LASER ABLATION OF POLYMERS, CAUSED BY MECHANICAL STRESSES

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Ablation of polymethylmethacrylate (PMMA) runs effectively when the polymer is affected with pulsed laser radiation in ultra-violet range of electron absorption at the wavelength λ shorter than 260 nm. This effect only takes place when the energy density of laser radiation Φ exceeds a certain threshold. The model of ablation of PMMA proposed in this work takes into account the processes which run under UV irradiation of polymer: photochemical breaking of bonds, heating of polymer film by laser radiation, as well as the change of absorption coefficient (self-darkening of PMMA) and the sharp increase of volume of molecules due to the photochemical reaction. The increase of the volume of polymer molecules induces mechanical stresses. Its temporal dependence is rather complicated, namely, in addition to the wave of loading-unloading the quasi-static mechanical stress appears in the film. This component of mechanical stress is the main factor that leads to breaking of bonds of PMMA macromolecules, thus causing ablation. We have obtained the calculated dependence of threshold energy density Φ_0 on wavelength λ which agrees well with literature experimental data and those we have obtained.

The model developed in this work was used to determine the range of parameters (in the scale of energy density versus wavelength) for which the effect of self-darkening is essential $\Phi_d(\lambda)$. During a pulse of excimer laser, the polymer gets heated to the depth of penetration of radiation. Then this region cools down due to thermal conductivity. Since the time of cooling is rather long, the polymer melts. This is only observed in the case when the threshold of polymer melting $\Phi_m(\lambda)$ is lower than $\Phi_0(\lambda)$. According to the estimates, melting is only essential for radiation with $\lambda > 235$ nm. Really, radiation of ArF-laser ($\lambda = 193$ nm) leaves clean surface of PMMA after ablation, while KrF-laser ($\lambda = 248$ nm) leaves traces of melting.

The model of ablation of PMMA allowed us to consider the question about the ultimate spatial resolution which can be achieved no matter what optical system is used to shape the laser beam. It was shown that the limit of spatial resolution of ablation of PMMA is $\Delta \approx \gamma^{-1} / \pi$, where γ is the coefficient of light absorption. The dependence $\Delta = \Delta(\lambda)$ was analyzed.