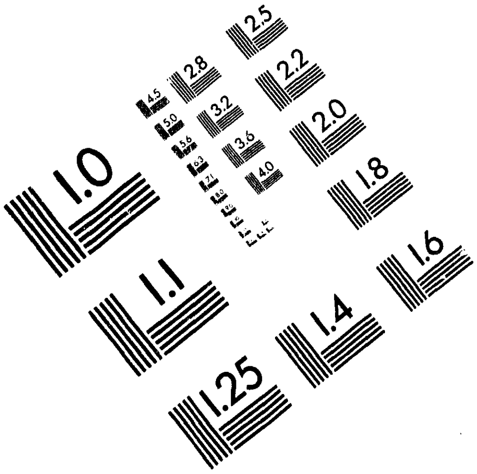
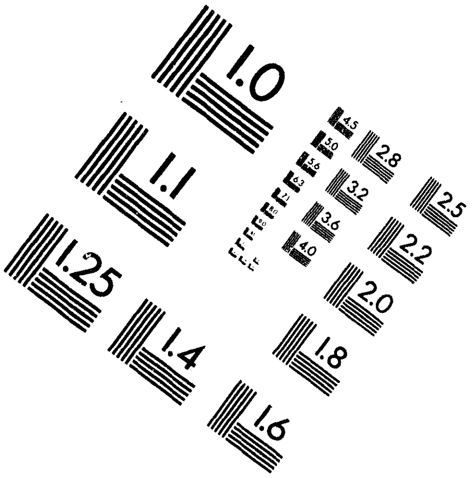


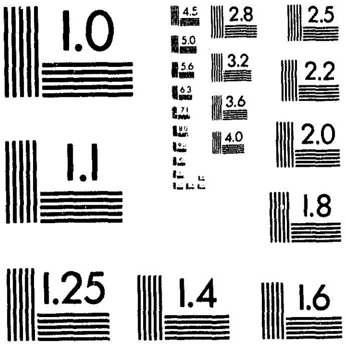
AIIM

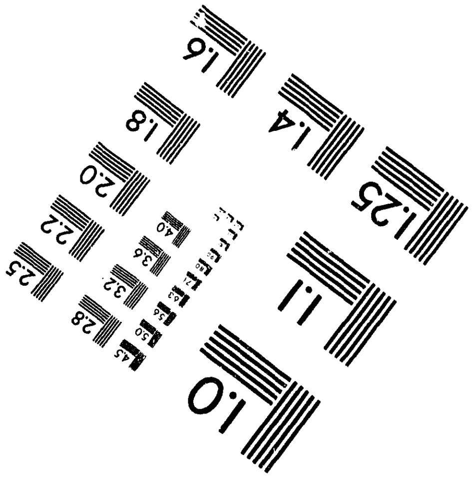
Association for Information and Image Management

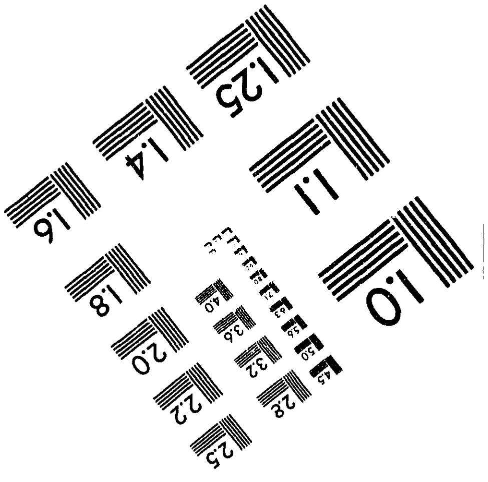
1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

