Interaction of femtosecond structured beams with transparent dielectrics

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Synopsis: Coupling polarization of powerful ultrashort Bessel beam with transient permittivity of transparent dielectrics reveals a new mode of interaction of structural laser beams with matter.

Emerging trend in laser-matter interactions relates on using the laser beams with intricate internal structure with spatial and temporal distributions of intensity, polarization and phase – so called structured beams. The examples are vortex beams, Bessel beams, Airy beams, and their combinations. Our experiments on interaction of powerful ultrashort Bessel beams with wide band gap dielectrics revealed the formation of long channels in the bulk of a crystal.

We present here the experimental studies on the interaction of the intense femtosecond Bessel beam focused inside the bulk of a sapphire crystal. We demonstrate that the energy density in a range of tens of megabars was created in the volume, which is by more than two orders of magnitude larger when compared with that produced by a Gaussian pulse.

Analysis evidences the concentration of energy much higher than expected, indicating the change in the interaction mode. We show that the Bessel beam interaction, namely – the process of absorption and resulted intensity distribution in the bulk of transparent dielectric are strongly entangled in time and space in a stark contrast to the interaction of the Gaussian beam.

The light beam gradually transforms the initially transparent state with positive part of permittivity to opaque and highly absorbing plasma state. The interplay between the gradient of transient permittivity and polarisation of the incident laser field results in a new interaction mode. This occurs at a particular relation between the polarization and transient permittivity gradient. The incident field increases significantly near the surface of zero permittivity, leading to increase in the absorbed energy density.

We demonstrate that the Bessel beam proves to be an effective tool for producing extreme pressure/temperature conditions in transparent materials on the laboratory table-top experiments. This tool allows for search of novel high-pressure material phases [1-3], for the 3D laser machining and for creating Warm Dense Matter as those in planets cores, in laboratory environment.

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