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Measuring Opacity of Shock Generated Argon Plasmas

David Erskine, Balazs Rozsnyai and Marvin Ross

Lawrence Livermore National Laboratory
Livermore, CA 94550

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MEASURING OPACITY OF SHOCK GENERATED ARGON PLASMAS

DAVID ERSKINE, BALAZS ROZSNYAI, and MARVIN ROSS

Lawrence Livermore National Laboratory, Livermore, CA 94550

Plasmas are generated by passage of a strong planar shock wave through gas. Initial experiments in argon have produced plasmas with 2 eV temperature, 0.004 - 0.04 gm/cm^3 density, and coupling parameter Γ~0.3-0.7. Plasmas having Γ>1 are attainable with greater initial gas pressure. The opacity of the plasma is measured versus wavelength by recording the risetime of emitted light. Initial measurements are in visible light. Preliminary results are compared with calculations using the HOPE code.

1. INTRODUCTION

Opacities, both theoretically calculated and experimentally measured are an important area of study in plasma physics. Unfortunately, there is a dearth of measured opacities in the optical wavelengths. Recently Schmidt et al.[1] measured the opacity of Al plasma generated by laser heating. Earlier, Fortov et al.[2] developed a technique for measuring opacities of plasmas generated by shock compression. This latter technique has advantages of a well-defined plasma density and temperature, accurate measure of the opacity in optical wavelengths, and applicability to a variety of plasma species, densities and temperatures. In this report we are extending Fortov's technique in several ways. In place of explosive drivers, impactors accelerated by a two stage gas gun are used to generate shocks having accurately known intensities, yielding accurately controlled plasma states. The opacities are simultaneously measured at multiple wavelengths, and modern high speed recording electronics are used. Further extensions in the technique in terms of wavelength range, and wavelength and time resolutions are planned. In this preliminary work, we measure opacities in the visible wavelengths of argon plasmas having two different densities. The plasma density was controlled by the initial gas pressure. The plasma temperature was ~2 eV, density ρ=0.004 and 0.04 g/cm^3 and the coupling parameter was Γ=0.3 and 0.7 respectively.

2. METHOD

The opacity is measured in a plasma generated by shock compression of a gas contained in the target shown in Fig. 1. A cylindrical chamber of aluminum encloses the gas having an initial pressure 0 - 10 bar. A two stage gas gun accelerates a tantalum disk projectile to speeds up to 8 km/s. Impact of the disk on the aluminum baseplate generates a planar shockwave which enters the argon chamber, heating the gas to an incandescent plasma. The plasma volume has the shape of a slab with a thickness increasing linearly with time at the shock speed (U_s) minus the velocity of the baseplate (U_p). The incandescence (I) emitted grows from zero to an asymptotic value (I_0) with a risetime determined by the plasma opacity $\sigma(\lambda)$ at the wavelength λ observed. In the ideal case, where baseplate reflectivity is neglected, this is expressed as

$$I(\lambda) = I_0(\lambda)[1 - e^{-\sigma(\lambda)\rho[U_S - U_P]\Delta t}] \quad (1)$$

where ρ is the plasma mass density and Δt is the time after the shock enters the argon.

Light from the plasma enters a bundle of optical fibers leading to six photomultiplier tubes. A bandpass filter from 340 nm to 700 nm in front of each tube selects the wavelengths observed. The photomultiplier outputs are recorded by digitizing oscilloscopes with 1 ns sampling rate. Figure 2 is an example of the output of one of the photomultipliers. The entrance of the shock in the chamber is marked by the appearance of light. The arrival of the shock at the fiber window is marked by the discontinuity in the signal at ~460 ns. Since the width of the chamber is precisely known the shock speed can be computed accurately. In turn, the density (ρ) and pressure (P) of the shocked state are determined from the shock speed, the impactor velocity and density through elementary shock relations[3] conserving momentum and energy across the shock front.

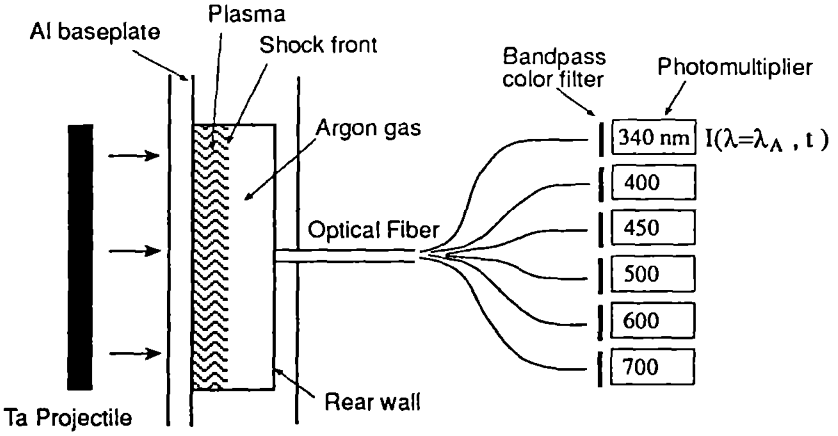

FIGURE 1
Experimental Arrangement. Ta impactor disk generates shock which propagates through Al baseplate and into argon gas. Light emitted from plasma travels through optical fiber bundle to be recorded by photomultiplier with ns resolution. Bandpass filters provide wavelength selectivity. Projectile diameter is ~24 mm.