301/587-8202









MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

C 3 - 3803 C

CONF-940634--16

VUV SPECTROSCOPIC OBSERVATIONS ON THE SABRE APPLIED-B ION DIODE

A. B. Filuk, T. J. Nash, D. D. Noack

Sandia National Laboratories, P.O. Box 5800, Albuquerque NM, 87185-1187

Abstract

We are using VUV spectroscopy to study the ion source region on the SABRE applied-B extraction ion diode. The VUV diagnostic views the anode-cathode gap perpendicular to the ion acceleration direction, and images a region 0-1 mm from the anode onto the entrance slit of a 1 m normal-incidence spectrometer. Time resolution is obtained by gating multiple striplines of a CuI- or MgF_2-coated micro-channel plate intensifier. We report on results with a passive proton/carbon ion source. Lines of carbon and oxygen are observed over 900-1600 Å. The optical depths of most of the lines are less than or of order 1. Unfolding the Doppler broadening of the ion lines in the source plasma, we calculate the contribution of the source to the accelerated C IV ion micro-divergence as 4 *mrad at peak power. Collisional-radiative modeling of oxygen line intensities provides the source plasma average electron density of $7x10^{16}$ cm^{-3} and temperature of 10 eV. Measurements are planned with a lithium ion source and with VUV absorption spectroscopy.*

BACKGROUND

High-power applied-B ion diodes are being studied at Sandia as drivers for light-ion ICF [1]. Spectroscopy has been used successfully on ion diodes as a non-perturbing probe of conditions in the ion source anode plasma and in the anode-cathode (AK) gap [2] [3]. The readily-accessible visible part of the spectrum can yield a wealth of information from spectral line shapes [3], but unfolding competing line broadening effects can be difficult, and for some ions such as Li^+ the strongest lines are in the vacuum-ultraviolet (VUV). Optics, detectors, and calibration sources make the VUV a challenging part of the spectrum to work in. We are doing what are to our knowledge the first detailed spectroscopic measurements of diode physics in the VUV. The goals of this work are to obtain the ion beam divergence at the source (loosely referred to as the source 'temperature') from Doppler broadening of ion emission lines, and to study mechanisms for beam divergence growth in both the anode plasma and in the acceleration and drift regions. This work reports on observations of a flashover ion source anode plasma.

VUV DIAGNOSTIC ON SABRE

VUV observations are made on the extraction ion diode on SABRE [4]. The device generates an ion beam of about 5 MV peak voltage, 100 kA peak ion current, and 25 ns full-width-half-maximum (FWHM) duration. A passive wax flashover ion source generates an anode plasma from which proton/carbon mixed ion beams are produced.

The VUV diagnostic on SABRE has been described in earlier work [5]. Figure 1 shows schematically the components and the line-of-sight relative to the SABRE AK gap. The vacuum line-of-sight elliptical mirror focuses light from the AK gap into a 1 m normal-incidence spectrograph. The 7 striplines of the CuI-coated micro-channel plate (MCP) in the exit plane are gated with 3 ns time resolution at intervals of 8 ns, to provide the spectrum at 7 time frames. The MCP frame signals are converted to visible photons via a phosphor, and a fiber-optic faceplate couples the light to film.

The ~1 mm wide line-of-sight at the anode is inclined about 1° toward the anode face to view emission from even a very thin anode plasma and to reduce possible optical depth effects. Alignment is done by reverse-propagating a visible laser

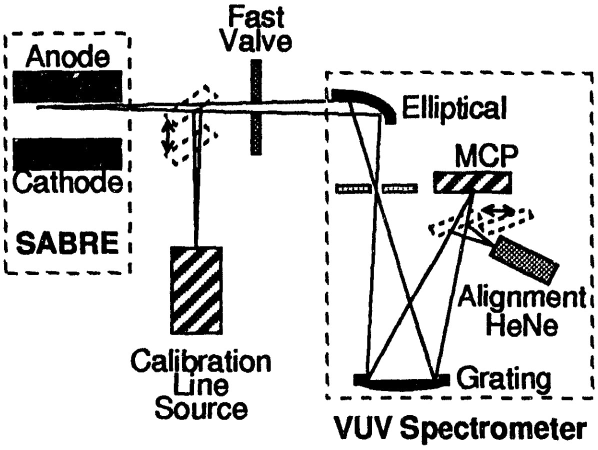


Fig. 1. Schematic of VUV diagnostic relative to the SABRE AK gap.

through the VUV system to the anode face. The observations reported here viewed the 900-1600 Å portion of the spectrum with a 2400 l/mm grating. An Ar calibration source is used to characterize the instrument function. The films are digitized and analyzed on a computer.

