electron scattering.

In previous reconnection experiments anomalous resistivity has been observed and claimed to be responsible for current disruptions.[11-13] However, there the resistivity is calculated only from one component of the fields, i.e., the parallel induced electric field $-\dot{A}_y$ and current density J_y. Ignoring space charge fields and three-dimensional effects must lead to erroneous conclusions.

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Silicon Satellite Spectra from Laser-Imploded Microballoons

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The dielectronic satellite spectral lines, on the long-wavelength side of the hydrogenic Si XIV Lyman-α line, have been observed in the space-resolved spectra from laser-imploded glass microballoons. In the electron density range 1×10^{22} to 2×10^{23} cm^{-3}, the intensities of the Si XIII $2s2p\ ^3P$–$1s2s\ ^3S$ and $2p^2\ ^3P$–$1s2p\ ^3P$ satellite lines increase with density in agreement with numerical modeling. These satellite lines are a promising density diagnostic for the imploded glass plasma.

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The implosion core regions of laser-irradiated glass microballoons are intense sources of x-ray line radiation from highly charged ions. The hydrogenic resonance lines from the imploded shell and the gas fill have been used to measure the plasma parameters that are important for laser fusion.[1-5] There has been interest in using dielectronic satellite lines for the diagnosis of the core plasma.[6-11] Advantages of this diagnostic technique are that the satellite lines are less susceptible to opacity effects, and the plasma parameters are obtained from the relative intensities of closely spaced spectral lines.

Time-resolved x-ray spectroscopy[12] indicates that dielectronic satellite radiation is emitted only briefly from the hottest plasma region, whereas resonance radiation persists for a longer period of time in the cooler recombining plasma. Thus the satellite radiation is more characteristic of the hot, dense core region and is less affected by time averaging.

In this paper, we report the analysis of the dielectronic satellite lines on the long-wavelength side of the Si XIV Lyman-α line. The Lyman-α and satellite intensity distributions are obtained from the space-resolved x-ray spectra from a series of two-beam laser implosions at the Rutherford Laboratory. It is shown that the intensities of the $2s2p\ {}^3P$–$1s2s\ {}^3S$ and $2p^2\ {}^3P$–$1s2p\ {}^3P$ satellite lines increase with plasma density in agreement with numerical modeling. This work establishes the utility of these satellite lines for measuring the density of the silicate-glass plasma of imploded microballoons. The corresponding argon satellite lines, which have also been observed to be quite intense in the core regions of argon-filled microballoons, should be useful for measuring the density of the gas fill.

The parameters for four representative laser shots are shown in Table I. The diameter of the imploded silicon plasma is determined from the spatial extent of the Si XIV and Si XIII recombination continua. The electron temperature is calculated from the slopes of these recombination continua, and the electron density is determined from the Stark broadening of the Si XIV Lyman series lines, corrected for opacity.[2] The parameter NR, the density of the hydrogenic Si XIV ground state multiplied by the optical path length, is obtained from the optically thick Si XIV Lyman-α line.

The silicon Lyman-α and satellite spectra from the ablation and implosion core plasmas of shot 328 are shown in Fig. 1. The intensities of the $2s2p\ {}^3P$–$1s2s\ {}^3S$ and $2p^2\ {}^3P$–$1s2p\ {}^3P$ satellite lines, relative to the intensity of the $2p^2\ {}^1D_2$–$1s2p\ {}^1P_1$ satellite line, are stronger in the implosion core plasma (electron density 1.1×10^{23} cm^{-3}, electron temperature 400 eV) than in the ablation plasma (1×10^{22} cm^{-3}, 500 eV). The four core satellite spectra are shown in Fig. 2, where the intensities of the triplet satellite lines increase with elec-

