Mass-polariton theory of light: from theory to planning of experiments

Conventional theories of electromagnetic waves in a medium assume that only the energy of the field propagates inside the medium. Consequently, they neglect the transport of mass density by the medium atoms. We have recently presented foundations of a covariant theory of light propagation in nondispersive [1] and dispersive [2] media by considering a light wave simultaneously with the dynamics of the medium atoms driven by optoelectrical forces between the induced dipoles and the electromagnetic field. The theory is based on coupling the electrodynamics of continuous media to the continuum mechanics, which are both very well established theories. In the quantum picture, the light quanta in a medium are described as mass-polariton (MP) quasiparticles that have a nonzero transferred mass.

Using the MP theory, we have shown that an electromagnetic pulse having field energy $E$ propagating in a nondispersive dielectric transfers a mass equal to $\delta M = (n^2 - 1)E/c^2$, where $n$ is the refractive index. This mass is transferred by an atomic mass density wave (MDW), where the atoms are spaced more densely inside the light pulse as a result of the field-dipole interaction. Another key observation of the MP theory of light is that in common semiconductors most of the momentum of light is transferred by semiconductor atoms moving under the influence of the optical force. While the total MP momentum is $p_{MP} = nE/c$, the field’s share of the MP momentum is $p_{\text{field}} = E/(nc)$, and the atoms coupled to the field and moving with the MDW transfer a share $p_{\text{MDW}} = (n - 1/n)E/c$. For example, in the case of silicon at wavelength $\lambda = 1550$ nm, the MDW’s share corresponds to 92% of the total momentum of light. The splitting of the total MP momentum into the field and MDW parts provides a resolution to the centennial Abraham-Minkowski controversy of photon momentum in a medium.

In this seminar, we review the foundations of the MP theory of light. We also consider experimental measurement of the mass transferred by the MDW atoms when an intense light pulse propagates in an optical fiber. In particular, we consider optimal intensity and time dependence of a Gaussian pulse and account for the breakdown threshold irradiance of the material. The optical shock wave property of the MDW, which propagates with the velocity of light instead of the velocity of sound, prompts for engineering of novel device concepts like very high frequency mechanical oscillators not limited by the acoustic cutoff frequency. We also apply the MP theory to describe the angular momentum of Laguerre-Gaussian pulses.