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TEMPERATURE MEASUREMENTS OF ET PLASMAS USING ATOMIC EMISSION SPECTROSCOPY

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13. ABSTRACT *(Maximum 200 words)*

We report here the results of preliminary work in determining the temperature of electrothermal gun plasmas using atomic emission spectroscopy. Work to date on laboratory scale plasmas indicate temperatures around 15,000 K (1.32 eV).

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I. INTRODUCTION

The electrothermal accelerator (ET gun) is an advanced propulsion technique in which an electrically generated high temperature, high pressure plasma interacts with a "working fluid" to produce the gases necessary to accelerate a projectile. In the development of ET technology, the characterization of the temperature and pressures generated by this plasma is critical for modeling of the ET process and ultimately, complete understanding of a fielded weapon system. We report here the results of an experimental effort aimed at determining the temperature of ET plasmas using atomic emission spectroscopy. The ultimate goal of this work is to develop a technique at the benchtop level that will be directly transferable to measuring the temperature in a large scale ET gun.

The preliminary approach we have taken is to seed the plasma with barium perchlorate ($BaClO_4$) and look at the emission from the barium atoms in the plasma. The excitation energies, degeneracies, and oscillator strengths of the different barium transitions necessary to determine the temperature of the plasma are readily available in the open literature. Before discussing the experimental details and results, a brief description of the theory involved is presented.

II. THEORY

The Boltzmann equation (Eq. 1) relates the number of atoms populating a given energy level to the total population as a function of temperature

$$\frac{N}{N_T} = \frac{g e^{-E/kT}}{u} \tag{1}$$

where N is the number of atoms with energy E, g is the number of states at this energy (degeneracy), k is Boltzmann's constant and T is the absolute temperature (K). Using Eq. 1, the intensity I, of a spectral line can be written

$$I = \frac{g e^{-E/kT}}{\mu} h\nu N_T A \tag{2}$$

assuming the emitter follows a Boltzmann energy distribution. In Eq. 2, u is the partition function for the particular atom, h is Planck's constant, ν is the frequency of the line, and A is the Einstein transition probability for emission.

For a given spectrum, a plot of $\ln (I\lambda/gA)$ versus E, where $\lambda = 1/\nu$, yields a straight line whose slope is equal to -1/kT, again assuming a Boltzmann distribution in the populations. This treatment implies that the emitting material is in local thermodynamic

equilibrium with the surrounding plasma, and the temperature is constant throughout the observed region.

III. EXPERIMENTAL

The experimental layout for measuring the temperature of the plasma is shown in Figure 1. The light emitted from the plasma is collected by a fiber optic bundle. One end of the bundle is inserted into the plasma and the other end is placed at the entrance slit of a 1 m spectrometer. The bundle consists of 37 fibers of uv-grade fused silica, each 240 micrometers in diameter. The fiber optic bundle was used so that the interior portion of the plasma would be probed. If lenses had been used to image the plasma emission on to the entrance slit of the spectrometer, detected emission may come only from the outer edge of the plasma due to its high optical density. The light is dispersed by a 300 gr/mm grating and detected by a Princeton Applied Research, Inc. (PAR) model 1420 intensified photodiode array (OMA). The OMA has 700 intensified elements, which provides a spectral coverage of approximately 560Å with a resolution of 2Å. The OMA is interfaced to a 20 MHz 80386 microcomputer through a PAR model 1461 detector controller. The acquired data is stored on the microcomputer for future data analysis and plotting.

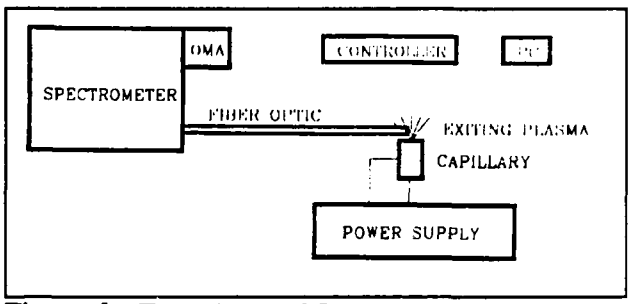

Figure 1. Experimental Layout

The capillary assembly is shown in Figure 2. The capillary consists of a polyethylene rectangular bar, 75 mm long x 10 mm square, that has a 4 mm diameter hole bored axially through the bar. A 0.1143 mm diameter aluminum wire is threaded through the polyethylene. At one end of the polyethylene, a stainless steel electrode (cathode) is inserted, with contact made between the aluminum wire and the electrode. At the other end of the polyethylene, a few crystals of barium perchlorate ($BaClO_4$) are inserted. These crystals serve as the barium source for measuring the temperature spectroscopically. The free end of the aluminum wire is then fed through a 4 mm hole in a graphite block and bent over the top of the graphite, as shown in Figure 2. The graphite block serves as the negative electrode (anode). A G-11 housing is installed around the polyethylene assembly. The entire capillary is then inserted into a steel housing, which is bolted together. This insures that electrical contact is made between the graphite electrode, the aluminum wire, the lead contact in the G-11, and the steel housing. The lines from the power supply are connected to the rear electrode and the steel housing, thus forming a complete circuit. The 675 J power supply

