Percolation approach to laser-induced damage of optical materials

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INTRODUCTION

Optical damage limits the performance of high-power laser systems. In the non-linear crystals used for frequency conversion for example, the intensity of the laser is critical because high efficiency is obtained at high intensities, however the risk of causing damage also increases.

The optical damage can be initiated by local absorption due to inhomogeneities, defects, and impurities in the material. Previous studies [1] identified the effect of multiphoton excitation of short laser pulses that can cause damage by increasing the electron density. Kato et al. [2] investigated optical damage based on a rate-equation model. From these studies, electrical breakdown due to the laser's strong electric field has been considered to cause the development of the optical damage. To date, the critical behavior optical damage, including the experimentally observed transition to $\tau^{1/2}$ (τ pulse duration) dependence of damage fluence remains unexplained.

METHODOLOGY

Based on the theory of coarse graining and the model developed by Sasaki et al. [3] for electric discharge, a macroscopic cell representation of a material was adapted in the percolation model of optical damage. Each of the cells can change randomly between two possible states, i.e. insulator or conductor depending on the laser intensity. This behavior was investigated in the context of two-photon absorption by an optical material, representing the transition from insulator to conductor using a rate equation. The interaction between the laser field and the free electrons were considered using a circuit model. The current and power dissipation through the cells were measured. The temperature change from joule heating was obtained based on the heat capacity and density of the material. The spatial and temporal evolution of optical damage were investigated.

RESULTS AND DISCUSSION

The development of the damage from insulator to conductor transitions for several time steps between 100 fs to 1.2 ps is shown. Color maps represent the voltage distribution in the 2D lattice. Cell sites of equal voltage are drawn by the contours. The electric potential distribution is uniform at the start of a pulse as shown, and the cell transition from insulator to conductor states is localized at the region irradiated by the laser. As the current in the cells percolates, the conductor cell sites develop gradually outward of the laser spot. This is coupled with some distortion in the voltage distribution shown by the contour lines and consequently in the laser field. The damaged cell sites generally originate from the center as shown.

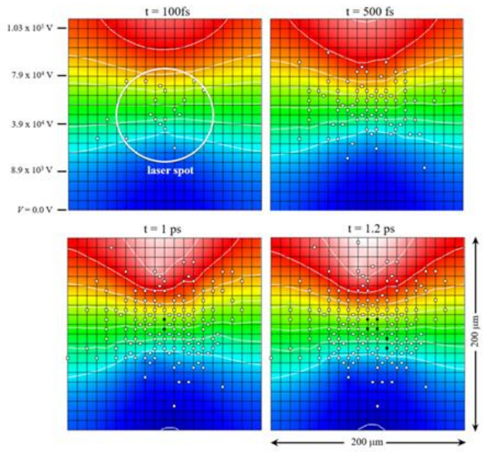

Fig. 1. Simulation of laser-induced damage in a thin film, with white squares represent a conducting cell, black squares represent a damaged cell due to joule heating.

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