Photon mass drag and the momentum of light in a medium

We present foundations of a covariant theory of light propagation in a medium by considering a light wave simultaneously with the dynamics of the medium driven by the optomechanical forces between the induced dipoles and the electromagnetic field. One manifestation of our theory is that a light pulse having a total electromagnetic energy $\hbar\omega$ propagating in a nondispersive medium transfers with itself a mass equal to $\delta m = \left(n^2 - 1\right)\hbar\omega / c^2$ where n is the refractive index. The transferred mass is made of atoms, which are denser inside the light pulse due to the field-dipole forces. We also prove that the transfer of mass with light wave, the photon mass drag effect, gives an essential contribution to the total momentum of the light wave, which becomes equal to the Minkowski momentum $p_M = n\hbar\omega / c$. We consider the coupling between the light field and the medium atoms using two independent theoretical approaches which both lead to the photon mass drag effect. In the mass-polariton (MP) quasiparticle approach, we consider the light pulse as a coupled state between the field and matter, isolated from the rest of the medium and fulling the covariance condition as well as the fundamental conservation laws of nature. In the second approach, we generalize the electrodynamics of continuous media to account for the space- and time-dependent optomechanic dynamics of the medium driven by field-dipole forces. We show that, with an appropriate space-time discretization, we can obtain numerically accurate solution of the continuum dynamics of the medium when the light pulse is propagating in it. The computer simulations show that the optomechanic dynamics of continuous media gives the same momentum and the transferred mass for a light pulse corresponding to the total electromagnetic energy $\hbar\omega$ Our simulations also show that, after photon transmission, some non-equilibrium of the mass distribution is left in the medium. This leads to dissipation of photon energy, which depends on the pulse shape and the refractive index of the material.