Growth of crystalline $Gd_3Ga_5O_{12}$ thin-film optical waveguides by pulsed laser deposition

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Abstract

Crystalline and stoichiometric thin films of $Gd_3Ga_5O_{12}$ have been deposited onto heated $Y_3Al_5O_{12}$ substrates by a pulsed laser deposition technique. The refractive indices of the films are in excellent agreement with the bulk crystal.

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Summary

Optical waveguides of laser gain media are highly desirable because the high intensity-length product and good pump-signal mode overlap, which can be achieved in the waveguide geometry, leads to a reduced threshold pump power as compared to bulk lasers. Although optical waveguides of $Gd_3Ga_5O_{12}$ (GGG) have been fabricated by ion-implantation of the GGG crystal[1], the technique is very expensive and a cheaper and simpler alternative is the pulsed laser deposition (PLD) technique. To our knowledge, the successful growth of crystalline laser-host thin films by PLD has

not been previously reported.

The experimental arrangement for the PLD of thin films is shown in figure 1. The cylindrical GGG single-crystal target was ablated along its length using a KrF excimer laser beam (λ = 248nm) with an incident laser fluence of $\approx$ 5J/cm^2. A $Y_3Al_5O_{12}$ (YAG) substrate was positioned 2.5cm away from the target and heated on its front surface to a maximum temperature of 750°C with a 10W CO_2 laser beam. Deposition was carried out in a vacuum chamber, at a background pressure of $\approx$ 10^{-5}mbar and then backfilled with an oxygen partial pressure ranging from 1.2×10^{-2}mbar to 1.9mbar just prior to ablation.

The stoichiometry of the GGG thin films was investigated using Rutherford backscattering spectroscopy (RBS). The solid line in fig. 2 corresponds to the computer simulation of a $Gd_3Ga_5O_{12}$ film which has a close fit with the experimental RBS results.

The crystalline quality of the GGG thin films was investigated with a D-500 Siemens, grazing incidence x-ray diffractometer. Figure 3(a) represents a film grown at 530°C which was completely amorphous with only the (444) YAG substrate peak present. Figs 3(b)-3(d) show that as the substrate temperature was increased, the (444) GGG peak appeared which was progressively sharper, implying improved crystallinity at elevated temperatures. The (444) GGG peak in fig 3(d) was located at a d-spacing of 1.798Å so that the lattice spacing difference between the film and bulk crystal of GGG was only 0.6%. In all the x-ray spectra, no other diffraction peaks were identified implying that the GGG had grown exclusively in the highly-oriented (444) plane parallel to the (444) YAG surface.

Finally, the waveguiding properties of the GGG film shown in figure 3(d) were investigated by coupling light from a He-Ne laser at 633nm into the layer using a rutile prism[2]. The refractive index of the layer was calculated to be 1.972 which is in excellent agreement with the bulk crystal value of 1.965[3].

Current work involves in-situ doping of the films with Nd ions to obtain some fluorescence data for further laser waveguide studies.

References

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2 H. Nishihara, M. Haruna and T. Suhara, Optical Integrated Circuits, McGraw-Hill, p.235 (1989)

