Consiglio Nazionale delle Ricerche
Istituto di Fisica Applicata "Nello Carrara"
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REPORT

On the visit of Dr. István Bányász at the Istituto di Fisica Applicata "Nello Carrara" in the framework of the Short Term Mobility (STM) Program of CNR

Date of the visit: October 3rd–October 14th, 2016
Place of the visit: Istituto di Fisica Applicata "Nello Carrara", Sesto Fiorentino, Italy
Host: Dr. Stefano Pelli
Title of the research project: **Development and characterisation of optical waveguides fabricated by ionic implantation in glasses and crystals**

Results of the research

During the stay of Dr. István Bányász, we have tested the functionality of two types of optical channel waveguides, both fabricated in Er:$TeO_2W_2O_3$ glass samples.

The first set of channel waveguides was fabricated using 3.5 MeV energy N^+ ion macrobeam, and implantation was performed through a silicon mask containing 24 micron wide slits. Fluence received by the sample was between $1 \cdot 10^{15}$ and $4 \cdot 10^{16}$ ions/cm^2.

The second set of channel waveguides was directly written in the sample via irradiation with a 15 µm wide carbon ion microbeam. For one set of the channel waveguides C^{3+} ions of 6 MeV energy were used, while the other group was irradiated with a C^{4+} ion beam with 11 MeV energy. Irradiated fluence was in the range of $1 \cdot 10^{14}$-$3.3 \cdot 10^{16}$ ions/cm^2.

We have proven that the N^+ ion-implanted channel waveguides worked up to the wavelength of 1540 nm (in the C optical telecommunication band).

Also the waveguides directly written in the Er:$TeO_2W_2O_3$ glass using 6 MeV C^{3+} and 11 MeV C^{4+} ion microbeams proved to be operative at λ = 1540 nm. However, measured propagation losses of the as-implanted channel waveguides were rather high, above 10 dB/cm. Based on our previous research work on the fabrication of planar waveguides in the same glass using 1.5 and 3.5 MeV N^+ ion macrobeam implantation, we decided to apply stepwise thermal annealing to the sample containing the channel waveguides to reduce propagation losses. A moderate thermal annealing at 150 °C in normal atmosphere during 30 minutes caused a dramatic improvement of the guiding properties of the channel waveguides. As it can be seen in Fig.1, propagation losses measured at λ = 1540 nm were 12.5 dB in an as-implanted channel waveguide. Propagation losses decreased to 1.38 dB after the 150 °C thermal annealing. Further stepwise thermal annealing up to 300 °C resulted in increasing propagation losses.

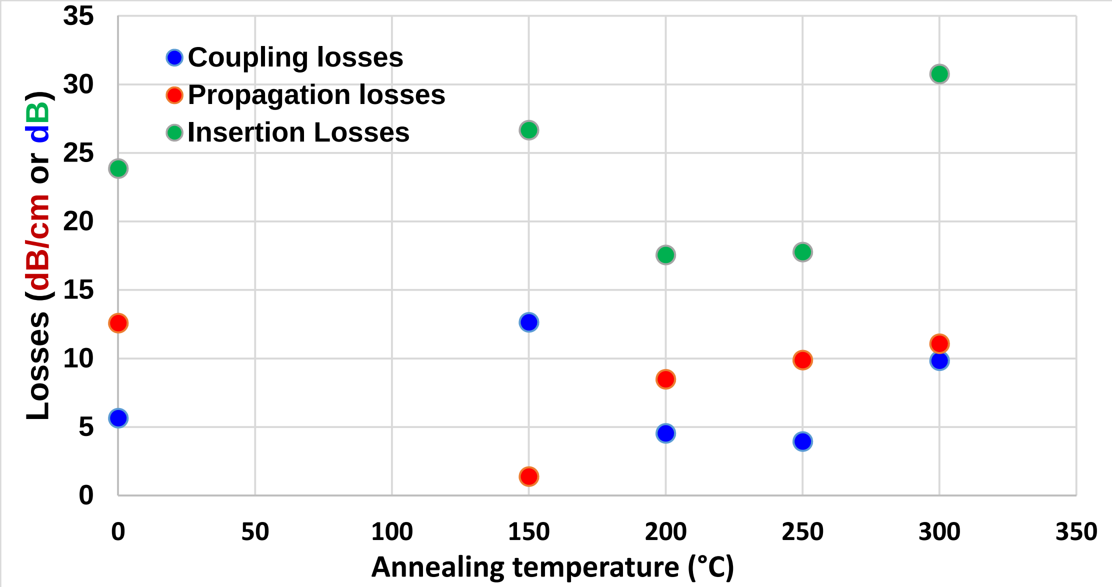

Figure 1. Losses (in dB for coupling and insertion losses, in dB/CM for propagation losses) measured at λ = 1540 nm in a channel waveguide *vs.* temperature of the 30-minute annealing steps. The channel waveguide was written with an 11 MeV C^{4+} ion microbeam at a fluence of $3.3 \cdot 10^{15}$ ions/cm^2.

While propagation losses could be reduced by thermal annealing, and depth confinement (normal to the sample surface) of the focussed ion beam written channel waveguides was good, lateral confinement in the channel was not optimal, because of the small refractive index contrast between the waveguide core and the unimplanted bulk material at both sides, as shown in Fig. 2.

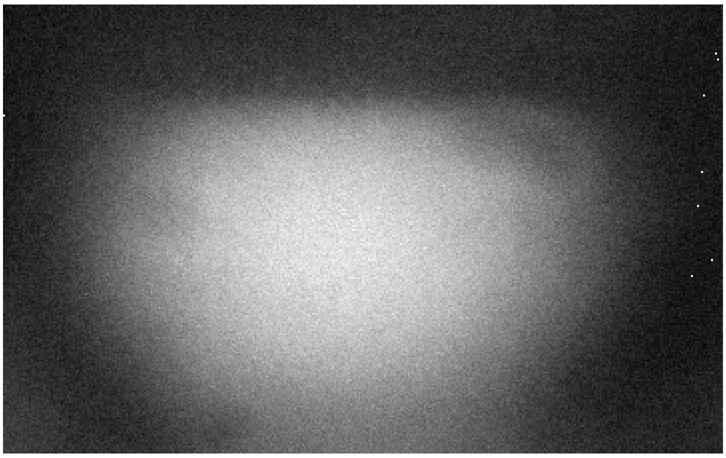

Figure 2. 1540 nm laser beam emerging from the end face of the channel waveguide. The transversal mode seen in the microphoto is much wider (cca. 30 µm) that the nominal width of the channel waveguide (15 µm).

Based on an idea of the Guest Researcher, we are planning to fabricate a new type of focussed ion beam written channel waveguides with added sidewalls to improve lateral confinement.

Besides the time consuming characterisation of the channel waveguides, we have also begun to test some recently fabricated ion beam implanted planar waveguides. Preliminary spectroscopic ellipsometric results (obtained in Budapest, Hungary) showed that a planar waveguide written in a $KDy(WO_4)_2$ crystal via 10.5 MeV N^{4+} ion implantation at a fluence of $4 \cdot 10^{15}$ had a very high refractive index modulation. Rare-earth (double) tungstate crystals are an emerging class of excellent laser and amplifier materials.

Therefore, the main goals of the visit have been fully reached and a journal article has been planned to publish the experimental results obtained in the course of the visit of Dr. István Bányász.