*29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. **26B**, P-4.020 (2002)*

Resonance Absorption, Ablation Pressure And Absorption-Quenching in Laser-Plasma Experiments from Planar Targets

K. P. Rohr[1], R. Dinger[2] and B. K. Sinha[3]

[1]Fachbereich Physik, Universität Kaiserslautern,
D-67663 Kaiserslautern, Germany

[2]Rofin and Sinar Laser, Berzelius
Strasse 83, D-22113, Hamburg, Germany
[3]Laser & Plasma Technology Division,
Bhabha Atomic Research Centre, Mumbai – 400 085, India

Abstract: *The profiles of resonance absorption by measuring the ablation pressure arising from laser produced plasmas produced from planar targets of plexiglass, aluminum, silicon and copper have been obtained and are reported. The laser had a wavelength λ of 1.060μm and a pulse duration of 45 psec and the most of the experiments were performed at about 6x10^{13}W/cm^2 of the laser intensity. The resonance profiles were extensively investigated with respect to three regimes of the surface roughness r consisting of (1) r<<λ, (2) r=λ, and (3) r>>λ. For r>>λ it was observed that the resonance absorption was completely quenched. The peak angle θ_m where the maximum of the resonance curve occurs was estimated with an accuracy better than ±2^o. The density scale lengths L were estimated through three techniques consisting of (1) the measurement of the resonance profile, (2) the derivations on hydrodynamics without the effect of profile steepening and, ultimately, (3) the formulations of hydrodynamic expansion including the effect of profile steepening. The results, thus obtained, were consistent with the theory and are interesting with a point of view of both theoretical and experimental investigations. The density scale length data are presented in a tabular form and the results are discussed.*

Though many experiments have been reported on plasmas produced from planar targets, no information is available with reference to the smoothness of the target surface and its effect on the profile of resonance absorption as a function of the angle of incidence Balmer and Donaldson [1] reported a surface finish of the planar targets better than λ/4 and studied the absorption process using a Nd:YAG TEM$_{oo}$ laser (λ=1.06µm, τ=35 psec) at an intensity of 2x10^{13}W/cm^2. They measured the electron temperature by the absorption-foil method using two absolutely calibrated x-ray detectors and displayed the variation of the electron temperature as a function of the angle of incidence for both p- as well as s-polarized light. Though the angle of incidence at which the peak of absorption process occurs can be unambiguously ascertained, the profile itself gives an unsymmetric long tail at larger angles of incidence in contrast to the one reported by other workers [2-6].

In the present work we have investigated the resonance absorption profile of plasmas from plexiglass, aluminum, silicon and copper using a 1.060µm, 45 psec, Nd:YAG mode locked laser with a clean laser pulse, practically free from prepulses. The laser intensity was varied between 2x10^{13} to 6x10^{13}W/cm^2 and the resonance profile was obtained from the measurements of ablation pressure. The characteristics of the resonance profile with respect to the surface-roughness r was investigated in three roughness-regimes consisting of (1) r<<λ, (2) r=λ, and r>>λ. It was observed that, in the first case, a sharp symmetric profile and, in the second case, a broad symmetric profile was obtained. In the third case the resonance absorption completely disappeared. Moreover, the density scale lengths of the plasma so produced were measured using three techniques derived from (1) the resonance absorption profile, (2) the hydrodynamic formulation without the consideration of profile steepening, and ultimately, (3) from improved hydrodynamic formulation which gave approximate but better results when profile steepening due to pondermotive force of light was incorporated. The results are discussed and presented in a tabular form.

The plasma is formed by focussing the light pulse of a mode-locked Nd-YAG laser onto thick, planar targets of plexiglass ($C_8H_5O_2$), silicon, copper and aluminum inside a vacuum chamber. The laser system incorporates detectors to monitor continuously the incoming and back reflected laser energy as well as spatial and temporal pulse shape. The laser operates in the TEM_{oo} mode delivering an energy of 20mJ, at 1.06µm wavelength and with a pulse duration of 45 psec (full $1/e^2$ width). The focussed spatial intensity distribution at the target surface was determined carefully by successively passing the laser through pinholes with increasing diameter and measuring the energy behind the pinholes [7]. The focal spot diameter obtained that way was 20µm (full $1/e^2$ width). Care had been taken that the plasma was created by a single pulse, and that there was no prepulse. Ablation pressure was measured by means of a piezoelectric crystal affixed at the rear side of the target.

