Spectral measurements from laser-produced plasma in OMEGA

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Curved- and flat-diffraction crystal spectrographs were developed to collect x-ray spectra from high-atomic-number elements (cadmium–rare earths) in the 5–17-Å region. The plasma source was generated by the 24-beam, frequency-tripled light of the OMEGA laser system. The spectral patterns were identified with the aid of atomic structure calculations and from Moseley plots of isoelectronic sequences. The Ne-like (third-order diffraction) and Na-like ionization stages were observed in the Cd and Sn spectra. The rare-earth spectra were predominantly $3d$-$4p$, $4f$ transitions over a range of ionization stages involving the M shell. Calibration spectra were obtained with L-series transitions from Fe and Cu targets and K lines from Si plasma excited in the glass supporting stalk.

INTRODUCTION

X-ray spectra were collected for high-atomic-number elements with curved (mica) and flat (beryl) crystals using the 24-beam OMEGA system at the University of Rochester, operated at 1–2 kJ with frequency-tripled (351 nm) laser illumination. Spectra in the 5–17 Å region were acquired from cadmium, tin, and several rare-earth elements. The spectral lines were measured with a Grant comparator densitometer and a scanning PDS microdensitometer. The calibration lines were K-series lines from the glass stalk supporting the microsphere targets and Be- and Li-like L-series transitions from iron and copper targets. The spectra were identified with the aid of atomic structure calculations[1] and isoelectronic comparison with prior work[2–5] on L- and M-shell spectra from laser-produced and exploded-wire generated plasmas. The rare-earth spectra are characterized by arrays of $3d$-$4p$, $4f$ transitions beginning with Ni-like ionization stages. The spectra from cadmium and tin have transitions in Ne-, Na-, and Mg-like ions. The $2p$-ns,nd transitions in Ne-like Cd XXXIX and Sn XLI fit a Moseley isoelectronic plot.

I. EXPERIMENTAL

The curved-crystal spectrograph was designed for mounting inside the OMEGA experimental chamber on an 8-in.-diam port as illustrated in Fig. 1. The base-mounted translator allowed target-shutter-crystal alignment. Dual flat crystal spectrographs were designed for mounting on a 12-in.-diam port as shown schematically in Fig. 2. The three

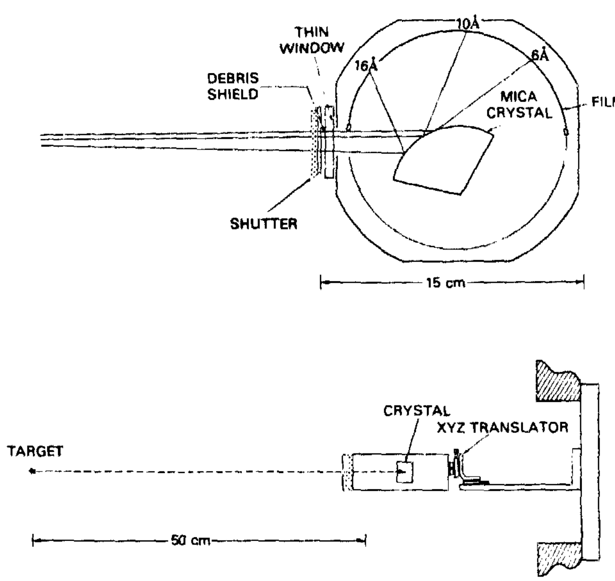

FIG. 1. Curved-mica, diffraction crystal spectrograph.

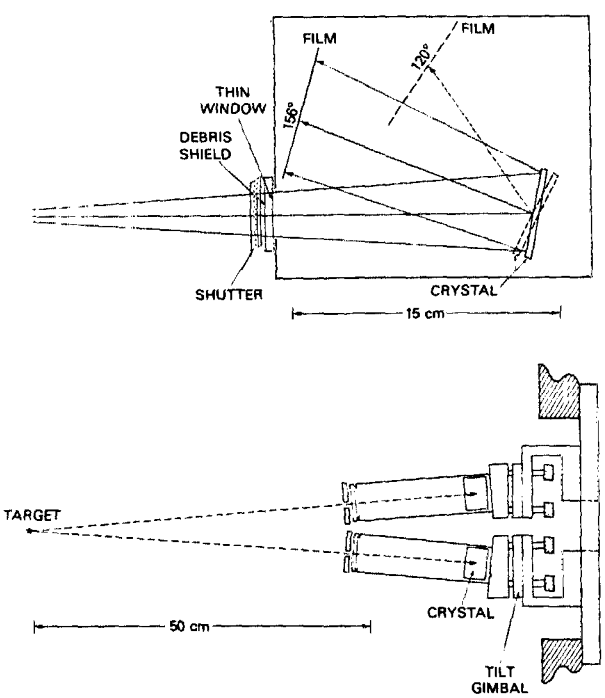

FIG. 2. Schematic of dual flat-crystal spectrographs.

