Low loss silica-titania waveguide films

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Received March 3, 2010; accepted March 12, 2010; published March 31, 2010

Abstract—The paper presents research results on two-component waveguide films SiO₂:TiO₂ produced in sol-gel technology. The waveguide films were deposited on soda-lime glass substrates using the dip-coating method. For the produced waveguide films, the dispersion characteristics of the refractive index and of the extinction coefficient were determined. The AFM method was used to investigate the typology of waveguide film surfaces. The attenuation of waveguide films was determined using the streak method.

As the precursors of silica (SiO₂) and titania (TiO₂) we applied respectively tetraetoxysilane Si(OC₂H₅)₄ (TEOS) and tetraetoxytitannate (TET). Ethanol (C₂H₅OH) was used as a homogenizing agent, and hydrochloric acid HCl as a catalyst. For the produced sols, the molar ratio TEOS:TET was 1. After the deposition of sols on glass substrates, the structures were heated at 500°C for 60min. The thickness of the produced waveguide films was controlled through a substrate withdrawal speed. The dispersion characteristics of the films SiO₂:TiO₂ were determined with the application of the spectral ellipsometer Woollam M2000 (λ=200±1700nm). The dispersion characteristics of the refractive index n and of the extinction coefficient κ are presented in Fig.1. These relations, and in particular the dispersion characteristic of the refractive index is indispensable in the designing process of planar elements or systems produced with the application of the presented waveguide films. Fig.2 presents the topography image of a waveguide film surface obtained with the use of an atomic force microscope AFM. The surface root mean square roughness determined for the whole area 1×1µm² was σrmS =0.225nm. Roughness is one of the basic parameters characterizing surface quality.

Attenuation measurements were carried out using the streak method. The setup of such a measuring system is presented in Fig.3. Planar waveguides SW were excited using a prism coupler PC. A laser diode LD (λ=677nm)
was used as a light source. The polarization state of a light beam was determined using the polarizer P and rotator R. The streak image of light scattered in the waveguide was recorded with a CCD camera coupled with a computer. Through the application of photo lens OB it was possible to illustrate the image of the whole observed waveguide on a camera chip.

Fig.3 Schematic diagram of the measurement set-up. LD- laser diode (λ~677nm), P - polarizer, R – rotator, PC – prism coupler, SW – slab waveguide, OB. – photo lens

Fig.4 Schematic diagram of the measurement set-up. LD- laser diode (λ~677nm), P - polarizer, R – rotator, PC – prism coupler, SW – slab waveguide, OB. – photo lens

Fig.4 presents an exemplary image of the excited waveguide, which was recorded in the measurement setup shown in Fig.3. We can distinctly observe a streak of scattered light. When the structure is uniform along the light propagation path, then the intensity distribution of the scattered light corresponds to the light intensity distribution in the waveguide along the propagation direction. In this way, basing on the intensity distribution of the scattered light along the waveguide, we can determine the waveguide attenuation. Fig.5 presents the intensity distribution of the scattered light along the waveguide (Fig.4). By matching this distribution with the exponential relation $S(x)=S(0)\exp(-\mu x)$ (solid line on the picture) the loss coefficient $\mu$ was determined, from which the waveguide attenuation $\alpha=4.343\mu$ was calculated. For the presented case we obtained the attenuation $\alpha=(0.18\pm0.07)$dB/cm. In the same way as above the attenuation for waveguides of different thickness was determined. The obtained results for the polarization TM are presented in Fig.6. We can observe the rise of attenuation with the rise of waveguide film thickness. The attenuation values are changing from ~0.2dB/cm to ~1.5dB/cm. As for waveguide films of a high refractive index (n~1.8), these are very low attenuation values. In view of sensor applications, waveguide films of the thickness d~200nm are most attractive, and the ones presented here have the lowest attenuation. Detailed analysis involving the influence of surface roughness of a waveguide film on light scattering shows that the main loss is affected by the dissipation on the boundary surface with the substrate. The attenuation is proportional to the square of $\sigma_{rms}$ and to the power density on the surface, which is the source of light scattering [8]. Therefore, for the waveguide films of lower thickness $d$, the attenuation is rising with the rise of film thickness, since, at the same time, the power density is rising on the boundary surface of a waveguide film. For thicker films ($d$>200nm) stronger attenuation within the film volume is probably taking place. Such films are characterized by high stresses which result from film compression during the heating process. The said stresses may contribute to the creation of microcracks in the film structure. And for this reason,
in the sol-gel technology of inorganic films SiO$_2$:TiO$_2$ we cannot produce single cracked free films of a thickness higher than 300nm [9].

The work is sponsored by the Polish Ministry of Science and High Education within Grant N 515 057 31/2432.

References