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# Optical planar waveguides based on tungsten-tellurite glass fabricated by rf-sputtering

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## ABSTRACT

Planar waveguides based on tungsten-tellurite glasses doped with erbium and ytterbium ions are created. Planar structures with a superimposed strip based on tungsten tellurite glasses were formed by methods of Radio Frequency Magnetron Sputtering and lithography. Waveguide operation up to 1.53 mkm was observed. Optical losses at a wavelength of 1.53 mkm in the test channel waveguides with a width of 15 μm are ~0.44 dB/cm. The dependence of the optical signal enhancement at a wavelength of 1.53 mkm on the pump power was investigated for different lengths of waveguide.

## 1. Introduction

Tellurite glasses are multifunctional materials for the optical fiber and integrated optics [1,2]. It should be emphasized that these glasses have a wider luminescence band of erbium $Er^{3+}$ than, for example, a phosphate glass. Thus the glasses can provide a wider range of wavelengths for work of optically active devices. Among the important properties of this material are the low energy of phonons, low susceptible to chemical damage occurring at the surface of the sample during steps of standard photolithography and high resistivity to atmospheric moisture. Therefore, the planar waveguides based on $Yb^{3+}$ sensitized $Er^{3+}$ doped tungsten-tellurite glasses (TTG) is very promising candidate for integrated optical (IO) devices [3,4].

Many different technologies have been employed for the fabrication of integrated optical components such us sol-gel [5], ion-exchange [6], silica-on-silica technology [7] and other. One such technology is Radio Frequency (RF) magnetron sputtering that has proven itself for fabrication planar waveguides on base different materials [8,9].

In present paper, planar waveguides with a superimposed strip based on tungsten tellurite glasses undoped and doped with rare earths (RE) ions were formed on substrates of thermally oxidized silicon by methods of RF magnetron sputtering and lithography.

The research results of their optical properties, surface conditions and optical loss are presented. The dependence of the factor of optical signal enhancement at a wavelength of 1.528 mkm on the pump power for different lengths of waveguide was investigated.

## 2. Experimental

Composition of the glass developed for our experiments was 71.75TeO2-25WO3-2La2O3-0.25Er2O3-1Yb2O3 (% mol.). Conditions of TTG synthesis are same as in [10]. Planar waveguides with a superimposed strip based on TTG undoped and doped with RE ions were formed on substrates of thermally oxidized silicon by methods of RF magnetron sputtering and lithography. Conditions of formation of TTG thin film, in which the parameters of the photoluminescence (PL) in them (the lifetime of the PL intensity) were similar to the corresponding parameters of the PL in bulk glasses [11], have been found. A thin film of an Ag layer, that covering a deposited RE-doped glass layer, was made by RF magnetron sputtering technique. Strip-loaded waveguides were made by etching the waveguide pattern into this Ag layer using standard photolithography techniques. Photoresist S1813 G2 SP15 was used as the masking layer during etching. A wet chemical process was carried out with a buffered HF etch to remove 0.4 mkm of the Ag layer. The waveguide width was 15 mkm. The samples were cleaved perpendicular to the waveguide for enable fiber butt-end coupling.

The planar waveguides topography studies were performed using atomic force microscopy (AFM) by TopoMetrix® TMX-2100 Accurex™ microscope equipped with silicon cantilevers (MicroMach Co) in contact mode.

Refractive indices of the each layer of planar waveguide were measured at room temperature with an ellipsometer PHE-102 (Micro Photonics Inc.).

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Optical loss of planar waveguides measurements was carried out by photographic analysis [12,13,14]. Digital single-lens reflex camera NIKON D50 was used to capture a top-view streak image of luminous planar waveguides for optical losses studying. In each measurement, a TE mode of light beam from a 2-mW He-Ne laser (0.6328 mkm) was coupled with an edge of planar waveguide through the optical fiber. A control of light beam polarization was achieved by Glan–Taylor prism.

The photoluminescence measurement was performed by 0.98 mkm line of a diode laser with an excitation power of 150 mW. The laser spot size was 1 mm on a surface of samples. The PL spectra of the bulk glasses and the films were registered using 600 mm single-grating monochromator with resolution 2 nm (MDR-23, LOMO) equipped with InGaAs photodiode of DILAS Co., Ltd.

For the planar waveguides, the PL and factor of optical signal enhancement measurements was performed in waveguiding configuration by fiber butt –coupling at each edge of waveguides. A 0.97 mkm line of a single-mode fiber pigtailed laser diode (JDSU 30-8000-660-FL) was used as the pump. A signal beam at 1.53 mkm, emitted from a laser diode (DMPO 1550-21, DILAS Co., Ltd) with a single-mode fiber pigtail was used in experiment. The pump and signal were combined by a 0.97 mkm/1.53 mkm fiber wavelength division multiplexer, and were then coupled into the waveguide with a tapered optical fiber. The signal transmission change through the 6-mm- and 3-mm-long waveguide as a function of pump power in the input fiber before the sample was performed. The light propagated thorough planar waveguide was collected by a single mode fiber and was mechanically chopped before it was coupled into a monochromator equipped with InGaAs photodiode.

## 3. Results

Schematic cross section of the strip-loaded TTG waveguide structure with the groove width of 15 μm and its dimensions is shown in Fig. 1. The mode intensity contour is also marked, and shows that the mode is well confined. A surface topographic image of one of the waveguide channels is shown in Fig. 2.

