Rib waveguides based on the sol-gel derived SiO_2 :TiO_2 films

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Abstract— This work presents rib waveguides fabricated by chemical etching of inorganic two-component SiO_2:TiO_2 films. Silica-titania films were fabricated using sol-gel method. In all technological processes involving masking, standard photolithographic procedures were used. A photoresist was used as a mask in the chemical etching processes. Rib waveguides of 5 nm rib height and rib width of less than 4μm were single mode for a wavelength of λ=635nm. The attenuation determined for fabricated rib waveguides approximately equal to 1,5dB/cm.

Rib waveguides are essentials components of integrated optical planar systems for signal processing and for optical sensors. The present work concerns the fabrication technology of rib waveguides developed by our research group [1], [2]. This technology is based on two-component SiO_2:TiO_2 optical waveguide films fabricated with a sol-gel method. The fabricated waveguide films are characterized by high refractive index (~1.8) and low attenuation (~0.3 dB/m).

The diagram of a rib waveguide is show on Fig.1. The optical and geometrical parameters describing a rib waveguide are: a refractive index of waveguide film n_l, substrate n_b, cover n_c and thickness h in a rib area, rib height t and width w. A theoretical analysis of rib waveguides was carried out using an effective index method [3].

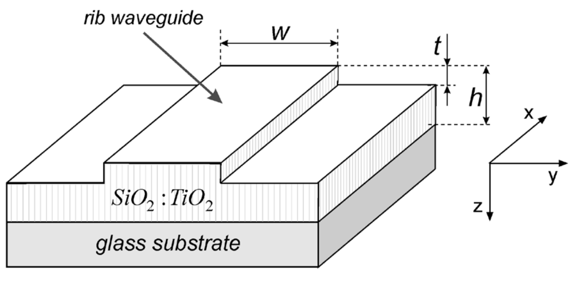

Fig.1 Diagram of a RIB waveguide

Fig.2 shows the calculated modal characteristics of a slab waveguide for TE polarization and a wavelength of λ=635nm. The values of waveguide refractive indices taken for calculations are: waveguide layer n_l=1.793, substrate layer n_b=1.515 and cover layer n_c=1.000. Such values of refractive indices characterized the structures fabricated in our group.

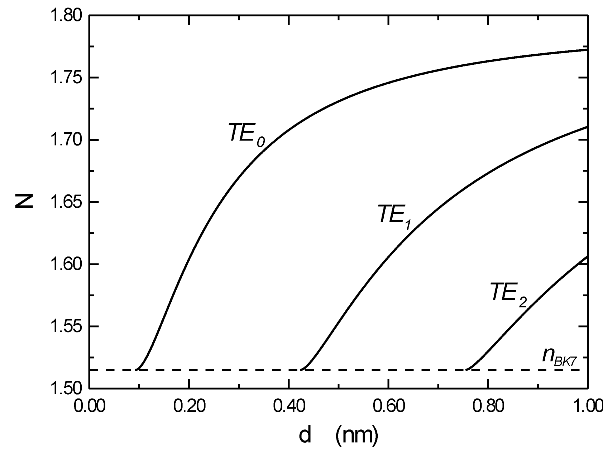

Fig.2 Modal characteristics of a planar waveguide

The modal characteristics of a rib waveguide for selected values of height t are shown in Fig.3. It can be seen that along with an increase in rib height t the cut-off width w_{cut} of TE_{01} mode is decreasing. For a rib height of $t=5nm$, the TE_{01} cut-off width is w_{cut}=2.83μm. Silica-titania films were fabricated using a sol-gel method [4]-[6].

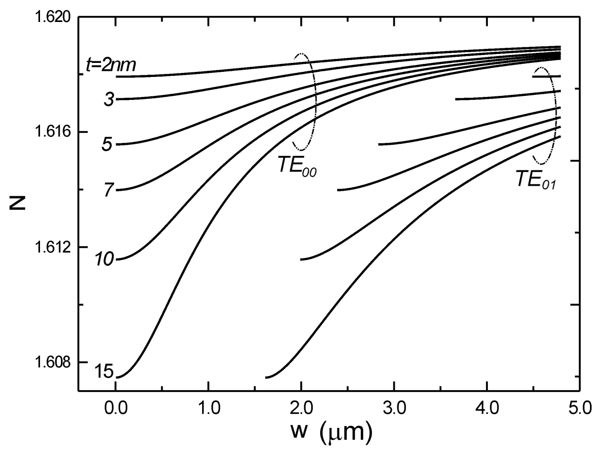

Fig.3 Modal characteristics of a rib waveguide, h=219nm

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The precursors of silica (SiO_2) and titania (TiO_2) were tetraethyl orthosilicate $Si(OC_2H_5)_4$ (TEOS) and tetraethyl orthotitanate $Ti(OC_2H_5)_4$ (TET) respectively. Ethanol C_2H_5OH was used as a homogenizing agent and hydrochloric acid HCl as a catalyst. The TEOS:TET molar ratio of prepared soles was 1. The sol films were deposited on BK-7 glass substrates using a dip-coating method. After depositing sole films on substrates, the structures were annealed for 60 minutes at 500°C. The thicknesses and refractive indices of fabricated films were measured with a monochromatic ellipsometer Sentech SE400 (λ=632,8nm).

