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Laser Intensity Modulation by Nonabsorbing Defects

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The relevance of absorbing defects, such as inclusions, to laser induced damage in transparent media has long been recognized. Such defects generate thermal and mechanical stresses which are transmitted directly to the surrounding medium.

We wish to point out that nonabsorbing defects can also be dangerous. Defects such as voids, microcracks and localized stressed concentrations, even if they differ from the surrounding medium only by refractive index, can serve as positive or negative lenses for the incident laser light. The resulting interference pattern between refracted and diffracted light can result in intensity increases on the order of a factor of 2 some distance away from such a microlens. Thus, the initial damage site can be physically removed from the defect which initiates damage. The parameter that determines the strength of such lensing is $(Ka)^2 \Delta\varepsilon$ where K is $2\pi/\lambda$, a is the linear size of the defect and $\Delta\varepsilon$ is the difference in dielectric coefficient between matrix and scatterer. Thus, even a small change in refractive index results in a significant effect for a defect large compared to a wavelength. Geometry is also important. Spherical (eg. voids) as well as linear and planar (eg. cracks) microlenses should be considered.

As an example, consider a spherical void of radius 2 μm in glass. Assuming the void is empty, an incident unit amplitude plane wave at wavelength 1 μm strongly scatters. The large change in refractive index leads to a shadow region behind the void. The intensity modulation persists for long distances. The shadow region gradually fills in, but intensity increases of 20% still occur at distances over 10 times the void diameter. The range over which significant intensity modulations occur is roughly correlated with the Raleigh range corresponding to the void size.

The situation with linear defects is qualitatively similar. Two differences are that refracted fields tend to die off slower transverse to the defect than in the spherical case, and the component of wavevector transverse to the linear axis plays the leading role. For example, we have modeled a "crack" as an empty cylinder 2μm in radius. With the laser incident at an angle of $\pi/3$ to the cylinder axis, significant intensity modulation persists for appreciable distances.

These intensity peaks can then cause damage at a susceptible site removed from the microlens. Implications for laser induced damage can be drawn from a comparison of scattering results for various types of defects.

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