GENERAL OBSERVATIONS

VUV spectral lines of predominantly C and O ions are first observed during the rise in the main ion beam current, after the peak brems-induced noise signal and about 15-20 ns after the start of measurable ion current in the precursor pulse [6]. The appearance of C and O lines in the anode plasma appears to be correlated with the onset of a significant fraction of higher-charge, non-protonic ions in the beam as seen by filtered Faraday cups. On every shot the C and O lines were seen at or before this rise in higher-charge non-protonic ions in the beam at the anode. The Ly_α line of H was occasionally seen at the detection threshold, later in the pulse when all line intensities were greatest.

As shown in Figure 2, the line emission is mainly from C and O ions. Lines of C II-IV and O III-VI were seen. The C lines are generally more intense and wider than the O lines, which are dominated by the instrument width. The lower-charge-state ion lines were much brighter earlier than later relative to lines of the higher charge states, reflecting the non-equilibrium level populations.

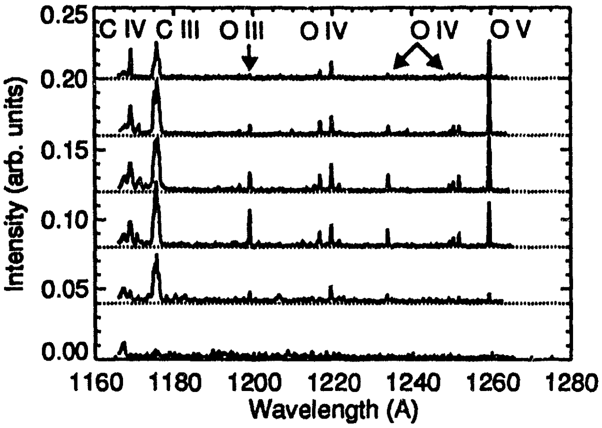


Fig. 2. Lineouts of spectra at 8 ns intervals. Spectra are offset for clarity.

Estimates for the absolute sensitivity of the VUV instrument require that the emission seen originates in a dense (~10^{15}-10^{18} cm^{-3}) plasma rather than in the low-density (~10^{12} cm^{-3}) AK gap region. Indeed, no emission was detected when the line-of-sight was more than 2 mm off of the anode face. Spectral lines of C III and O IV,V were observed when viewing near the cathode tip. Comparable intensities were seen including and excluding the tip from the field of view, so the lines are unlikely to be an artifact of anode plasma light scattering off the tip into our instrument. Our conclusion is that a cathode plasma extends a few mm into the AK gap from the cathode tip.

WIDTHS & DOPPLER TEMPERATURES

One of our main objectives is to measure the Doppler broadening of ions to obtain the beam divergence at the ion source. The lower-energy, well-populated levels of VUV transitions are less susceptible to Stark broadening and Zeeman splitting than those in the visible. For anticipated anode plasma magnetic fields less than 2 T on SABRE, the Zeeman splitting would increase the linewidths by less than 0.1%. The Stark broadening of the lines is also small because of the low-lying upper levels; for example C IV 1548,1551 Å has a Stark-broadening FWHM of 0.006 Å at an electron density $n_e = 1 \times 10^{17}$ cm^{-3} and temperature $T_e = 5$ eV [7].

In our case the two effects that compete with Doppler broadening are the instrument width and opacity broadening. The instrument function is well-characterized as a Gaussian of 0.29(1) Å FWHM. The O lines have measured widths of about 0.3-0.4 Å, making them instrument-width dominated even when viewed in second-order to reduce the $\Delta\lambda/\lambda$. When opacity effects were not dominating, the instrument width was subtracted in quadrature from the measured width to obtain an upper bound for the Doppler broadening. The "Doppler temperature" T_D (in energy units) is defined from the unfolded Doppler FWHM $\Delta\lambda$ and ion mass M as

$$T_D = \frac{Mc^2}{4\alpha}\left(\frac{\Delta\lambda}{\lambda}\right)^2$$

where $\alpha = 2\ln 2$.