Rib waveguides were fabricated by selective etching of silica-titania films. For this purpose a water solution of ammonium fluoride (NH_4F) was used. The following composition of an etching solution was used: 200ml of water (H_2O) + 20ml of NH_4F + 10 ml of 80% acetic acid (CH_3COOH). Our investigations on the composition of etching solutions were carried out on the assumption that the etching speed would be sufficiently low in order to control the etching depth and therefore the rib height, with the etching time. The second obvious demand against an etching solution was its inability to etch a masking layer during the time period, exceeding several times the anticipated etching time. For the etching solution kept at a temperature of 30°C, the determined etching speed was (0.225±0.003)nm/s. The SiO_2:TiO_2 films were masked with a Shipley-Microposit S1813SP15 photoresist. We fabricated rib waveguides of the rib width w=1÷10μm and rib-based directional couplers which had the rib width w=2μm.

The fabricated rib waveguides and directional couplers were investigated using the measurement setup shown in Fig.4. The investigated structures were excited by a laser diode, operating at the wavelength λ=635nm coupled with a single mode optical fiber. The investigated structure was coupled with an optical fiber through a precise x,y,z translational stage. The near-field distributions of optical power at the end of excited structures were registered using a CCD camera and stored in a PC computer.

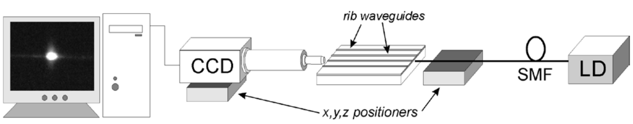
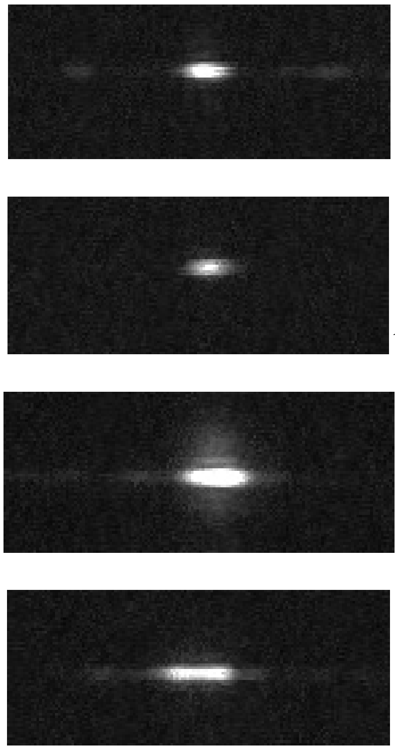


Fig.4 The schematic diagram of measurement setup

Registered optical power distributions at the end of rib waveguides of the rib width w=2÷5μm are shown in Fig.5. All investigated rib waveguides had the same rib height t=5nm.



a)
b)
c)
d)

Fig.5 Registered optical power distributions at the end of rib waveguides for ribs of different width:
a) w=2μm, b) w=3μm, c) w=4μm, d) w=5μm.

The analysis of registered optical power distributions showed that rib waveguides of the rib width w=2μm and w=3μm are single mode, whereas those for the rib of a width greater than 3μm are multimode for the wavelength λ=635nm. The determined attenuation of fabricated rib waveguides is approximately 1.5dB/cm. The attenuation was measured using a streak method. At the current stage of investigations, sidewall roughness is the main source of attenuation. This roughness results from copying, in a photolithographic process, the defects the photolithographic mask is burden with. The photolithographic mask used in a rib fabrication processes is negative.

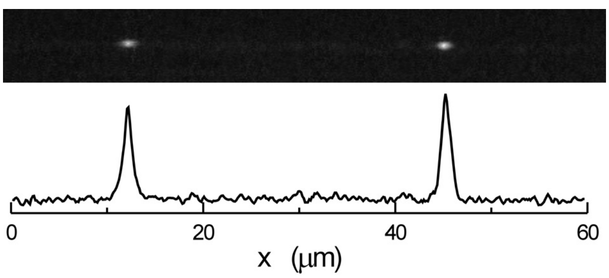


Fig.6 Near-field picture of a 1x2 directional coupler outgoing rib waveguides and related distribution of optical power

The registered near-field picture of a 1×2 directional coupler outgoing rib waveguides is shown in Fig.6. In this figure is also shown optical power distribution determined on the basis of this picture. It can be seen that the values of optical power in both rib waveguides are very close to one another.

The presented rib waveguides and directional couplers may be the basis for developing planar interferometers for sensor applications. We except that improvement in the quality of a photolithographic mask as well as the optimization of an etching process will allow us to fabricate structures characterized by lower attenuation.

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