Ellipsometric measurements of the refractive indices values of TTG thin films revealed that n = 1.914 at a wavelength of 1.0 mkm, that approximately coincided with the refractive indices of the bulk glasses.

A planar waveguides were tested onto propagation of the laser radiation with the wavelength of 0.6328 mkm along the waveguide. Top-view photograph of a planar waveguide showing propagation of the laser radiation along the waveguide is displayed in Fig. 3. The length of the waveguide is 1.30 cm.

At optical loss of planar waveguides measurements by photographic analysis it is assumed that the intensity of scattered light is proportional to the intensity of light in the waveguide [12]. Scattered light can be observed on the upper surface of the waveguide as visible radiation, its direction coinciding with the direction of the light propagated along a waveguide. The intensity of scattered light was recorded by means of CCD camera NIKON D50, provided with an optical system which permits to focus on the surface of the waveguide. For carried out of this investigations the linear sensitivity characteristics of CCD camera in the given range of wavelength was found [15]. The loss analysis is performed by sampling the light intensity from surface along the propagation direction. The relative intensity at each step of digital photo along the propagation direction is obtained by the integration of the light intensity perpendicular to the strip of light within the width of the waveguide. The logarithm of the relative scattered power versus the propagation position is then plotted. A linear least-square fit of this plot gives the propagation loss coefficient for the waveguide under test. Practically the value of attenuation coefficient α is expressed in the logarithmic scale, i.e. in dB/cm [13,14]. Fig. 4 shows the logarithmic intensity decay along the length of the waveguide. The slope of fit line is 0.5666 and $\alpha_{dB}$ = 2.56 dB/cm at wavelength 0.6328 mkm.

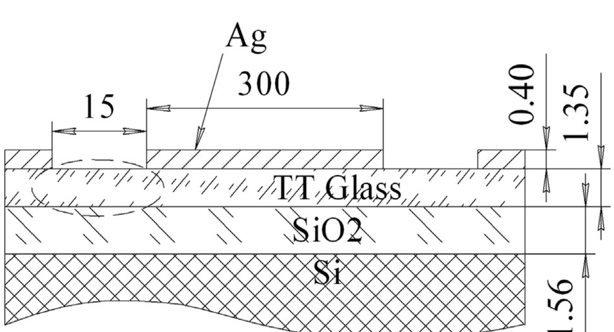


**Fig. 1.** Schematic cross section of the strip-loaded tungsten–tellurite glass waveguide structure on silicon. The linear dimensions are given in micrometers. The mode intensity contour (not scaled) is also plotted in the dashed line.

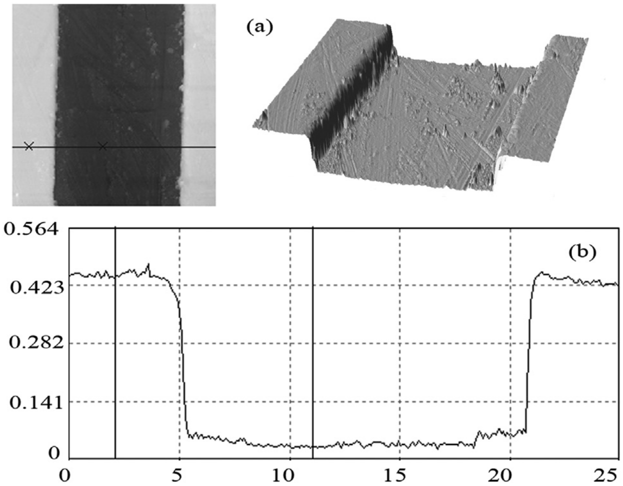


**Fig. 2.** Topographic image of the waveguide structure surface with the strip width of 15 μm: (a) - 3D plane, (b) – the three profiles in 2D (height ∗ width) plane. The linear dimensions are given in micrometers.

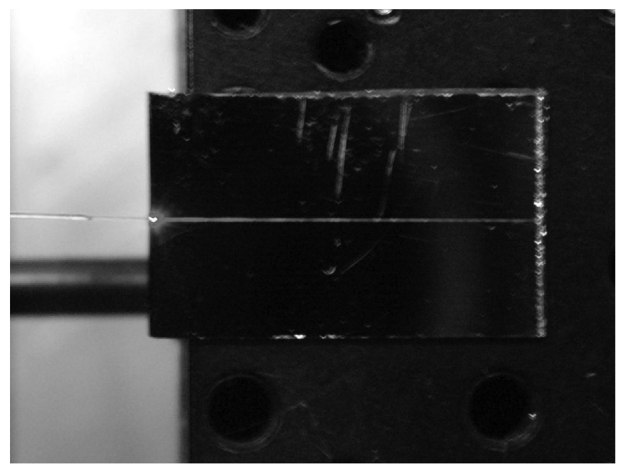

**Fig. 3.** Top-view photograph of a planar waveguide showing propagation of the laser radiation with the wavelength of 0.6328 μm along the waveguide. The length of the waveguide is 1.3 cm.

The method for determining the factor of optical signal enhancement was based on detecting the radiation associated with the stimulated transitions in the $Er^{3+}$ ions and comparing its intensity level with the intensity of the probe radiation propagating in the same waveguide. The factor of optical signal enhancement calculation was performed according to the formula:

$$FOSE = 10\log(I^{sp-p}/I^{s}) \tag{1}$$