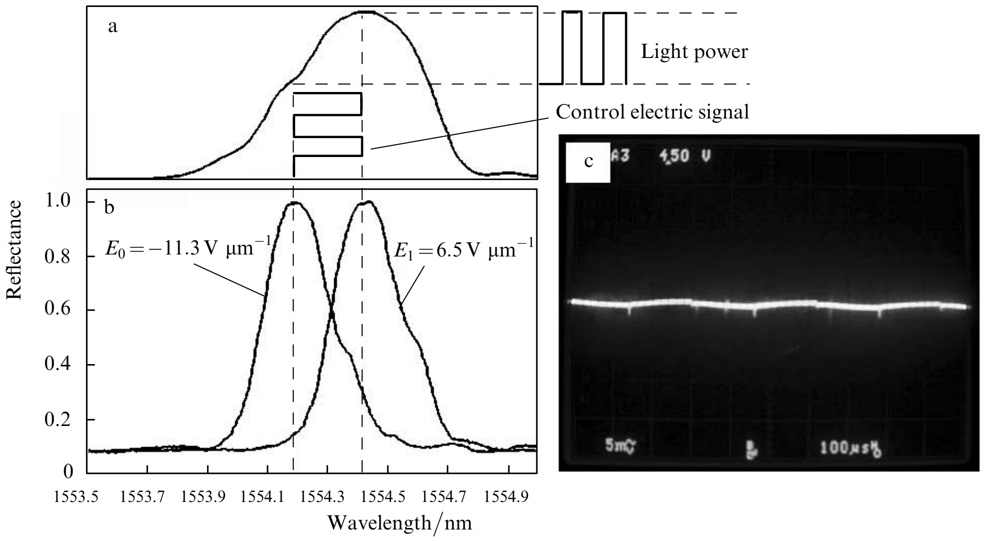

Figure 2. Scheme explaining the discrimination of a frequency-modulated optical signal on a FBG: the experimental reflectance of the FBG (a); optical spectra of the frequency-modulated signal at the output of the integrated optical modulator for the states 0 and 1 of the transmitted binary signal (b); oscillogram of the optical power at the modulator output (c).

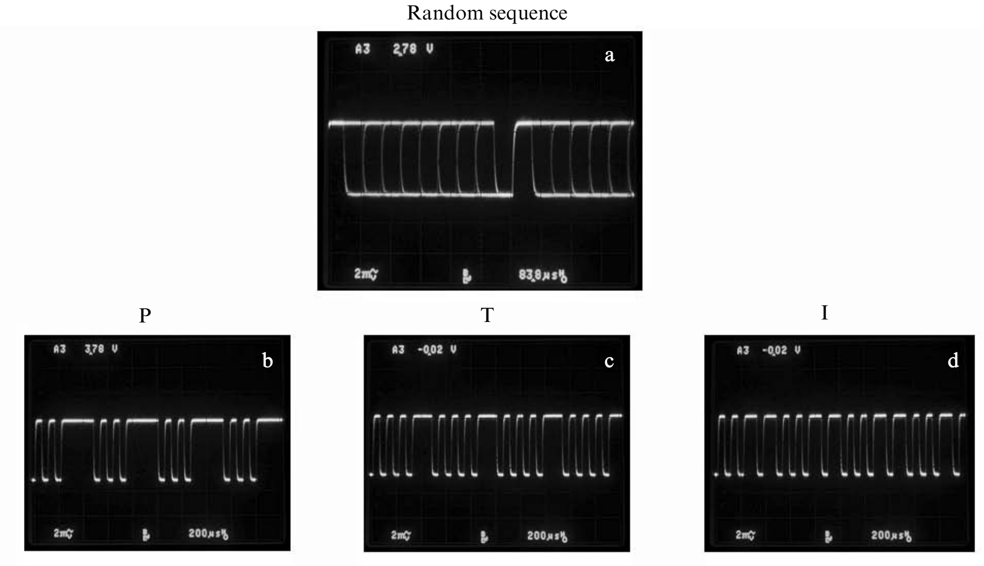

Figure 3. Oscillograms of a signal at the photodetector output after discrimination: a random sequence of pulses (a), symbol P (b), symbol T (c), symbol I (d).

4. Conclusions

We have demonstrated experimentally the formation, transmission and detection of a frequency-modulated optical signal by using electrooptically controlled Bragg gratings. The new type of an integrated optical frequency modulator developed in the paper provides the high frequency deviation (25 GHz) without considerable changes in the output signal power. Note that, although we have used in the demonstration the low data transfer rate (19200 bit s^{-1}), the electrooptical control method and the high frequency deviation can provide the data transfer rate up to 10 Gbit s^{-1} and higher. The results of the paper are most interesting for applications in local optical networks, interrogation systems for optical sensors and airborne telecommunication and telemetry systems.

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