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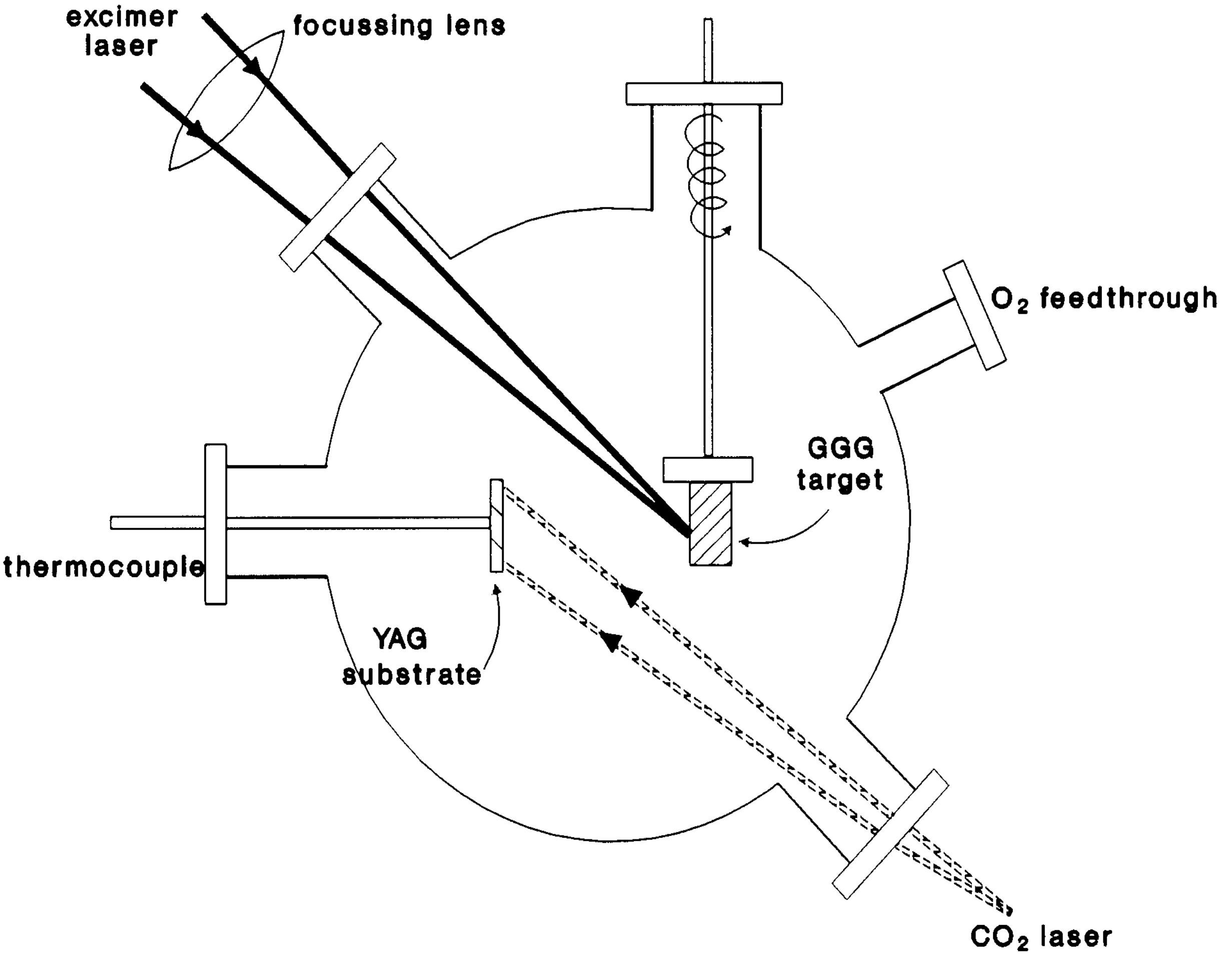