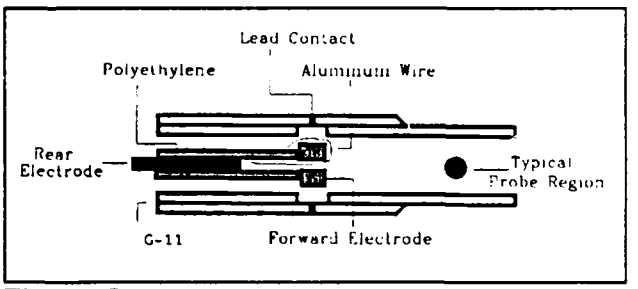

Figure 2. Capillary Assembly

contains a 3 stage pulse forming network (PFN) for tailoring the shape of the current pulse delivered to the capil' ıry. In all of the experiments performed to date, the power supply was charged to 2000 volts. Approximately 2000 amperes of peak current is delivered to the capillary in a pulse of 300 microseconds duration. Figure 2 shows the region of the plasma typically probed, which is axially located approximately 90 mm from the end of the polyethylene tube.

IV. RESULTS

Figure 3 show a typical spectrum of the plasma emission. In this spectrum, the spectrometer was centered at 4709Å. The four transitions labeled are emission lines from the barium ion (BaII). Table 1 lists the spectroscopic quantities[1] of the observed transitions needed to calculate the temperature. The intensities are the measured peak heights from the baselines shown in Figure 3.

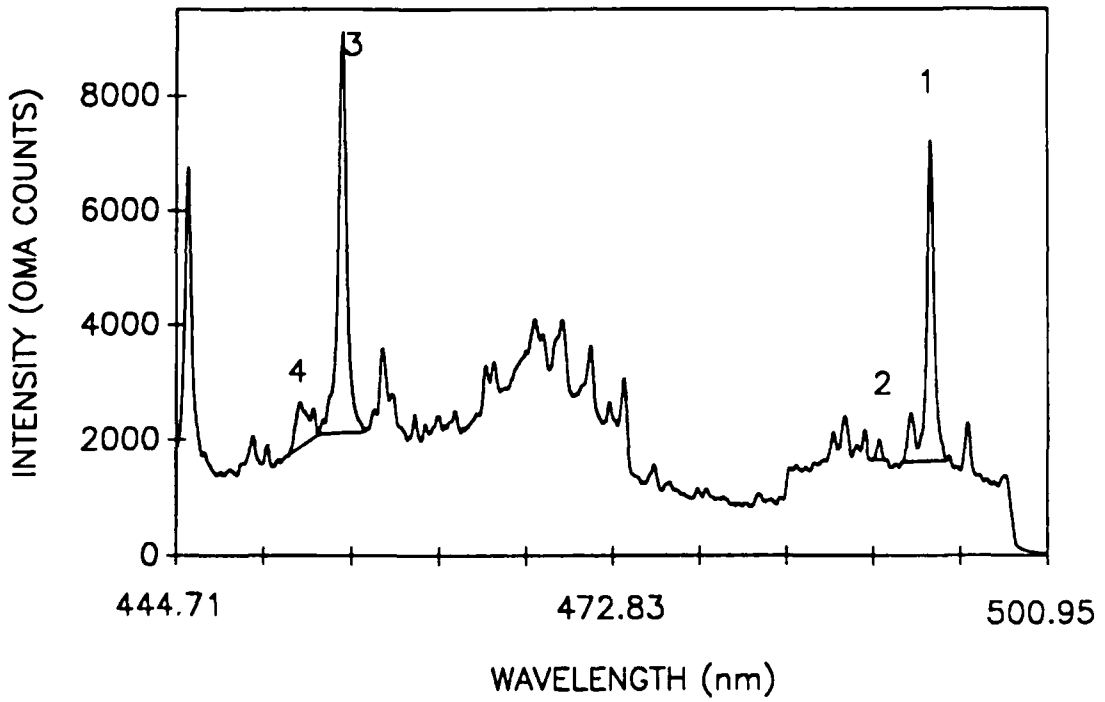

Figure 3. Typical Spectrum of Plasma Emission. Labeled transitions are barium ion (BaII) emission lines.

For this spectrum, ℓn (Iλ/gA) is calculated for each transition and plotted versus the upper state energy of each transition. This plot is shown in Figure 4. The straight line shown is a least squares fit to the data points. The calculated temperature from this data is 15,318 K (kT=1.32 eV). Theoretical calculations of the plasma temperature using a one-dimensional steady state plasma discharge model[2] indicate temperatures within the polyethylene tube to be approximately 15,000 K.