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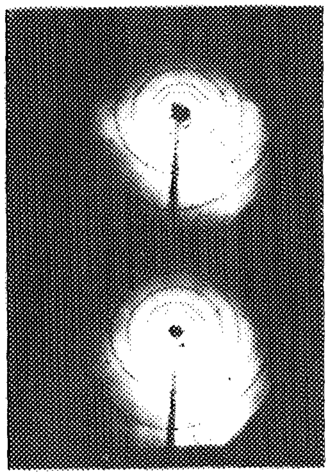

FIG. 3. Targets configured as powders and coatings on microspheres supported by glass fibers.

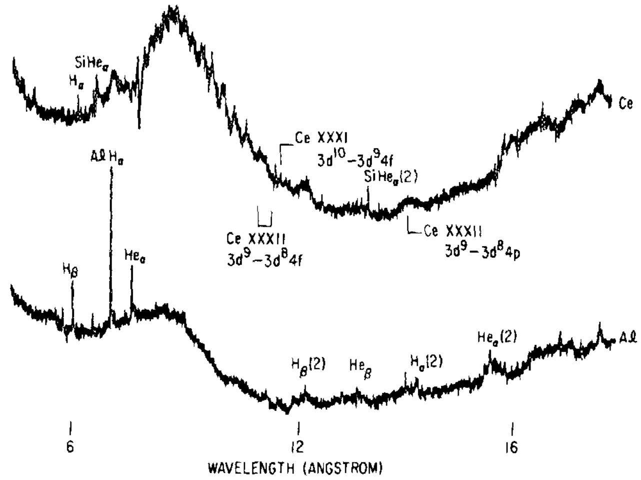

FIG. 5. Spectral traces of Ce and Al in the 5–17-Å region.

spectrographs were instrumented with gear-controlled, translation shutters (slits) for acquiring several spectral strips on a single film exposure. The windows of the spectrographs were comprised of aluminized stretched polypropylene for light securing the spectrographs and uncoated stretched polypropylene for debris shields.

Figure 3 shows the alignment of targets in the experimental chamber with the OMEGA viewing optics. Ideally the targets were to consist of 1-μm coating on thin-walled plastic microspheres. This was the case for the Fe, Cu, and Sn targets where the target diameters were about 150 μm. The rare-earth targets were comprised of micron-sized powders adhered to solid plastic spheres with sizes of 400–600 μm.

The spectrogram collected on DEF film with the curved mica crystal is shown in Fig. 4. The upper strip shows the Ce spectrum juxtapositioned between the Al and Cu spectral strips. The spectral line positions on the film were read on a Grant comparator densitometer. The procedure for wavelength measurements involved identifying the Si lines in both first and second order that are superimposed on the Ce strip. Also, calibration lines were present and were read for the Al *K*-series lines and the Cu and Fe spectra. To make accurate wavelength measurements, calibration lines of known wavelengths should be found in the spectrum or in juxtapositioned spectral strips. The Al *K*-series lines and Cu and Fe *L*-series lines served this purpose for the Ce spectrum.

II. DATA AND ANALYSIS

The Ce and Al spectral traces are shown in Fig. 5 collected with the curved mica crystal spectrograph. The lower spectral strip shows Al lines in first and second order while the upper strip has silicon lines. The Ni-like Ce XXXI $3d$-$4f$ transitions were distinct lines while the Co-like Ce XXXII $3d^9$-$3d^8 4p$, $4f$ transitions were found as an array of overlapping lines. The $3d$-$4f$ line arrays from over ten ionization stages are observed above a somewhat irregular background between approximately 8 and 12 Å in the Ce spectrum.

Although the spectral lines were broadened as a result of the plasma source size, the transition arrays were observed stripping through the *M* shell. Weak lines were identified as $3p$-$4f$ lines in Na-like Ce XLVIII.

Calibration lines were collected with Cu and Fe targets. Li- and Be-like ionization stages were identified in Fe by spectral matching with previous spectroscopic data for *L*-series spectra.[6] Isoelectronic extrapolation was used to estimate wavelengths for the copper spectrum. The Cu spectral strip also had faint Fe lines together with Si *K*-series lines. The Be-like transitions in Cu XXVI were identified from calculations with the atomic structure program using scaled Slater parameters that were previously determined for Be-like Cr XXI liner.[7] The agreement between the observed and

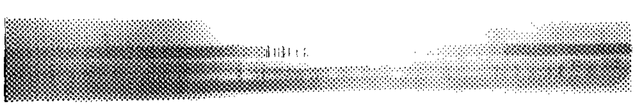

FIG. 4. Spectrogram of Al, Ce, Cu, Fe, and Te spectral strips collected with the curved mica spectrograph.

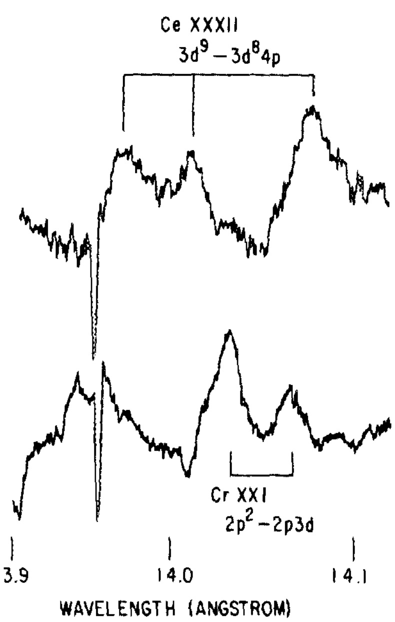

FIG. 6. High-resolution spectra of Ce and Cr near 14.0 Å.