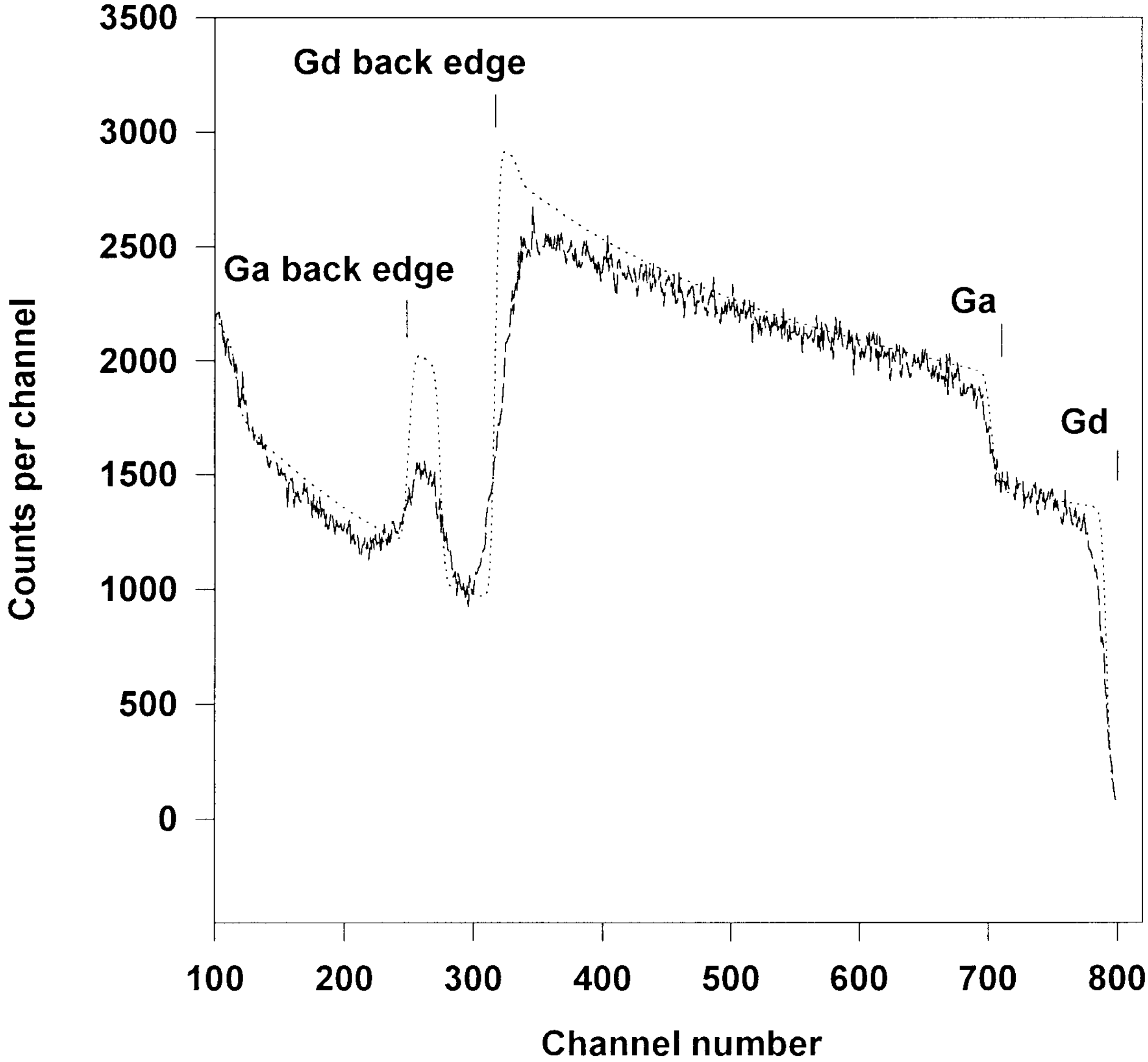
Figure Captions