Table 1. Spectroscopic Parameters of Observed Transitions					
Peak	Wavelength (Å) (air)	Intensity (mm)	Energy (eV)	g	A ($10^8 s^{-1}$)
1	4934.09	81.5	2.51	2	0.955
2	4899.96	5.5	5.25	2	1.2
3	4554.03	99.0	2.72	4	1.19
4	4524.93	11.0	5.25	2	0.72

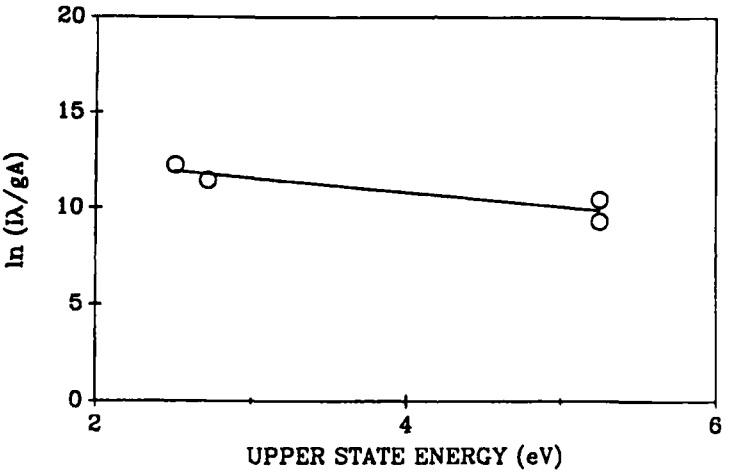

Figure 4. Plot of ln (Iλ/gA) vs. Upper State Energy. The solid line is a linear least squares fit through the data points.

V. DISCUSSION

There are several sources of error that need to be addressed when making this type of measurements. The first of these is the problem of self-absorption. Self-absorption occurs when an atom emits light that is subsequently absorbed by another atom of the same element. This phenomenon can be readily seen in Figure 5, where a "valley" is seen in the middle of the peaks marked with an asterisk. In our work, self-absorption was most obvious in the first shot after seeding the plasma with the barium salt. Therefore, several shots were fired, without reseeding the plasma, in an attempt to lower the barium

concentration in the capillary. This seemed to be effective in minimizing the self-absorption problem, as evidenced by the lack of a "valley" in the peaks in Figure 3. While the lack of a "valley" doesn't suggest definitively that self-absorption is not occurring, it does prove that the self-absorption problem has been reduced.

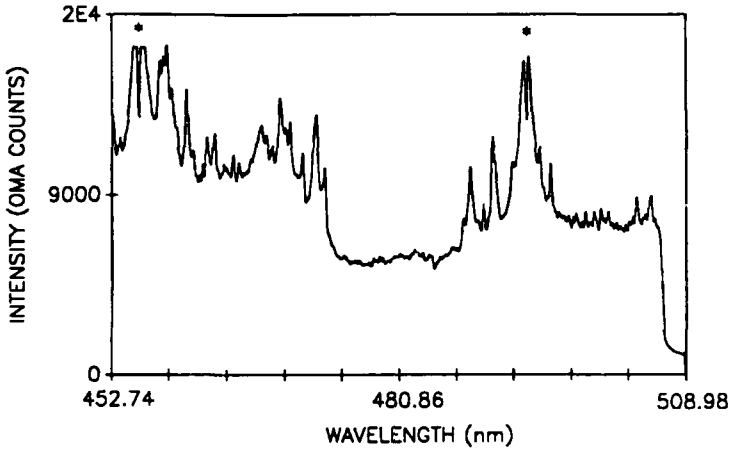

Figure 5. Example of Self-Absorption Occurring in Observed Spectrum. The asterisks indicate self-absorbed transitions.

The second problem concerns the low number of barium transitions we are able to see at one time due to the number of intensified elements in our detector and the resolution of our spectrometer. Ideally, one would like hundreds of transitions to be seen in one spectrum, so that the fitted temperature would be better determined. In addition, errors in the spectroscopic constants, particularly the A values, would be averaged out. Variations among different references[3] can amount to factors of 2, 3, and in a few cases, even 10. Since we can only see 4 lines in one spectrum, any errors in the A values reported will translate into an erroneous temperature calculation.

The final potential source of error involves assigning a baseline for determining the intensity of the observed transition. As can be seen in Figure 3, a large continuum is observed below the transitions. Assigning the correct baseline, therefore, is quite difficult. Any errors in our assignment will effect the calculated temperature.

VI. FUTURE STUDIES

As discussed earlier, the ideal situation is to calculate the temperature from many transitions occurring from the same material. We plan to temporarily remove the OMA system and insert a film holder in its place to record the spectrum on photographic film. This arrangement should provide a spectral coverage on the order of 2500Å with the 300 gr/mm grating. By increasing the spectral coverage by approximately five times over what is currently available, we should be able to observe many more transitions, thus allowing us to compare our results with the OMA system with the temperature calculated from a larger data set.

Another area to be investigated involves gating the OMA detector after the aluminum wire has exploded. This would allow measurement of the plasma temperature during a specified time interval, rather than the time integrated approach currently pursued. Once the gating of the OMA has been mastered, we also plan to do absorption studies using a pulsed flashlamp as a radiation source.

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