ACL
EQEC91/QE10

ION-IMPLANTED CRYSTAL WAVEGUIDE LASERS

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Abstract

We report laser action in planar waveguides formed by ion implantation in five different neodymium-doped host crystals. The performance of these devices, including thresholds, slope efficiency and diode-pumped operation, will be described.

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Summary

The technique of high energy ion implantation for the fabrication of planar waveguides in optical crystals offers an interesting alternative to the chemical techniques usually used to make optically integrated circuits. Since ion implantation forms waveguides by a physical damage process it can be applied to a range of materials with widely varying crystal structures and chemical properties. The success of glass fibre lasers and amplifiers has drawn attention to the high gains and very low thresholds that can be achieved in guided-wave laser action. Glass is however in some ways limited as a laser host, for example because of its lack of electro-optic properties and also because it offers neither the broad-band tunability, nor, at the other extreme, the narrow linewidths that crystals can provide. The existence of a generally applicable technique for making waveguides in laser crystals is therefore of considerable importance.

Laser action has been demonstrated to date in planar waveguides formed by ion implantation in five different neodymium-doped laser crystals. Of these, two were electro-optic crystals ($LiNbO_3$[1] and $Bi_4Ge_3O_{12}$), two were garnets[2], including $Gd_3Ga_5O_{12}$ (GGG), a host in which chromium exhibits broadly tunable laser action, and one was the perovskite $YAlO_3$[3], the only oxide crystal in which an upconversion laser has so far been demonstrated. The physical effects of ion implantation vary from one host to another, but guidance is usually due predominantly to one of two mechanisms. The first is the formation of a low refractive index barrier in the damaged region at the end of the ion track and the second is an increase in the refractive index in the surface layer traversed by the ions; lasing has been observed in both types of waveguide. The effect of implantation on the stimulated emission cross-section of dopant ions in the guide region may or may not be significant, depending on the ion dose required to damage the crystal and the type of damage that is produced.

The ion-implanted waveguides typically exhibit losses of at least 1 $dBcm^{-1}$, and this excess loss over that of the bulk crystal offsets the enhancement of the gain produced by optical confinement in one dimension. Laser thresholds in these planar devices were therefore usually somewhat higher than thresholds in conventional bulk lasers. In a channel waveguide, however, the additional confinement can potentially reduce the pumped volume of the laser, and hence the threshold, by more than an order of magnitude provided that the waveguide losses are not significantly increased. Ion-implanted channel waveguides have been successfully fabricated in a garnet with losses of approximately 2 $dBcm^{-1}$ at the laser wavelength. With improved techniques to ensure that channels are formed precisely perpendicular to the crystal end faces, submilliwatt laser thresholds should ultimately be achieved. Furthermore a channel waveguide fabricated in a vibronic laser material such as chromium-doped GGG could in principle exhibit low threshold broadly tunable operation.

References

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