

Thermal Diffusion of Ti³⁺ into Sapphire for Active Integrated Optical Devices

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Abstract

Thermal diffusion of Ti³⁺ into sapphire is demonstrated, with depths in excess of 50μm observed after 8 hours annealing at 1950°C. Appropriate fabrication conditions for the future development of active integrated optical devices are identified.

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Summary

The thermal diffusion of metal ions into dielectric hosts is routinely exploited in the preparation of active and passive integrated optical devices with applications in telecommunications and sensing. Sapphire is a well-known gain medium when doped with transition metal ions such as Cr³⁺ or Ti³⁺. However, its potential as a planar optoelectronic substrate remains undeveloped. The realisation of versatile active integrated optical devices in standard, high quality sapphire

substrates requires the development of optical waveguides, allowing low-power pumping and device integration, and the local introduction of the active ions, allowing spatial variation of the dopant concentration. In this paper, the thermal diffusion of Ti^{3+} into sapphire is demonstrated, with the ultimate aim of developing a broadly tunable waveguide laser source in the near infra-red.

A combination of optical imaging techniques and Secondary Ion Mass Spectrometry (SIMS) have been used to identify the distribution of fluorescent Ti^{3+} ions below the substrate surface, and the Ti surface concentration. The spectroscopic properties of the fluorescent region are in excellent agreement with those typical of a high quality, bulk-doped Ti:sapphire laser crystal[1]. The diffusion kinetics observed for a range of temperatures up to 1950°C, for a selection of diffusion times and for varied amounts of titanium source, will be presented. Measured diffusion characteristics using these analysis techniques are given below.

Figure 1 shows the distribution of fluorescence emission from diffused Ti^{3+} ions obtained for diffusion times of between 1 and 8 hours at a temperature of 1950°C, in comparison to that obtained for a high quality, uniformly doped Ti:sapphire crystal. The penetration depth of the titanium ions, of up to 50 μm , is substantially greater than predicted by considering previously published data for other transition metal ions in sapphire (Cr, Ni and Fe)[2][3], and is described by a diffusion rate of order $10^{-14} \text{ m}^2 \text{ s}^{-1}$. It is believed that the discrepancy is due to diffusion through dislocations in the sapphire lattice. The location of the peak Ti^{3+} fluorescence emission some 15 μm below the surface is not expected from standard diffusion theory. Work is underway

to determine whether titanium showing reduced fluorescence efficiency is present at the surface, or whether there is a reduced titanium concentration in this surface region.

Figure 2 shows the concentration of Ti at the surface (<100nm depth), after diffusion for times between 1 and 8 hours at a temperature of 1950°C, measured using SIMS. The measured surface concentration is comparable to doping levels in high quality bulk-doped laser crystals. The reduction in surface concentration with increasing diffusion time indicates that the diffusion source is depleted during diffusion under these conditions.

The characterisation of diffusion of titanium into sapphire presented in this paper is expected to advance the realisation of active integrated optical devices based on the well-known Ti:sapphire material system.

References

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Figure Captions

Figure 1 Depth distribution of fluorescence from diffused Ti^{3+} ions after diffusion at 1950°C; *S1: 1 hour diffusion, S2: 2 hour diffusion, S3.7: 3.7 hour diffusion, S8: 8 hour diffusion.*

Figure 2 Measured Ti concentration at the substrate surface (depth <100nm) after diffusion at 1950°C; *S1: 1 hour diffusion, S2: 2 hour diffusion, S3.7: 3.7 hour diffusion, S8: 8 hour diffusion.*



