Summary of Magdalena Zięba's doctoral dissertation

Waveguide films produced by the sol-gel method and activated with selected lanthanide ions - technology and characterization

prepared under the supervision of dr hab. inż. Pawła Karasińskiego, prof. SUT and dr Katarzyny Wojtasik

Thin-film technologies are the basis for the development of many fields of science and technology. They play a special role in optoelectronics. Photovoltaic cells, light sources, and detectors are multilayer systems composed of thin layers. Integrated photonics is currently the particularly intensively developed field of optoelectronics. It is based on waveguide films and waveguide optics. Functional, integrated photonics systems are produced from waveguide films using selective masking and etching processes, mainly used in data processing centres and fiber-optic telecommunication. These systems operate in the near-infrared (NIR) spectral range and are manufactured using silicon (Si) and indium phosphide (InP) material platforms. The third proven material platform for the Vis-NIR spectral range is the TriPlex platform from Lionix. The fourth mature integrated photonics platform is based on SiO_x:TiO_y waveguide films developed at the Department of Optoelectronics of the Silesian University of Technology. It allows the fabrication of passive integrated photonics components. Developing a mature material platform for integrated photonics is a complicated technological challenge, and the most severe problem to be solved is to achieve acceptably low propagation losses. Achieving low optical losses is only possible in single-crystalline or amorphous waveguide films. The doctoral thesis is based on the SiO_x:TiO_y material platform, and its implementation was dictated by the need to expand this platform with active elements. Hence, **the assumed goal of the doctoral thesis was to develop a method for producing active waveguide films obtained by doping SiO_x:TiO_y composite films with selected lanthanide ions.** The waveguide films were produced using the sol-gel method and dip-coating technique. Achieving the assumed goal of the doctoral thesis required verification of the following theses:

- doping SiO_x:TiO_y composite waveguide films with selected lanthanide ions do not have a destructive effect on the structure of the matrix material.
- doping SiO_x:TiO_y composite waveguide films with selected lanthanide ions does not cause a significant increase in optical losses.
- active waveguide films can be excited effectively using a grating coupler.
- photoluminescence effect may occur in SiO_x:TiO_y waveguide films doped with lanthanide ions.
- the sol-gel method and dip-coating technique are suitable for producing active waveguide layers with high parameter uniformity.

As part of the doctoral thesis, methods were developed for synthesizing sols doped with selected lanthanides (erbium or europium), which were used to produce waveguide films. The produced films were routinely characterized by the following methods: monochromatic ellipsometry, transmission and reflection spectrophotometry, m-line method, and spectrofluorimetry. The surface morphology of the films was examined using atomic force microscopy (AFM), optical profilometry, and SEM/TEM. Based on the reflectance spectra, the optical uniformity of the films was determined. Based on the transmission spectra and using the Tauc method, the widths of optical band gaps were determined, which were used to estimate the diameter of anatase (TiO_2) nanocrystallites. The HRTEM method was applied to investigate the material structure of SiO_x:TiO_y waveguide films. The results confirmed the amorphous nature of the layer materials and the uniform distribution of admixtures. The diameters of nanocrystallites determined from TEM images confirmed their sizes determined from the quantum size effect.

The completed doctoral thesis results are technological procedures for producing erbium-doped and europium-doped waveguide films with ultra-low propagation losses below 0.2 dB/cm. The influence of technological parameters on the material structure of the films, the distribution of admixtures, and the morphology of the layer surfaces was examined. It has been shown that doping SiO_x:TiO_y composite waveguide films with lanthanides does not adversely affect their propagation properties. The ultra-low optical losses have been achieved thanks to the amorphous structure of the material, uniform distribution of dopants, and very smooth layer surfaces. Photoluminescence bands and decay times in sols and xerogels doped with europium were determined.

The results of the completed doctoral thesis confirm the achievement of the assumed goal and validate the thesis, demonstrating the significant impact of the research in optoelectronics.