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MASTER

THE EFFECT OF RE-HEATING
ON THE HOT ELECTROM TEMPERATURE

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3.3.5 The Effect of Re-heating on the Hot Electron Temperature

Theory and simulations of resonant absorption have been described in the past few years of annual reports and in the literature^{1,2,3}.

Briefly, resonant absorption is the direct conversion of the transverse laser light to longitudinal electron plasma waves (epw) at the critical density $[10^{21} (1.06 \mu\text{m}/\lambda_0)^2 \text{ cm}^{-3}]$. The oscillating longitudinal electric field of the epw heats the electrons by accelerating them down the density gradient to a temperature of approximately $21T_e^{0.25} \{ [I(\text{W}/\text{cm}^2)/10^{16}] (\lambda_0/1.06 \mu\text{m})^2 \}^{.4}$. This section extends the previous work by studying the effects of magnetic fields and collisions (albedo) which return the heated electrons for further heating. We find that a magnetic field increases their temperature and collisions do not. Work by Albritton (sec. 3.6.2) also looks at the effects of resonant absorption.

We studied the non-linear processes of resonant absorption with the two dimensional, relativistic, electromagnetic, kinetic simulation code ZOHAR^{1,2,4}. Processes for forming macroscopic magnetic fields were examined in ref. 5 for example. We modeled macroscopic, slowly time varying magnetic fields by assuming the field to be an initial condition uniform in space over the simulation region. The time scale of the simulation is less than a picosecond of real time but is about 90 laser cycles which is adequate if the magnetic field is large enough for the electron gyro radius of the super thermal electrons not to run into the boundary condition and for there to be enough time for several gyro cycles $[2\pi/(eB/m_e c)]$. Consequently we chose a magnetic field of 10MG for laser intensity 10^{16} . The magnetic field is a factor of 3-10 times

larger than that determined by 2-D LASNEX calculations but is necessary to fit the problem into the computer and a reasonable amount of computer time. We checked the scaling by also running smaller magnetic fields.

Figure 1. graphs the heated electron temperature vs time and shows about 20% increase in temperature per electron gyro period. There are complications which make the 20% uncertain by a factor of two: (1) the plasma is diamagnetic and reduces the external magnetic field (Fig. 2) and (2) the ambipolar electric field expands with the hydro motion. The heating nears saturation at late time which is caused by the reduced magnetic field and an effect described by Morales and Lee⁶ in that very fast electrons pass through the short region of the epw too quickly to be affected by the electric field.

Short pulse experiments⁷ showed that T_{hot} from x-ray diagnostics increased with the target $\bar{Z}$.²⁵ John Nuckolls suggested that perhaps the $\bar{Z}$ dependence might be due to collisions in the high density region which returned some of the hot electrons to be heated again. The collision frequency is dominantly ν_{ei} which is proportional to $\bar{Z}$. This "albedo" effect has an extensive literature in secondary emission of electrons from vacuum tube anodes. Typically, a beam of electrons lose about half their number and .3 of their energy in the high collisional medium. We mocked this up in ZOHAR by a boundary condition that analyzed the dynamic electron distribution and returned half the heated electrons with .7 of their energy. The hot density increased but the hot temperature remained about the same since the electrons lost about as much energy in the mock high density region as they gained from the heating. Rosen⁸ analyzed the asymptotic limit of η_{hot} and T_{hot}

given the scattering material's number albedo β and energy albedo K , and assuming the electrons receive α of the original energy per reheating pass through the resonance absorption region:

Equation (1)

Equation (2)

where T_{hot0} and n_{hot0} are the zero albedo hot electron temperature and density. In the ZOHAR simulation just described, $\beta = .5$, $K = .7$, and $\alpha = .3$, which explains why T_h remained the same and N_h increased. Since the number of electrons returned vs energy is not a simple multiplier perhaps a more careful treatment of the albedo model might yield results closer to the experiment.

The $\bar{z}$ effect may be due to the fact that the drift velocity threshold for electron-ion instabilities decreases with increasing z and the resulting transport inhibition increases both the density and temperature gradient which can drive macroscopic magnetic fields. Transport inhibition increases T_{cold} which also increases T_{hot} but not enough to explain the experiments. Valeo and Bernstein⁹ proposed that overdense collisions on the cold electrons provide an increase in T_{cold} at critical since there would not be as much cooling from the cold electrons from the overdense region. Mason¹⁰ suggested that the density dip from a supersonic expanding plasma¹¹ with spherical geometry could inhibit cold electron transport by its electrostatic field.

Long pulse length experiments show much more scatter in T_{hot} vs z and no clear z dependence indicating there may also be a geometric effect.

For example, a low $\bar{Z}$ target will expand more into the laser causing somewhat less irradiance than a high $\bar{Z}$ target. This effect has also been investigated and preliminary results show that the effect is not strong enough.

In conclusion, we have found that T_{hot} clearly increases with macroscopic magnetic fields since the heated electrons are re-cycled by the magnetic field to be re-heated again. The experimentally observed $T_{\text{hot}} \sim \bar{Z}^{.25}$ for short pulse lengths has not been clearly explained by the albedo effect since the hot electrons cool as much by overdense collisions as they heat by resonance absorption. The $\bar{Z}$ dependence may be due to transport inhibition increasing T_{cold} , or by increasing magnetic fields from $\nabla n \times \nabla T$ or from geometric effects.

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Authors

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M. Rosen

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Figure Captions

1. Resonant absorption T_{hot} vs time in laser cycles for the case of a 10 MG magnetic field imposed upon the simulation region as an initial condition.
2. The density profile and modified magnetic field as a function of x/λ_0 .

equation
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$$T_{hot} = T_{hot0} [1 - (1 - \alpha)\beta] / (1 - \beta)$$

(1)

$$n_{hot} = n_{hot0} / (1 - \beta)$$

(2)

2D KINETIC SIMULATIONS SHOW MACROSCOPIC MAGNETIC FIELD INCREASES T_{HOT}

50-60-1073-4286

3.3.5

P161

10
 8
 6
 4
 2
 0

LOCAL PLASMA DENSITY
 (10²⁰ m⁻³) vs. TIME (ms)

10/22/73
 09:00:00
 09:00:00
 09:00:00

$$\frac{\omega_c}{\omega_0}$$

AN INITIALLY UNIFORM MAGNETIC FIELD BECAME DEFORMED IN THE CRITICAL
 REGION BY PLASMA DIAMAGNETISM AND RESONANT ABSORPTION MAGNETIC FIELDS.

3-3.5 Fig 2