Reflectivity in Dense Xe Plasma

T. Raitza, H. Reinholz, G. Röpke
Universität Rostock, Institut für Physik, 18051 Rostock, Germany

Reflectivity can be used as a diagnostic tool for the investigation of dense plasma and its metallization. Measurements in shock wave produced dense Xenon plasmas at a temperature of around 30 000 K have been performed with a laser beam of three wavelengths: 1.06 μm, 0.694 μm and 0.532 μm [1]. A strong increase of the reflectivity indicating an onset of metallic behaviour was observed for densities above the critical density $n_\mathrm{e}^\mathrm{cr} = \epsilon_0 m_\mathrm{e} \omega_\mathrm{L}^2 / e^2$, where the plasma frequency coincides with the laser frequency.

Assuming a step-like shock front, the reflectivity is directly related to the dielectric function via the Fresnel formula [2]. The dielectric function is calculated from the generalized Drude formula

$$\epsilon(\omega) = 1 - \frac{\omega_\mathrm{pl}^2}{\omega[\omega + i\nu(\omega)]} \, . \tag{1}$$

The collision frequency $\nu(\omega)$ was determined from a frequency dependent dynamical collision frequency for electron-ion collisions taking into account dynamical screening and strong collisions. We also considered electron-electron collisions via a renormalization factor as well as electron-atom collisions. Bound state transitions contribute to the dielectric function following a cluster expansion. Despite these consistent approximations, the results for the collision frequency overestimate the reflectivity. Note, that molecular dynamics simulations also give an overestimation. In conclusion, a theoretical approach assuming a step like shock wave front is not able to explain the low reflectivity even above the critical density.

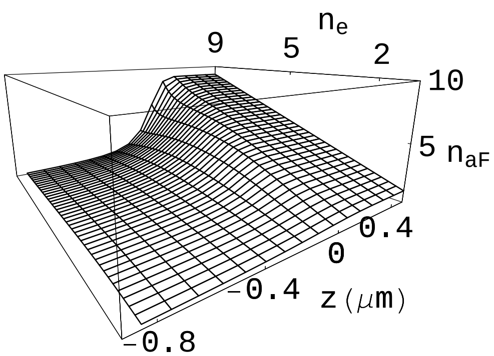

Figure 1: Adjusted density profile $n_\mathrm{aF}(n_\mathrm{e}, z)$ of the shock front, n_e and n_aF in $10^{21}\mathrm{cm}^{-3}$

This suggests more general assumptions about the spatial profile of the free electron density n_e within the shock wave front. In this case, the reflectivity is calculated using the solution of the Helmholtz equation

$$\frac{d^2 E(\omega_\mathrm{L}, z)}{dz^2} + \frac{\omega_\mathrm{L}^2}{c^2} \epsilon(\omega_\mathrm{L}, z) E(\omega_\mathrm{L}, z) = 0 \tag{2}$$

for the electric field. Using the measurements for the laser wavelengths 1.06 μm and 0.694 μm, we constructed a spatial profile $n_\mathrm{aF}(n_\mathrm{e}, z)$ for every final value of n_e in the produced plasma with z the distance from the high density region. An asymmetric Fermi profile [3]

$$\begin{aligned} n_\mathrm{aF}(n_\mathrm{e}, z) &= \frac{n_\mathrm{e}}{e^{Y(z)} + 1}, & (3) \\ Y(z) &= -\frac{z}{A} - e^{z/B} + C. & (4) \end{aligned}$$

is deducted and illustrated in Fig. 1. We find a profile width of about 1 μm. Using this profile, we calculated the reflectivity for the third laser wavelength. Fig. 2 illustrates the experimental results in comparison to the theoretical model of an extended shock wave front. The good agreement supports our assumption of a density profile during the plasma creation.

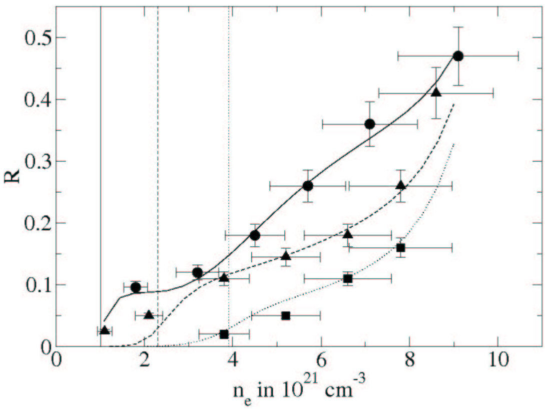

Figure 2: Reflectivity R as function of electron density; experimental results for 1.06 μm (●), 0.694 μm (▲) and 0.532 μm (■); in comparison to calculation for asymmetric Fermi profile; vertical lines indicate the critical density of the laser wavelengths

A microscopic approach may be found on the basis of simulations. First attempts using hydrocodes fail to explain this empirical approach. A kinetic approach taking into account nonequilibrium situations might have to be adapted to the experimental situation. Work is in progress.

Acknowledgement This work was supported by the DFG funded SFB 652 *Strong correlations and collective phenomena in radiation fields: Coulomb systems, clusters and particles.*

References

[1] Zaporoghets Y, Mintsev V, Gryaznov V, Fortov V, Reinholz H, Raitza T, and Röpke G, J. Phys. A: Math. Gen. **39** (2006) *in press.*

[2] Rozmus W, Tikhonchuk V, and Cauble R, Phys. Plasmas **327**, 360 (1996).

[3] Raitza T, Reinholz H, Röpke G, Mintsev V, and Wierling A, J. Phys. A: Math. Gen. **39** (2006) *in press.*