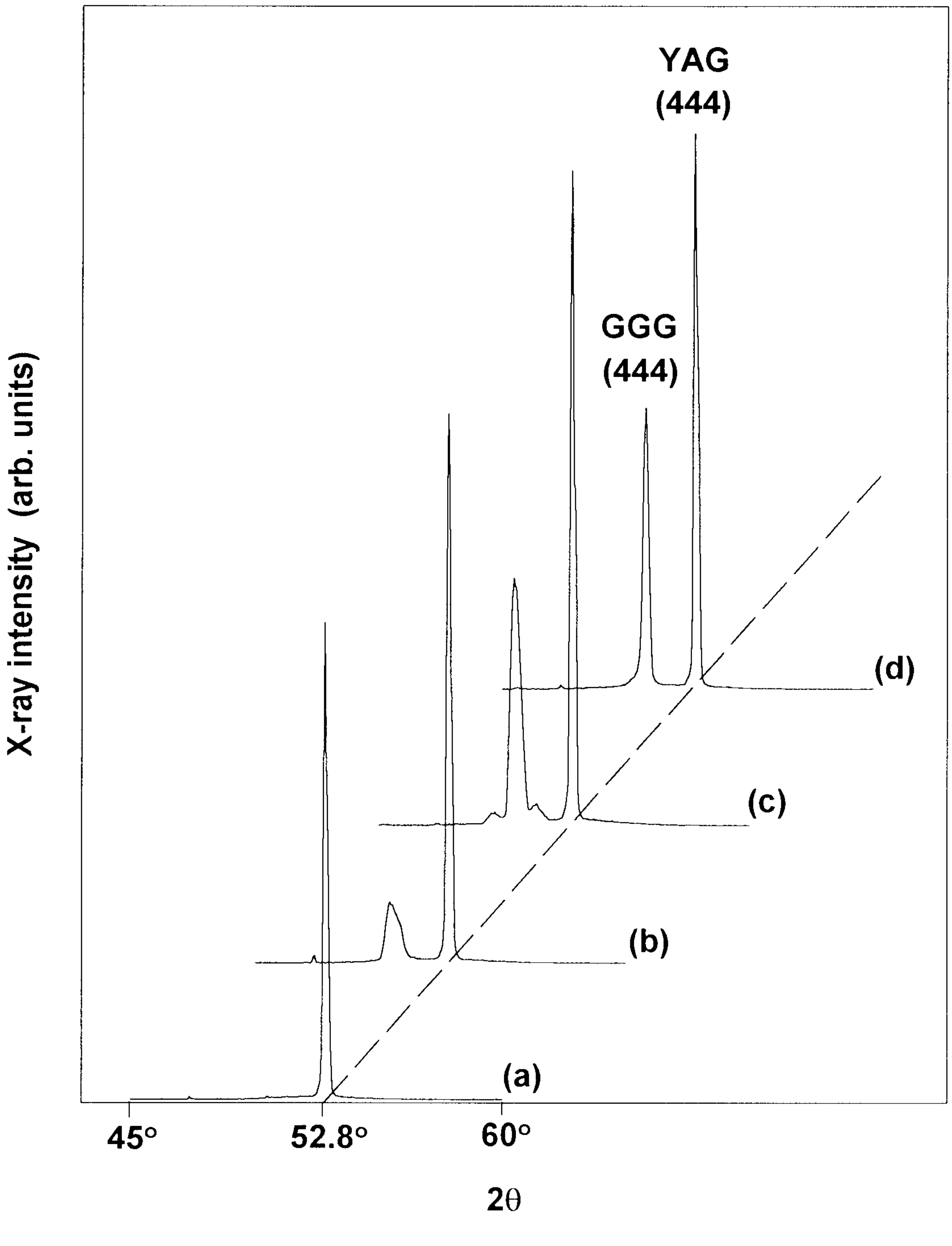
1) Experimental arrangement used for PLD and heating the YAG substrate with a CO_2 laser.

2) Rutherford backscattering spectra of a film grown on a (444) oriented YAG single-crystal substrate. The solid line represents the experimental results and the dotted line represents the fit assuming a film with a composition of $Gd_3Ga_5O_{12}$.

3) X-ray diffraction spectra of the films formed on (444) YAG single-crystal substrates at an oxygen partial pressure of $\approx 10^{-2}$ mbar and (a) a substrate temperature of 530°C, (b) a substrate temperature of 650°C, (c) a substrate temperature of 685°C and (d) a substrate temperature of 750°C. The dashed line corresponds to the diffraction angle of the (444) YAG substrate peak at $2\theta = 52.8°$.


excimer laser
focussing lens
O_2 feedthrough
GGG target
thermocouple
YAG substrate
CO_2 laser


Gd back edge
Ga back edge
Ga
Gd
Counts per channel
Channel number
3500
3000
2500
2000
1500
1000
500
0
100
200
300
400
500
600
700
800


YAG
(444)
GGG
(444)
X-ray intensity (arb. units)
(d)
(c)
(b)
(a)
45°
52.8°
60°
2θ