The advantage of a shock-generated plasma is that density, pressure and temperature are very uniform throughout the shocked volume of several cubic centimeters, and these parameters can be accurately determined. The thickness of the shock front is negligible and the relaxation mechanisms through the shocked volume are much faster than observation rate, so that local thermal equilibrium can be assumed.

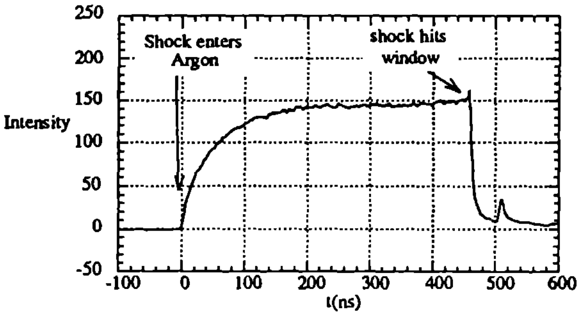

FIGURE 2
Incandescence at 400 nm from shocked argon plasma showing exponential-like rise to an asymptotic level.

The effect of the reflective surfaces of the chamber is to increase the apparent plasma thickness for early times when the plasma slab is thin, so that a slightly non-exponential intensity growth is produced. If R_1 and R_2 are the reflectivities of the baseplate and rear wall then

$$I(\lambda) = I_0(\lambda)\,[1-A]\,\frac{[1+R_1 A]}{[1-R_1 R_2 A^2]} \tag{2}$$

where

$$A = e^{-\sigma(\lambda)\rho[U_S - U_P]\Delta t}. \tag{3}$$

For our target R_2=0.7. The reflectivity of the baseplate under shock is lower than its ambient value and preliminary fits of the data suggest R_1 ~0.3. Experiments to measure R_1 explicitly are planned.

3. RESULTS

The opacities of two shots having 0.3 bar and 3 bar *initial* argon pressures are shown in Fig. 3 compared to calculated results using the HOPE code. The peak at ~3 eV is due to a 4s-5p bound-free transition. The "forest" of peaks above 10 eV are due to bound-bound transitions. The overall decrease of σ with photon energy from 1 to 7 eV is due to free-free transitions (bremsstrahlung). The vertical separation between experiment and theory could be accounted for by the current uncertainty in the baseplate reflectivity.

For a ~2 eV plasma temperature the peak of the blackbody emission is ~100 nm, beyond the range currently covered by our photomultipliers (340 nm to 700 nm). Because blackbody temperature is difficult to determine accurately from the long wavelength wing of the Plankian distribution, the plasma temperatures were inferred instead from the measured argon shocked state (ρ, P) using the calculated equation of state of argon.

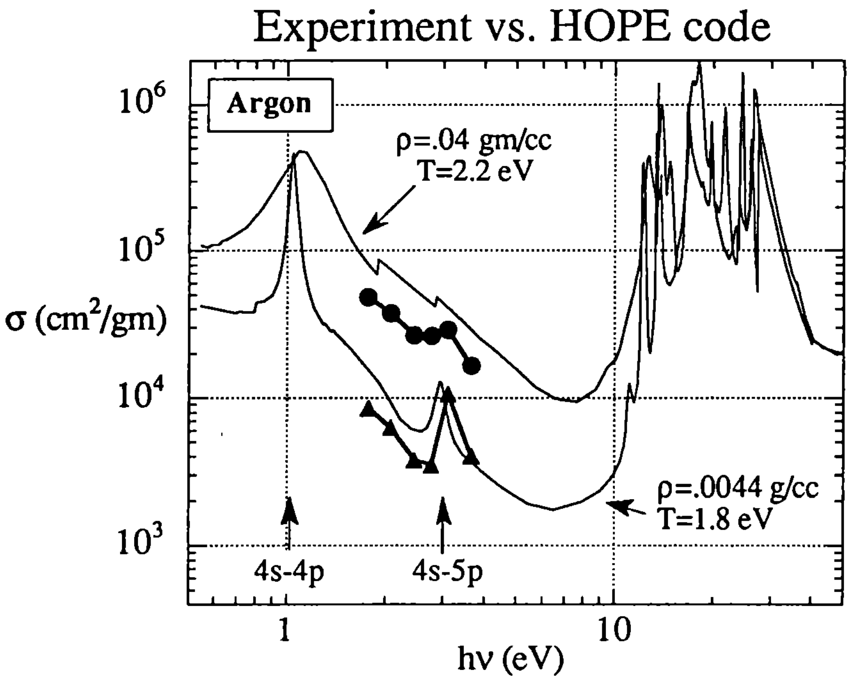

FIGURE 3
Measured opacities versus photon energy for two plasma densities compared to that calculated with HOPE code. Triangles - ρ = 0.0044 g/cm^3, circles - ρ = 0.04 g/cm^3.

4. SUMMARY

We have made preliminary measurements of the opacity in the optical wavelengths of a shock-generated argon plasma. The plasma density was ρ=0.004 - 0.04 g/cc, T ~2 eV and Γ~0.3 - 0.7. The opacity data consistently shows a peak at 3 eV on top of a sloping (due to bremsstrahlung) background. We believe the peak corresponds to a 4s-5p transition. Work is currently underway to extend these measurements to the VUV and IR and to obtain an independent measurement of the temperatures.

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