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Magnetically induced optical transparency of overdense plasmas due to ultrafast ionisation

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The propagation of em waves in a magnetised plasma, in the so-called "extraordinary mode", has not yet been taken into account for ultrashort optical pulse propagation through overdense plasmas. We have shown [D. Teychenné *et al.*, accepted for publication in Phys Rev. E, (1998)] that it can be efficiently activated with presently available very intense laser pulses. Taking into account the dispersion relation for this mode, the plasma refractive index, n is given by the following expression:

$$n^2 = 1 - \frac{n_e}{n_c}\,\frac{1-\dfrac{n_e}{n_c}}{1-\dfrac{n_e}{n_c}-\dfrac{\Omega^2}{\omega^2}}$$

where n_e and ω are the electron density and the laser angular frequency respectively, and $\Omega = eB_S/mc$ is the cyclotron frequency. Considering the characteristic frequencies ω_h (upper hybrid), ω_R, and ω_L, the propagation is allowed for waves of frequency $\omega > \omega_L$, excluding the forbidden frequency band $\omega_R > \omega > \omega_h$. In terms of the electron density, this means that propagation is possible also at electron density above n_c, providing $n_e < n_c\left(1+\Omega/\omega\right)$. In the regime of ultra-short laser interactions, a mechanism for the generation of such a magnetic field has been identified and proposed by Wilks, Dawson and Mori [Phys. Rev. Lett. **61**, 337 (1988)]. In fact, they have shown both analytically and via numerical simulations that, *provided the e.m. field is already inside the medium*, an intense static magnetic field parallel to the oscillating magnetic field is generated as a consequence of the ultrafast ionisation produced by an intense ultrashort pulse. The order of magnitude of the static magnetic field is

$$B_S = \omega_p^2 E_O / (\omega_p^2 + \omega^2),$$

which can approach the amplitude of the oscillating field in the case of $\omega_p >> \omega$, i.e. for well overdense plasmas. Those theoretical results were found to be consistent with the experimental observation and measurement of frequency up-shift of a microwave pulse in a rapidly growing plasma published later on [S.P.Kuo, Phys. Rev. Lett. **65**, 1000 (1990)]. The predictions of Wilks *et al.* may concern the propagation of femtosecond pulses through dense matter with consequent applications as, for example, particle acceleration and laser fusion ignition. For this effect to take place, it is crucial for the medium to be initially transparent to the e.m. wave, so that a plasma can be quickly created *in the whole* interaction volume. This *volume ionisation* is the necessary condition to produce the *discontinuity in time* (in place of the *discontinuity in space* occurring when the light has to propagate in a vacuum-plasma interface) required for the on-set of the magnetic field.

Experimentally, this implies that the intense pulse has to propagate in the medium *before* ionising it. Considering that ultrashort pulses are normally affected by the presence of some sort of prepulse, an additional necessary condition is that no significant ionisation is produced by the prepulse. A possible experimental method to study this effect consists in the interaction of femtosecond high-contrast laser pulses with thin foils of transparent material, whose thickness is comparable to or smaller than the light wavelength. This method has many experimental advantages; as the effects of the prepulse are minimised [L. A Gizzi *et al.*, Phys. Rev. Lett. **76**, 2278 (1996)], initial penetration of the leading edge of the short pulse is allowed with consequent possibility of volume ionisation. Also refractive effects on the propagating pulse are minimised, and direct measurements of transmittivity can be easily performed. Measurements performed with thin plastic foils irradiated by 30 fs, weakly relativistic laser pulses, have in fact shown high transmittivity of the overdense plasma slab [D. Giulietti et al. Phys.Rev.Lett., **79**, 3134, (1997)]. A quantitative interpretation of these results in terms of extraordinary mode propagation is still in progress.