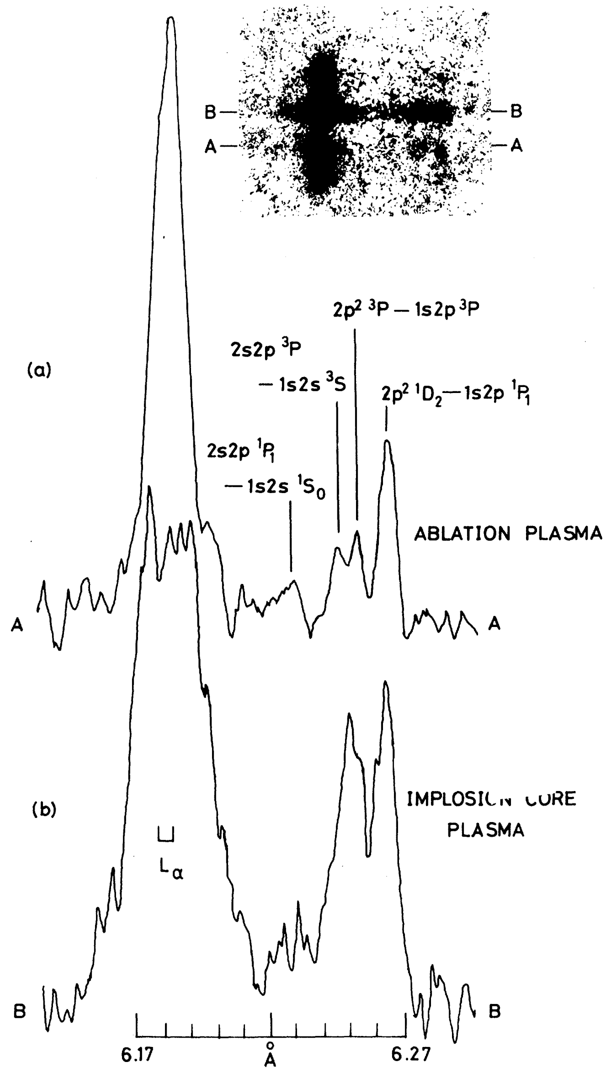

FIG. 1. Densitometer tracings of the silicon Lyman-α and satellite lines from (a) the ablation plasma and (b) the implosion core plasma of shot 328. The densitometer tracings, as indicated on the photograph of the spectrum, are along line AA through the ablation region and BB through the core region.

TABLE I. Parameters for the four shots.

Shot number[a]	Laser power (TW)	Shell diameter (μm)	Shell thickness (μm)	Gas fill (bar)	Silicon implosion plasma D (μm)	T_e (eV)	N_e (cm^{-3})	NR (cm^{-2})
323	0.17	50	0.59	10 DT	34	580	2×10^{22}	1.8×10^{18}
322	0.15	50	0.60	10 DT	25	500	6×10^{22}	1.7×10^{18}
328	0.34	67	0.71	0.4 Ar	22	400	1.1×10^{23}	8.8×10^{17}
209	0.22	66	0.75	0.3 Ar	22	430	1.4×10^{23}	1.6×10^{18}

[a]The shot numbers, appearing in the table and in Fig. 2, refer to the Rutherford Laboratory system of designating laser shots.

tron density. These spectra are recorded using a PET crystal and a 10-μm-wide slit resulting in a 12-μm spatial resolution.[1] The instrumental spectral linewidth, determined by the source size and the rocking curve of the crystal, is 4 mÅ.

The increase in intensity of the silicon triplet satellite lines with density is in agreement with numerical modeling of the satellite spectra. The steady-state rate equations for the ten $2l2l'$ levels, the three hydrogenic $n=2$ levels, and the fully stripped ionization stage are solved for the level populations relative to the hydrogenic ground-state density. The levels are coupled by electron collisional processes (dielectronic recombination, collisional-radiative recombination, ionization, and excitation[13]) and by autoionization[14] and radiative decay where appropriate. The Lyman-α radiative rate is reduced by the frequency-dependent escape factor for an emitting-absorbing plasma.[4] For $NR<10^{19}$ cm^{-2}, a condition that is well satisfied in these implosions (see Table I), satellite line opacity effects are negligible.[11] From the intensity ratio of the Si XIII $1s2p\,^3P_1-1s^2\,^1S_0$ intercombination line to the $2s2p\,^3P-1s2s\,^3S$ satellite line, typically equal to 4 for the core spectra, it may be shown[15] that the inner-shell excitation of the doubly excited levels from the metastable levels of the He-like ion is negligible.

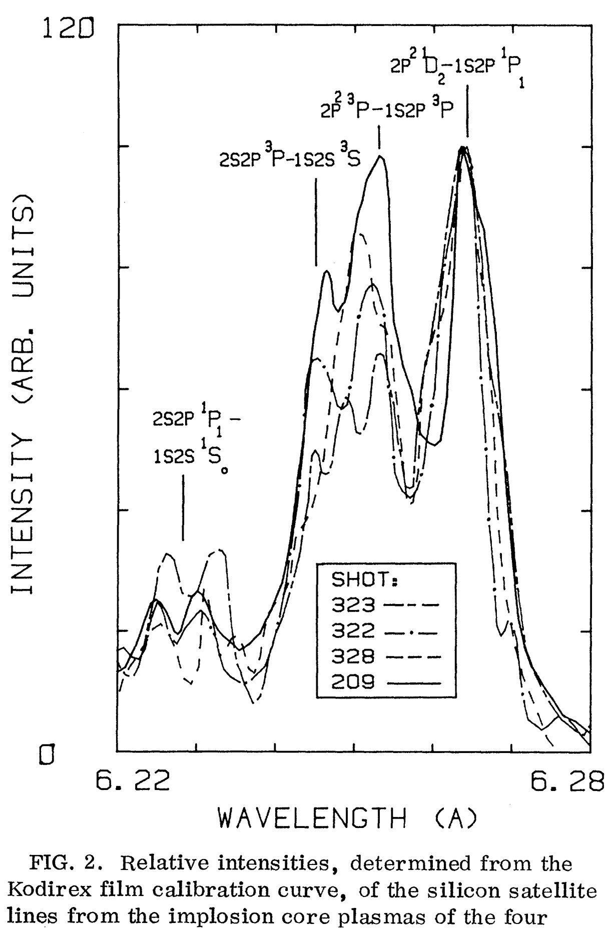

FIG. 2. Relative intensities, determined from the Kodirex film calibration curve, of the silicon satellite lines from the implosion core plasmas of the four shots listed in Table I. The intensities are normalized to the intensity of the $2p^2\,^1D_2-1s2p\,^1P_1$ satellite line.

