OPACITY BROADENING AS A DENSITY DIAGNOSTIC FOR SPOT SPECTROSCOPY

J. P. Apruzese
Naval Research Laboratory, Plasma Physics Division
Plasma Radiation Branch, Washington, D. C. 20375

Recently, a novel technique known as spot spectroscopy has been developed[1-4] for use in diagnosis of laser-produced plasmas. This method involves the implantation of tracer microdots (circular or rectangular) of material in laser targets whose composition and size (typically about 100 μm) are known. Aluminum has been a popular choice since its K-shell lines are readily produced; however, any element appropriate to the experiment may be chosen. A major advantage of this technique is that the plasma produced from each microdot is generally homogeneous in the direction parallel to the plane of the original target. Since the dots can be distinguished spectroscopically, the diagnosis of each spot is not subject to the ambiguities created by the presence of gradients. Gradients do exist in each blowoff tracer perpendicular to the target plane; however, it is possible to resolve spatially the cylindrical blowoff created by each dot with appropriate orientation of the spectrograph slit.[2]

It is our purpose to demonstrate and quantify an additional important benefit of this technique. The radius of the spot blowoff has been found to be equal to that of the original target implant, with little lateral spreading. Therefore, if the line center optical depth τ_o of a particular spectral line can be determined from the line profile, the density N of the ionic species emitting the line is unambiguously determined from $N = \tau_o/\sigma_o r$, where σ_o and r are the line center cross section and spot radius, respectively. The total ion density N_I is obtainable from calculations of the fractional abundance of the active species based on line ratios or other temperature diagnostics. Therefore, spectroscopic resolution of line profiles may serve as an important density diagnostic in conjunction with the spot spectroscopy technique.

A multistage, multistate model of ionized aluminum, analogous to the Ar model of Ref. 5, has been used to calculate the full-width-half-maximum (FWHM) of the helium-like resonance line $1s^2$-$1s2p\,^1P$ as a function of spot size, temperature, and density. As is described in Ref. 5 the line profiles are calculated with detailed multifrequency solutions of the radiative transfer equation, which are self-consistent with the steady-state atomic rate equations. The particular line chosen is most suitable for opacity-based density diagnosis for several reasons. First, it is the strongest and therefore most easily measured K-shell line. Second, it has the largest opacity of any line for a wide range of temperatures where K-shell ionization stages dominate. Third, the complicating effects of fine structure[5], which exist for the Lyman series, are absent. Finally, the Stark width of this line is negligible for the low-to-moderate densities considered here. Detailed Stark profile calculations[6] show that the Stark width of $1s^2$-$1s2p\,^1P$ is at most 10% of the Doppler width for the temperatures and densities considered here, for $10 \leq Z \leq 18$. Therefore, our assumed Voigt profile describes the line opacity accurately. Of course, the higher lines of the helium-like resonance series have much larger Stark widths, which may themselves be employed[3,4] for corroborative density diagnosis.

