# Buried planar and channel waveguides in sapphire and Ti:sapphire by proton implantation

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**Abstract:** Buried, stacked planar and channel waveguides in sapphire and Ti:sapphire are fabricated by proton implantation. Flexibility of the fabrication technique and good control over the implantation parameters result in variable design and excellent light confinement.

**OCIS codes:** (130.3130) Integrated optics materials; (230.7390) Waveguides, planar

## 1. Introduction

Due to its superior optical and thermo-optical properties, sapphire is suitable for high-power optical applications in, e.g., integrated optics. On the other hand, its hardness and high melting point make processing of sapphire passive and $Ti^{3+}$:sapphire active optical waveguides difficult [1-3]. The task becomes even more challenging when buried waveguide structures are to be achieved. Nevertheless, buried waveguides are associated with the absence of surface scattering losses and reduction of mode-propagation losses owing to the mode asymmetry commonly encountered in superficial waveguides. Light ion beam implantation is known as an alternative method for the fabrication of optical waveguides [4,5]. Recently, good guiding properties were demonstrated in proton-implanted sapphire surface waveguides [6,7]. We report here on the fabrication of buried, stacked planar and channel waveguides fabricated by proton implantation into sapphire and $Ti^{3+}$:sapphire.

## 2. Experimental results

### *2.1 Buried planar and stacked planar waveguides*

Buried planar waveguides can be achieved by means of multiple-energy implantation. Refractive-index and geometrical parameters of the buried structures were calculated to permit fundamental transverse-mode propagation at $\lambda$ = 780 nm near the maximum of the $Ti^{3+}$ fluorescence and to avoid crossover between the waveguide and the superficial layer by prohibiting light propagation in the upper layer.

The multiple-energy implanted $Ti^{3+}$:sapphire sample shows excellent light guiding in the buried structure with a bright IR fluorescence output when pumped with an $Ar^+$ laser into the $Ti^{3+}$ absorption band. In accordance with the initial requirements, no light propagation was detected in the superficial layer. The experimental fluorescence output profile shown in Fig. 1 (*left*) show good agreement with the simulation [Fig. 1 (*center*)] in terms of light confinement and localization. These results demonstrate the good control of the implantation parameters in $Ti^{3+}$:sapphire. Detailed results on fluorescence investigations in $Ti^{3+}$:sapphire waveguides will be reported at the conference.

Following the same process of multiple-energy implantation, stacked planar waveguides can be fabricated by using several suitable incident energies and fluences allowing the propagation in the superposed layers. As an example, Fig. 1 (*right*) presents output profiles of two stacked sapphire planar waveguides excited either individually or simultaneously.

### *2.2 Channel waveguide*

Furthermore, we investigate the possibility to fabricate an all-ion-implanted channel waveguide. The writing of strip-damaged areas by ion implantation through a slit-based set-up [8] into the guiding layer of a planar waveguide leads to channel confinement of the propagating light. Figure 2 presents the optical output profile of a 16-µm wide channel waveguide, which shows excellent light confinement in both the horizontal and vertical directions.

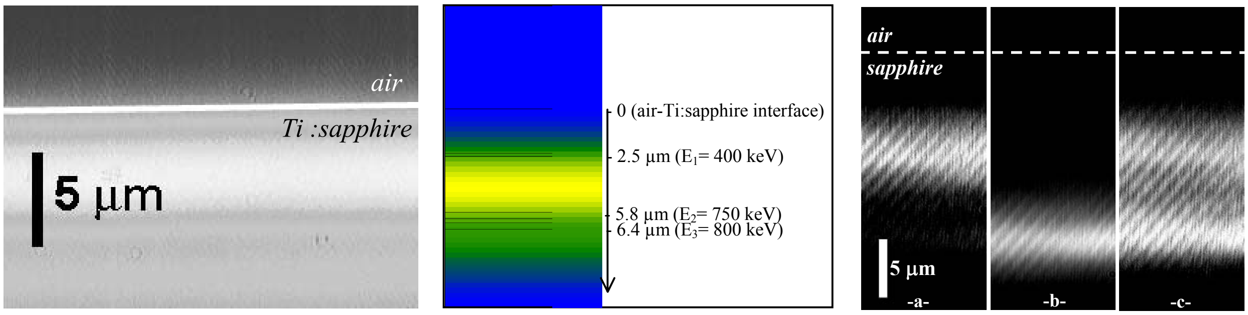


Fig. 1. (*left*) Fluorescence output profile of a buried planar waveguide in proton-implanted $Ti^{3+}$:sapphire. (*center*) Description and calculated mode-field pattern at λ = 780 nm for the buried planar waveguide investigated. (*right*) Optical output profiles of end-coupled, fundamental-mode laser light at λ = 632.8 nm from proton-implanted sapphire stacked buried planar waveguides. Selective excitation of (a) the upper, (b) the lower, and (c) both guiding layers. (Visible diagonal fringes are due to a detection artifact)

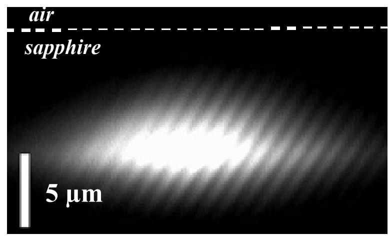


Fig. 2. Optical output profile of end-coupled, fundamental-mode laser light at λ = 632.8 nm from a 16-μm wide all-proton-implanted sapphire channel waveguide. (Visible diagonal fringes are due to a detection artifact)

This first all-proton-implanted sapphire channel waveguide supports low-transverse-mode propagation. Fundamental-mode channel waveguides can be achieved by optimizing the implantation parameters.

## 3. Conclusions

For the first time, several optical guiding structures (planar, buried planar, stacked planar, and buried channel waveguides) were fabricated by proton implantation into sapphire or $Ti^{3+}$:sapphire, showing the great flexibility of the fabrication method. Excellent guiding properties were observed in both passive and optically active samples. These results are very promising for the realization of active integrated optics devices in $Ti^{3+}$:sapphire such as, e.g., parallel buried channel waveguide or even two-dimensional array emitters.

## 4. References


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