With calculation of the level populations, the spectral intensity distribution is simulated by summing the contributions, from each radiative transition, at particular wavelengths in the wavelength region that includes the Lyman-α and satellite lines. The Doppler, Stark,[16] and 4-mÅ instrumental profiles are convolved, and the Lyman-α profile is further modified by opacity by using the frequency-dependent escape factor for an emitting-absorbing plasma. The resulting calculated intensity distribution is a function of N_e, NR, and T_e. Since these plasma parameters are measured independently of the satellite lines, there are no free parameters in the numerical model.

The silicon satellite spectra, calculated with use of the plasma parameters listed in Table I, are shown in Fig. 3. The calculated satellite spectra are in good agreement with the experimental spectra. A more sophisticated radiation transport model could be used for the Lyman-α

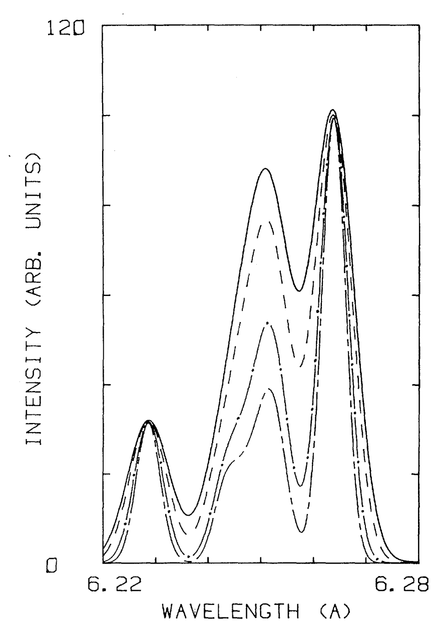

FIG. 3. Calculated relative satellite intensities for the four shots listed in Table I. The four curves are identified by the legend in Fig. 2.

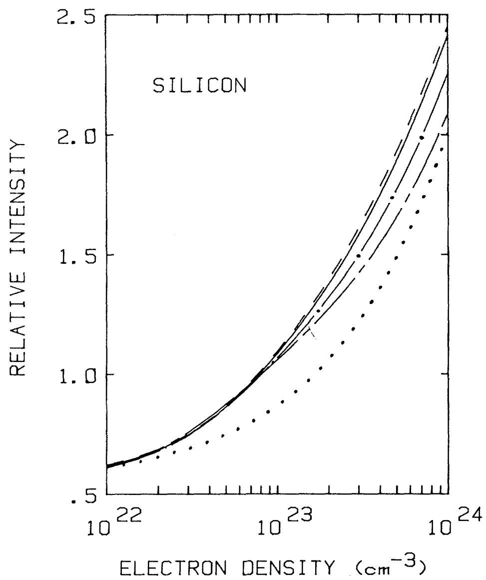

FIG. 4. The calculated intensities of the Si XIII $2s2p\ ^3P$–$1s2s\ ^3S$ and $2p^2\ ^3P$–$1s2p\ ^3P$ satellite lines, with wavelengths (Ref. 14) 6.2432 to 6.2545 Å, relative to the intensity of the $2p^2\ ^1D_2$–$1s2p\ ^1P_1$ satellite line at 6.2637 Å. The dotted curve is for an electron temperature of 400 eV and an optically thin Lyman-α line. The upper four curves (see legend in Fig. 2) are calculated by using the parameters of the glass plasma listed in Table I.

radiation, but since the temporal variations of the plasma parameters are unknown, the frequency-dependent-escape-factor approximation is adequate for the present analysis.

The calculated intensities of the Si XIII $2s2p\ ^3P$–$1s2s\ ^3S$ and $2p^2\ ^3P$–$1s2p\ ^3P$ satellite lines, relative to the intensity of the $2p^2\ ^1D_2$–$1s2p\ ^1P_1$ satellite line, are shown in Fig. 4 as functions of electron density. For electron density less than 10^{21} cm^{-3}, the $2l2l'$ levels are populated by dielectronic recombination, and the intensity ratio is constant and equal to 0.5. As the electron density increases, the $2s2p\ ^3P$ and $2p^2\ ^3P$ levels are populated by electron collisional excitation from the singlet doubly excited levels, and the intensity ratio increases to the value 2.7 in the limit of statistical occupation of the $2l2l'$ levels (dotted curve in Fig. 4). The increase in the hydrogenic $n=2$ population due to reabsorption of the Lyman-α radiation results in enhancement of the $2s2p\ ^3P$ and $2p^2\ ^3P$ populations by collisional recombination (upper four curves in Fig. 4).

Extension of this diagnostic technique to higher electron densities should be possible with use of the satellite lines of high-Z impurities in the glass plasma. These spectral lines, together with the corresponding argon satellite lines, are promising measures of electron densities greater than 10^{23} cm^{-3}.

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