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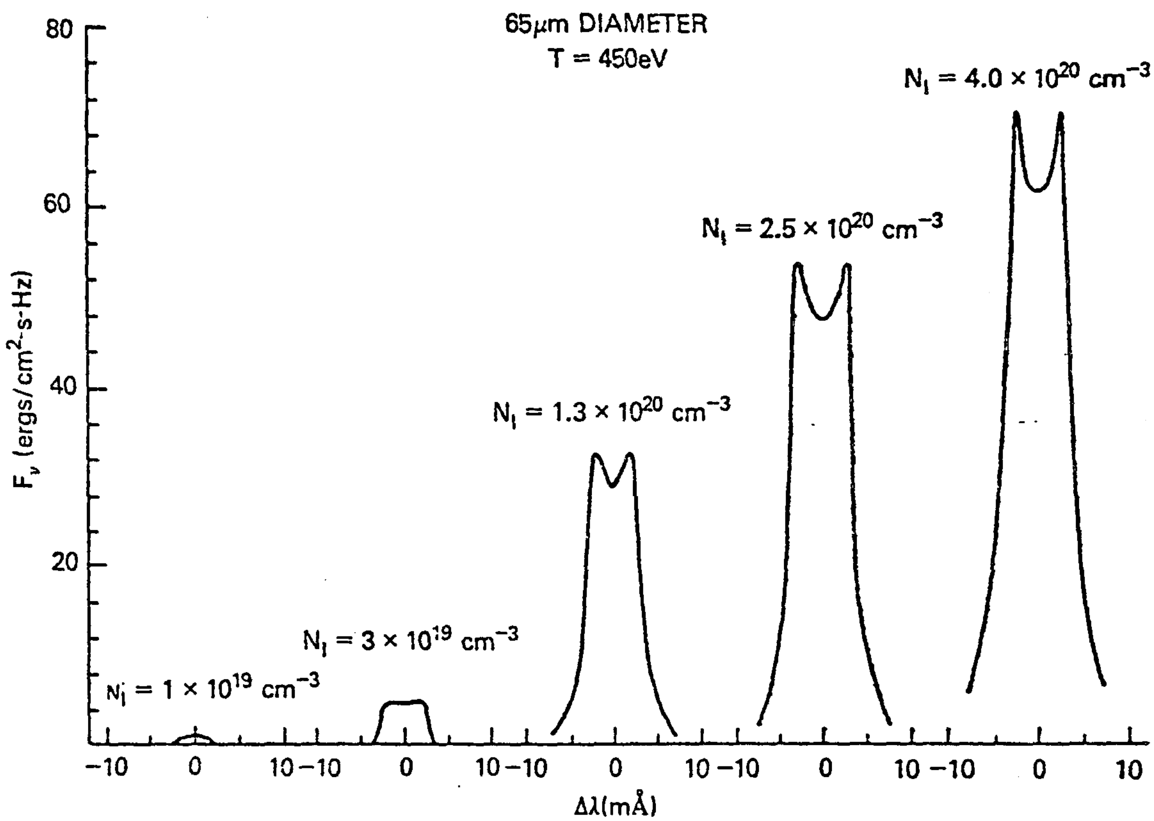
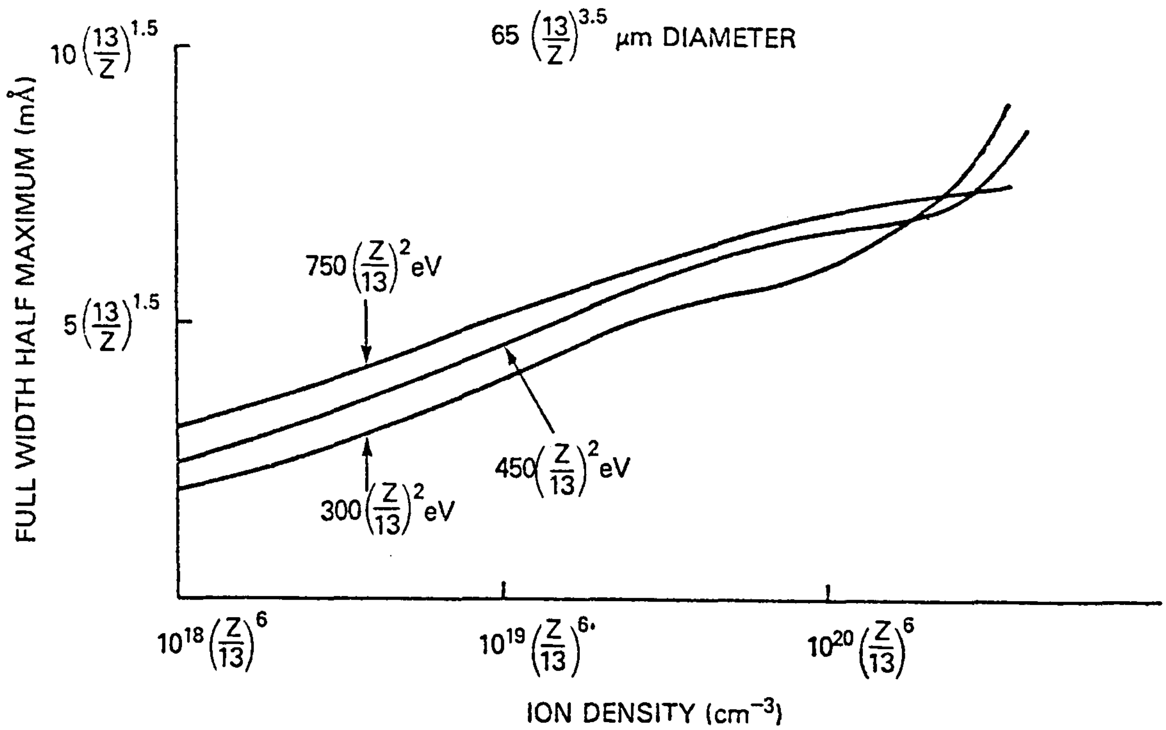
These calculations have been performed for a cylindrical geometry, which is appropriate for the blowoff created by circular tracer dots. The length of the cylinder is assumed to be much greater than the diameter. Two tracer diameters, 65 μm and 220 μm have been considered, each at three assumed ion temperatures (T_I, where $T_e = T_I$) of 300, 450, and 750 eV. Assumed ion densities (N_I) ranged from 10^{18} to 4×10^{20} cm^{-3}.