Opacity broadening of lines is of particular concern in the VUV because the most intense lines are resonance or near-resonance lines [8]. Viewing pairs of lines from nearly-degenerate J=3/2 and J=1/2 upper levels, such as C IV 2s-2p 1548, 1551 Å or O VI 2s-2p 1032, 1038 Å, provides a check on opacity effects. In an optically thin plasma where these two upper levels are in LTE, the line intensities should be in the ratio of the level multiplicities, 2:1. As the optical depth approaches 1 this ratio is reduced and the more intense line becomes wider. Figure 3 shows lineouts of the C IV line pair at 8 ns intervals for a single shot. The earliest lineout (t_3) shows the 1548 Å profile is strongly broadened and even partially self-reversed near line-center. Later in time, however, the line intensities and widths are consistent with small optical depth. On some shots it appears that the C IV line pair optical depth remained significant throughout the pulse. A similar phenomenon was seen for the O VI line pair.

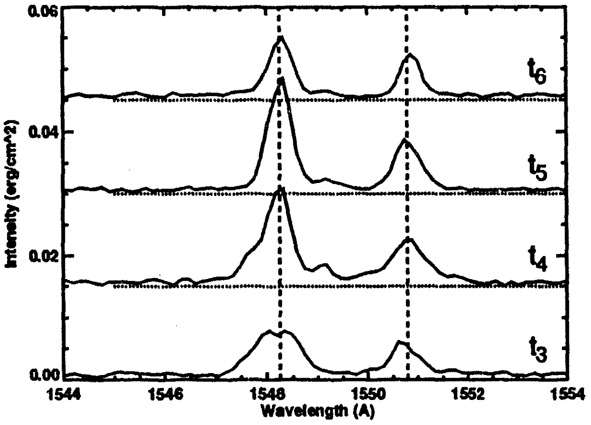


Fig. 3. Lineouts of the C IV 1548,1551 Å pair showing opacity effects early in time. Lineouts have been offset for clarity.

In general then, unless one has a clear indication of small optical depth as at the later times of Figure 3, the instrument-unfolded line widths cannot be assumed free of opacity broadening. On the other hand, it was observed that line widths where opacity effects were clearly present but not dominant were comparable to or slightly larger than widths where opacity effects were small. Further, non-resonance lines such as O IV 625.9 Å had widths comparable to those of the O IV resonance lines. Our conclusion is that in general the optical depths in our lines are less than or of order 1, and can modestly increase the line widths.

Figure 4 shows the unfolded C IV T_D for the times in Figure 3, along with an arbitrarily-scaled Faraday cup current for timing reference.

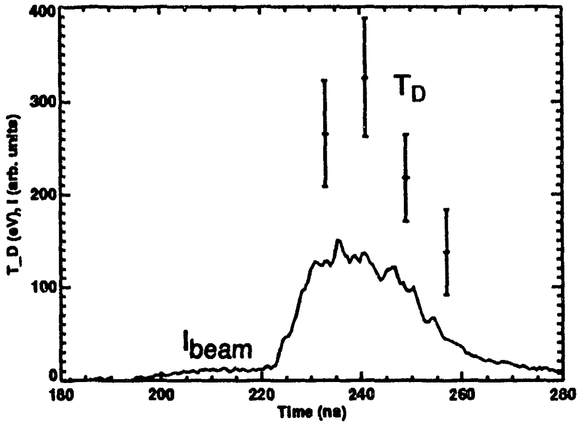


Fig. 4. Unfolded Doppler temperatures at times of Figure 3, along with relative ion beam current from Faraday cups.

Note that the T_D value for the earliest time, obtained from the width of the longer-wavelength peak at t_3 in Figure 3, is only an upper bound due to possible opacity broadening. Ions with large transverse temperatures have been seen using flashover ion sources on other applied-B diodes [9], but the mechanisms responsible are not yet well understood. With the diode voltage of 4 MV at peak power (230 ns in Figure 4), the T_D of

270 eV gives a divergence of 4 mrad for these ions.

Unfolding the C III 977 Å line widths on a different shot gave T_D values of 350-500 eV, but the significance of opacity broadening for this resonance line could not be determined so this range is an upper limit. The C II 1010 Å line seen was an unresolved triplet so the width could not be extracted.

