An Analysis of Defects in Single Crystal Yttrium Aluminum Garnet Laser Crystals

Research Experience for Undergraduates – Washington State University

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Background on Solid State Lasers

- LASER: Light Amplification by Stimulated Emission of Radiation
- Coherent waves emitted in powerful, highly focussed beam
- Stimulation occurs from electron transitions in the split energy band
- Requires inverted population: 50% electrons in excited state
- Lasers used in precision measuring, data retrieval/storage, and medical equipment

Steps in forming lasers:
- Pumping – ground state electrons are excited by UV radiation
- Excited electrons spontaneously relax to a lower energy level, giving off infrared radiation in the form of heat
- Electrons populate lower energy level, and one relaxes to the ground state, emitting a photon
- Ends of laser rod are polished (one side partially) so the waveform reflects along the rod axis
- Another electron relaxes to GS and releases a photon that is in phase with the first
- Each relaxing electron adds to the intensity of the coherent waveform until it is powerful enough to leave the system
- Process starts over from GS

Growth of Single Crystals

-Cochralksis growth (CZ) is a common method for growing single crystals
-Material for the crystal is melted and the temperature is adjusted so the solid/liquid interface is at equilibrium
-A seed crystal is placed at the interface and the melt cooled while the seed is drawn out to form the crystal
-Crystal size and shape are dictated by drawing rate of seed crystal – color is controlled by dopant atoms such as neodymium (Nd) and cerium (Ce)

Dislocations

-Dislocations in a crystal lattice that cause the shifting of a plane of atoms
-Edge dislocation – a ½ plane of atoms is forced between two other planes, distorting the crystal lattice
-Planes stresses on the atoms around the dislocation
-Dislocations arise during solidification and move along slip planes of the crystal

Focus of Study

-Determine what defects are present in YAG laser crystals that could act as scatter centers and how they are dispersed within the crystal
-Scatter center – defect in a crystal that scatters the coherent waveform and reduces laser output efficiency
-Scatter centers may include: dislocations, inclusions, secondary phases, and voids
-Dislocations – determine dislocation density and map how they move through the crystal
-Secondary phases/inclusions – determine if they are present in solidified melt samples and correlate with resulting crystal quality

Etch Pitting

-Dislocations can be identified by etch pitting
-Samples are diamond polished and etched in H3PO4 acid bath at 250°C
-Dislocations have higher energy than the surrounding crystal lattice so they etch preferentially in the acid, leaving a pit on the surface
-Pits have different morphologies depending on the plane being observed
-Pits on the (1 1 0) plane have a triangular shape while pits on the (1 1 1) plane have an elliptical shape
-Pit clusters appear around voids or inclusions while lines of pits tend to indicate the presence of dislocations sources

Polycrystalline Nd-YAG Analysis

-Two samples from different melts of Nd-YAG used in growing single crystals were analyzed using Energy Dispersive Spectroscopy (EDS) analysis techniques on a scanning electron microscope
-The samples were solidified, polycrystalline remains from a melt that produced a usable crystal and a melt that produced a defective crystal

Conclusions

-Dislocations in Nd-YAG crystals appear to increase in density from the center to the edge and from the center to the top of the boule, indicative of some dislocation movement in the crystal
-Dislocation morphology corresponded to the (1 1 1) and (1 1 0) planes, similar to those reported by Yang et al. [1]
-Nd-YAG crystals showed a high density of dislocations, especially in the form of large, stacked dislocation clusters
-EDS point analysis demonstrated some differences in local surface composition of polycrystalline samples from a usable and failed melt of Nd-YAG – could indicate some secondary phases or inclusions present
-Backscatter imaging shows the presence of different phases in the failed melt, which could be responsible for growth of a poor crystal

References


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