Improving a finite element thermal simulation of the nanosecond laser ablation on silicon targets

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Abstract

In semiconductor manufacturing, as in several other industrial sectors, lasers are massively used in many machining processes. In particular, nanosecond laser ablation is a valid alternative for the dicing of ultra-thin silicon wafers, providing better cut quality and lower production costs with respect to the more traditional mechanical sawing. Despite the broad application of lasers in industrial machining, much remains to be understood about the mechanisms underlying laser ablation. Numerical modeling is a useful tool in the understanding of the complicated mixture of tightly interconnected physics involved and in the optimization of the dicing process, which is nowadays still performed by a trial and error approach. Nevertheless, the complex multi-physical nature of laser ablation poses serious challenges in the simulation of the process and in the development of a common modeling framework. A gap exists in particular between pure and applied researchers. The former usually analyze in detail the fundamental mechanisms involved in the interaction of laser with matter, using analytical or one-dimensional models which are generally not suited for the simulation of real applications. The latter, while attempting to describe the overall industrial process typically by means of simulation packages, often approximate the problem by neglecting or over simplifying important aspects, as the effect of the laser-induced plasma or the target response at critical temperature. This work is aimed to bridge this gap. A thermal transient finite element model is developed using a commercial package. Additionally, theoretical and numerical techniques are described and implemented in order to account in a simplified, yet physically consistent manner, for the most relevant mechanisms underlying nanosecond laser ablation. The improved finite element model, among several other aspects, considers the initial non-equilibrium plasma formation governed by collisional and radiative processes. This description is essential, as the laser-induced plasma shields the target from the incoming laser beam and reduces both the efficiency and the controllability of the process. Further, the main mass removal mechanisms are qualitatively accounted for by an element deactivation technique. In particular the transition from evaporative to volumetric removal occurring at the target critical temperature is implemented. The numerical results are finally compared with experimental data.