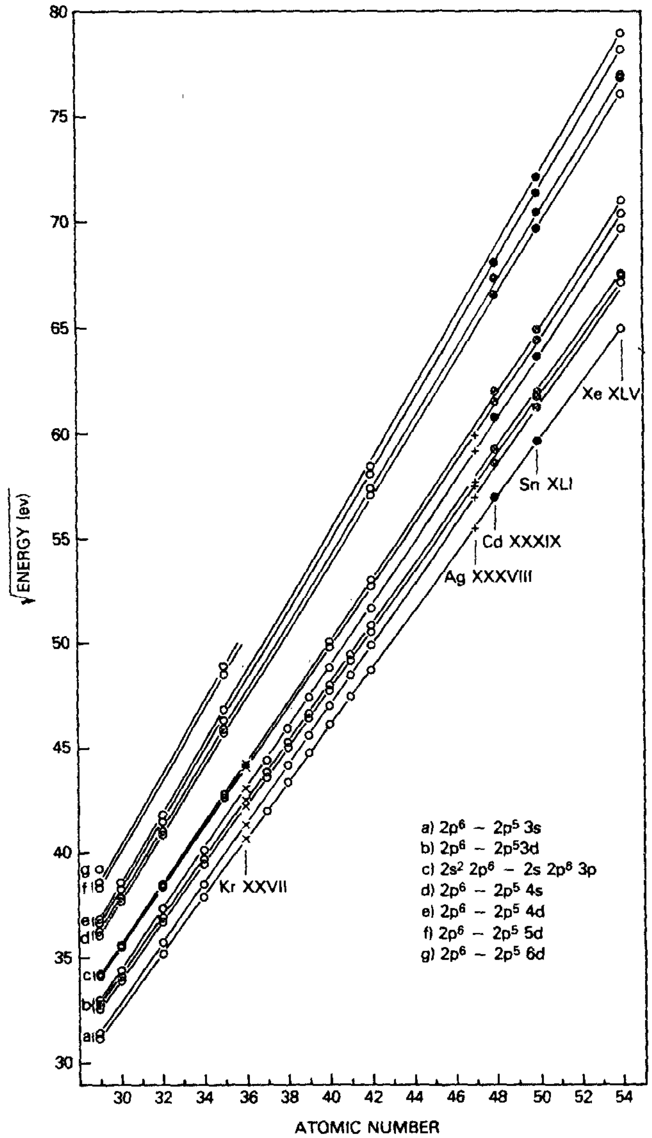

FIG. 7. Moseley plot of Ne-like transitions.

calculated wavelengths was ± 5 mÅ. Good correlation of the Be-like transitions was observed along the isoelectronic sequence for the $2s2p$-$2p3d$ and $2p^2$-$2p3d$ transitions in Cu XXVI.

High-resolution Ce and Cr spectra were collected with a beryl crystal at a Bragg angle setting of 61.0° in a flat-crystal spectrograph. Figure 6 shows the two spectra for the 13.9–14.1 Å region (limited by the 30-mm length of the crystal). Line calibration was provided by transitions in Be-like Cr XXI that have wavelengths near 14.0 Å.[7] The $2p^2$-$2p3d$ transitions at 13.948 and 13.954 Å have an absorption feature from a flaw in the detector window. Wavelengths were measured for the $3d$-$4p$ transitions in Co-like Ce XXXII from the high-resolution spectrum.

The L-series Ne-like spectral patterns were observed in third-order diffraction in Cd and Sn spectra collected with the mica crystal. The spectral identifications were made with the aid of atomic structure calculations. The first-order spectra in the 10–12-Å region in tin have lines from Na- and Mg-like ionization stages. A Moseley plot for L-series transitions is shown in Fig. 7. The wavelengths in Ne-like transitions in Cd XXXIX and Sn XLI were determined from broad range mica-crystal spectrograph data to an uncertainty of ± 10 mÅ. The plotted isoelectronic sequence represents data acquired from a variety of plasma generating devices and target types. The open circles are published data from laser-heated studies at NRL[3] and Culham[8] laboratories while the Xe XLV data points were collected from laser-imploded gas-filled microballons.[9] The Kr XXVII wavelengths were measured from puff gas experiments[8,10] and the Ag XXXVIII data from exploded wires,[5] all in pulsed-power implosions.

The M-series spectra from the several rare-earth targets had noteworthy similarities with previous laser-produced x-ray[2] and XUV spectra.[11] The x-ray spectrum from higher-atomic-number rare-earth elements such as Eu was comprised of Ni- and Co-like transitions as the plasma temperature was just sufficient to begin stripping into the M shell.

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