In Fig.1 we have displayed the variation of relative pressure from silicon plasma at a laser intensity of $I_o = 2.5x10^{13}W/cm^2$ and a focal spot size of ϕ=20µm. The top figure is for r=0.03µm i.e. r<<λ, the central figure, for r=1.0µm i.e. r=λ and the lowest figure for r=10µm i.e. r>>λ. In the first case we note that the resonance is well defined and it has a sharp peak at $\theta=30^o$. In the second case the resonance is not sharp. It is nearly flat between $\theta=25^o$ to 40^o. Here the fluctuations of the detector signal were so significant that it was not possible to record a sharp resonance. In the third case the resonance has completely disappeared, that is to say, that if we choose a rough surface such that r=10λ, the resonance due to p-polarized light disappears in the case of laser-interaction with planar targets. It has an advantage. If one chooses to quench the resonance absorption due to p-polarized light and investigate only the inverse bremsstrahlung process, one may very well choose a rough surface with roughness r>>λ. Secondly, we also note that the magnitude of the resonance peak as well as the signal ΔP gradually goes on decreasing and ultimately disappears for r>>λ. The reason for this is that, with increasing r, a larger surface area is at disposal for the absorption process and for every polarization-direction of the laser, in addition to the inverse bremsstrahlung process, the resonance absorption can occur.

From the well known relation $(k_oL)^{1/3}$ Sin θ_m=0.8 one can estimate the value of L, where θ_m is the angle of incidence where the resonance-maximum occurs. This straightaway gives the value of L as L = 0.68µm. Now it is interesting to estimate the value of L from the equation given by Kruer [8]. Balmer and Donaldson [1] considered plasma generated by 35 psec, 1.06µm laser pulses focussed onto perspex targets. Through two foil ratio technique they obtained profiles of electron temperature due to p- as well as s-polarized light as a function of the angle of incidence at a laser intensity of $2x10^{13}W/cm^2$. The maximum temperature corresponding to the resonance peak due to p-polarized light was obtained as 230eV. Since our laser parameters were nearly the same i.e. λ=1.06µm and τ=45 psec and our experiments were conducted at intensities varying from $2.0x10^{13}$ to $6.0x10^{13}W/cm^2$, it is quite reasonable to take the temperature corresponding to resonance peak as 230eV. At an electron temperature of 230eV, Mosher [9] gave the average ionization states for carbon, aluminum and copper approximately as 5.0, 10 and 20. Since silicon is very close to aluminum in the periodic table, we have taken the ionization state of silicon also 10 as that of aluminum for an electron temperature of 230eV. Having obtained the values of Z at a temperature of 230eV, the density scale length L for plexiglass, aluminum, silicon and copper have been calculated as 4.32, 4.07, 3.99 and 3.74μm respectively. Since, in plexiglass, carbon is the predominant atom, we have taken the average ionization state of carbon from Mosher's calculations. However, slight deviation of the correct ionization state from the one inferred will not have any significant bearing on the calculation of the density scale length.

Now it will be better and more useful if we take into account the effect of profile steepening [10]. This process gives the value of density scale length as is 2.19μm. Taking into account the experimental errors involved in several parameters and also the approximate solution of Estabrook and Kruer [10], the density scale length L = 0.68μm determined from the resonance profile is satisfactory as the considerations of hydrodynamic expansion usually give an upper limit to the value of L. However, the result obtained from modified profile steepening [10] from is much better than that from obtained without it [8]. This makes the treatment of profile steepening by Estabrook and Kruer much more interesting and it will be encouraging for the theoretical Physicists to make more endeavours in this direction. To have all the data at a glance a summary of all the estimates of the density scale length are displayed in Table I.

Table I

Targets	Estimated density scale length L	Technique	Comments
All (Plexiglass Al, Si, Cu)	L = 0.68μm	Resonance Absorption profile through measurements of ablation pressure using Denisov function [1]	All targets gave same results
Plexiglass Aluminum Silicon copper	L = 4.32μm L = 4.07μm L = 3.99μm L = 3.74μm	From considerations of hydrodynamics without profile steepening by Kruer [8]	--
All (Plexiglass Al, Si, Cu)	L = 2.19μm	From considerations of hydrodynamics with profile steepening by Estabrook and Kruer [10]	The formulation was approximate and independent of Z

[1] J.E.Balmer and T.P.Donaldson, Phys. Rev. Lett. 39, 1084 (1977).
[2] R.Dinger, K.Rohr, and H.Weber, Laser and Particle Beams 5, 691 (1987).
[3] W.Yu and J.Zhang, Opt. Comm. 134, 91 (1997).
[4] J.S.Pearlman and M.K.Katzen, Phys. Rev. Lett. 39, 140 (1977).
[5] A.G.M.Maaswinkel, K.Eidmann, and R.Sigel, Phys. Rev. Lett. 42, 1625 (1979).
[6] A.G.M.Maaswinkel, Opt. Comm. 33, 62 (1980).
[7] R.Dinger, K.Rohr, and H.Weber, Laser and Particle Beams, 4, 239 (1986).
[8] W.L.Kruer, "The Physics of Laser-Plasma Interaction", Addison-Wisley Publishing

Company, California, (1987).
[9] David Mosher, Phys. Rev. (A) 10, 2330 (1974).
[10] K.Estabrook and W.L.Kruer, Phys. Fluids 26, 1888 (1983).