INTENSITIES & CR MODELING

The O III-V lines provide line intensity ratios suitable for extracting plasma properties. A collisional-radiative (CR) code is used because the electron density is too low for LTE and too high for coronal treatments. Flashover plasmas have been characterized on other ion diodes with CR modeling [10]. The model uses fixed given values of n_e and T_e, and a source of O I whose supply rate increases linearly with time to account for continuous injection of anode material [10]. Since only relative level populations are used, the CR results are independent of the source rate and only depend on time and the average n_e and T_e. The calculation assumes a simple uniform region of optically-thin emission. The intensities of the lines will not be significantly different for optical depths of 1 or less [10].

The second-order lines of O III 600 Å, O III 610 Å, O IV 617 Å, and O V 630 Å were used to calculate three intensity ratios of O III/IV and O IV/V. These lines were chosen because of their charge states, strengths, and nearby wavelengths such that the instrument response could be assumed constant and all intensities acquired on a single shot. The frame-to-frame response does not enter into the line ratios, but with an earlier MgF_2-coated MCP it was observed to be approximately constant. Figure 5 shows the intensities of these lines from Figure 2, along with the beam current history.

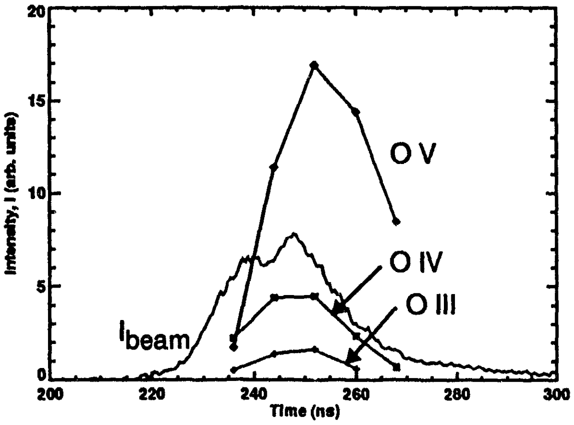


Fig. 5. Relative intensities of O III-V lines and relative ion beam current from Faraday cups.

The O line ratios fit a CR-modeled average n_e and T_e of 7×10^{16} cm^{-3} and 10 eV for most of the pulse duration. The fit was sensitive to 50% changes in n_e and 30% changes in T_e. The calculated and observed ratios are only weakly dependent on time after an initial phase. An unresolved issue is whether the O emission comes from the same plasma region as the C emission.

FUTURE WORK

Our plans are to use this diagnostic to determine lithium beam divergence at the source on upcoming lithium ion source experiments. With increased signal-to-noise we also plan to do absorption experiments using a continuum VUV light source, viewing absorption from the AK gap and the extraction region to study mechanisms for divergence growth.

The authors acknowledge helpful comments from J. Bailey and M. Cuneo. Thanks to Y. Maron for discussions and CR calculations, and to the SABRE experimental team. Funding for this work has been provided by the U. S. Department of Energy under Contract DE-AC04-94-AL85000.

[1] J.P. VanDevender and D.L. Cook, *Science* 232, 831 (1986)

[2] R. Pal and D. Hammer, *Phys. Rev. Lett.* 50, 732 (1983). Y. Maron et al, *Phys. Rev. Lett.* 57, 699 (1986), and *J. Appl. Phys.* 61, 4781 (1987).

[3] J.E. Bailey et al, submitted to *Phys. Rev. Lett.*

[4] M.E. Cuneo et al, "Observations of Reflected Waves...", 9th IEEE Pulsed Power Conference, 1993.

[5] T. Nash et al, *Rev. Sci. Instr.* 64, 2493 (1993).

[6] M.E. Cuneo et al, "Control of a Large Vacuum Wave Precursor...", these proceedings.

[7] M.S. Dimitrijevic and N. Konjevic, *J. Quant. Spect. Rad. Transfer* 24, 451 (1980).

[8] H.R. Griem, *Plasma Spectroscopy* (Academic, 1964), Ch 7.

[9] Y. Maron et al, *Phys. Rev. A* 39 5842 (1989).

[10] Y. Maron et al, *Phys. Rev. A* 40, 3240 (1989), and 41, 1074 (1990).

DISCLAIMER

DATE
FILMED

10/12/94

END