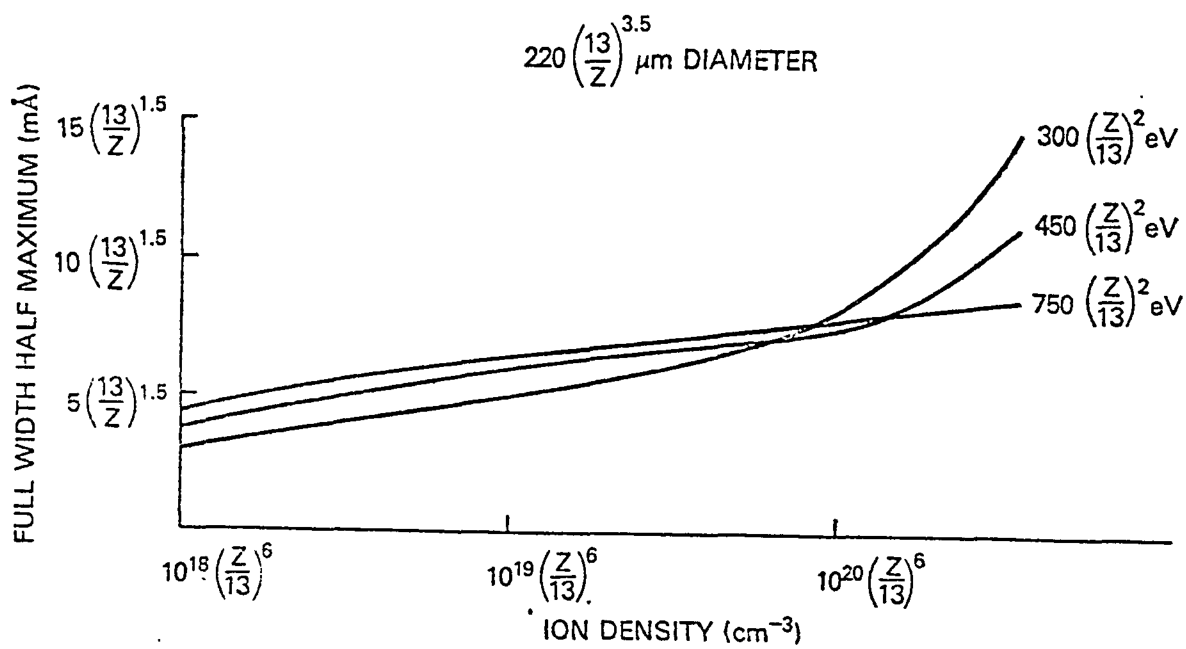
Some typical calculated profiles for Aℓ XII $1s^2$–$1s2p\,^1P$ appear below. The absolute intensity at the surface of the blowoff cylinder is plotted vs. displacement from line center in mÅ for 65 μm diameter spot cylinders. As the ion density increases the line broadens and develops the expected self-reversal as the higher optical depth forces the photons to the thinner line wings to escape the plasma.



The principal numerical result, directly applicable to experimental measurements, is the evaluation of line width (FWHM) as a function of plasma size, temperature, and density. This appears in the two figures below for aluminum plasma cylinders of diameter 65 μm and 220 μm, respectively. These calculations are strictly accurate only for aluminum. Note, however, that the densities, temperatures, and widths are scaled in these figures to provide for similar approximate diagnoses for elements of different atomic number. It is recommended that these scalings not be employed outside the range $10 < Z < 18$. A derivation of these Z-independent variables is given elsewhere[7].



$65 \left(\frac{13}{Z}\right)^{3.5}$ μm DIAMETER
FULL WIDTH HALF MAXIMUM (mÅ)
$10 \left(\frac{13}{Z}\right)^{1.5}$
$5 \left(\frac{13}{Z}\right)^{1.5}$
$750 \left(\frac{Z}{13}\right)^{2}$ eV
$450 \left(\frac{Z}{13}\right)^{2}$ eV
$300 \left(\frac{Z}{13}\right)^{2}$ eV
$10^{18} \left(\frac{Z}{13}\right)^{6}$
$10^{19} \left(\frac{Z}{13}\right)^{6}$
$10^{20} \left(\frac{Z}{13}\right)^{6}$
ION DENSITY (cm^{-3})



$220 \left(\frac{13}{Z}\right)^{3.5}$ μm DIAMETER
FULL WIDTH HALF MAXIMUM (mÅ)
$15 \left(\frac{13}{Z}\right)^{1.5}$
$10 \left(\frac{13}{Z}\right)^{1.5}$
$5 \left(\frac{13}{Z}\right)^{1.5}$
$300 \left(\frac{Z}{13}\right)^{2}$ eV
$450 \left(\frac{Z}{13}\right)^{2}$ eV
$750 \left(\frac{Z}{13}\right)^{2}$ eV
$10^{18} \left(\frac{Z}{13}\right)^{6}$
$10^{19} \left(\frac{Z}{13}\right)^{6}$
$10^{20} \left(\frac{Z}{13}\right)^{6}$
ION DENSITY (cm^{-3})

In applying the curves above to tracer dot sizes and temperatures other than those given, the following procedure using linear interpolation is recommended. First, determine the density which reproduces the observed width for both the 65 μm and 220 μm cases. Next, interpolate to find the density for the actual size of the experimental tracer plasma. Extrapolation to sizes as low as 50 μm or as large as 300 μm is reasonable. Needless to say, the "observed" width referred to above is the "bare" line width, i.e., all source and instrumental broadening should be deconvolved from the raw measured profile.

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