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Optical Defects in Nd:YAG Ceramics

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Abstract – Non-scattering optical defects, particularly those associated with grain boundaries, in Nd:YAG ceramics will be classified and linked with both chemistry and processing conditions. Confocal scanning optical microscopy, high resolution TEM, and electron paramagnetic resonance will be used to classify and visualize optical defects. In particular, the roles of liquid phase content and sintering conditions will be correlated with grain boundary chemistry and optical performance. The effects of optical defects unique to sintered materials on optical and laser properties will be discussed.

Neodymium doped yttrium aluminium garnet (Nd:YAG) crystals grown by the Czochralski method are commonly used as solid state laser gain media. However, these crystals suffer from defects including dislocations, thermally induced stresses, and compositional gradients that are inherent to the growth process. Because Nd:YAG has a cubic crystal structure, it is possible to fabricate high optical quality Nd:YAG in polycrystalline form by sintering to > 99.999% density, as first demonstrated by Ikesue in 1995 [1]. While polycrystalline ceramics have a more homogeneous Nd^{3+} concentration, similar concentrations of scattering defects, and higher refractive index homogeneity than Czochralski grown single crystals, polycrystalline materials consistently show higher threshold and lower efficiency during lasing than single crystals [2]. Therefore, it is clear that polycrystalline materials contain some inherent defects that limit their laser performance.

In order to characterize these defects, laser quality, polycrystalline Nd:YAG was produced by both the solid state reaction (mixed oxide) and chemical co-precipitation process. Green bodies were dry pressed or tape cast and sintered in vacuum between 1600 and 1800°C for 2-10 hours. Samples were characterized by SEM, HRTEM, UV-Vis spectrometry, confocal scanning optical microscopy (CSOM), and electron paramagnetic resonance (EPR).

CSOM fluorescence measurements with > 400 nm lateral resolution show that grain boundaries have 0.1 at % higher Nd^{3+} concetration than grain interiors. Grain boundary fluorescence spetra also show spectral satellites indicative of Nd-Nd interactions that may reduce laser performance, and the effective volume of these regions is up to 20% of the polycrystalline material [3]. Chemical analysis by TEM (both EDS and EELS) shows a 0.1-0.2 at% increase in Nd^{3+} content at grain boundaries, correlating well with CSOM measurements. HRTEM revealed that Nd^{3+} ions do not occupy the core of grain boundaries, rather they occupy a volume surrounding the boundary. Finally, EPR shows that after sintering, polycrystalline Nd:YAG contains high numbers of oxygen vacancies that lower in-line transmission, visibly darken samples, and reduce laser performance. By annealing the ceramics in air, the number of oxygen defects are greatly reduced and in-line transmission is increased.

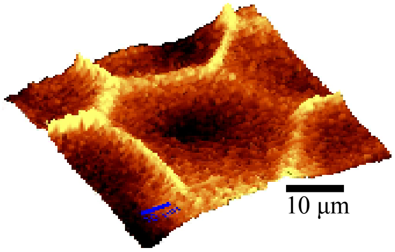

Figure 1: CSOM image of flurescence peak intensity associated with Nd-Nd interactions as a function of position in 1 at% Nd:YAG ceramic. Higher intensity regions are associated with grain boundaries.

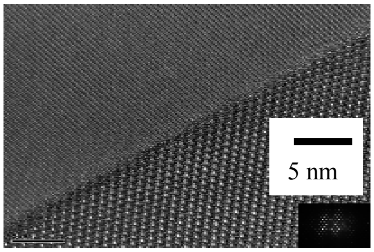

Figure 2: HRTEM image of a grain boundary in a 1 at% Nd:YAG ceramic showing no second phases present at the boundary.

References

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