New continua for absorption spectroscopy from 40 to 2000 Å

P. K. Carroll, E. T. Kennedy, and G. O'Sullivan

Physics Department, University College, Dublin, Ireland
Received November 7, 1977

The spectra of plasmas produced by focusing the output of a Q-switched ruby laser (output 1 J) on the rare-earth metals have been studied. From samarium ($Z = 62$) to ytterbium ($Z = 70$), strong quasi-uniform continua are emitted in the wavelength range 40–2000 Å. Line emission from the target elements is absent over most of this wavelength region, particularly below about 600 Å. The use of these continua as simple, reliable background sources for absorption spectroscopy in the vacuum-ultraviolet and soft x-ray region down to 40 Å is demonstrated.

Although continuum emission from laser-produced plasmas has frequently been noted, little effort seems to have been made to exploit its use in absorption spectroscopy. This is not surprising because usually the continuum is overlaid by a much stronger line spectrum. Thus, in the case of absorption of the radiation from one laser-produced aluminum plasma by a second aluminum plasma[1] (also laser-produced), the execution of the experiment and the interpretation of the results are both difficult. In the case of laser-produced plasmas on tungsten targets, however, the work of Ehler and Weissler[2] indicated that in the grazing incidence region the continuum predominates. Tantalum was also studied, more particularly at longer wavelengths, both by Ehler and Weissler and by Breton and Papoular,[3] the latter workers being primarily interested in obtaining a strong continuum near 1215 Å for the study of Lyman α in various high-power plasma devices. It was shown in this laboratory[4] that the tungsten continuum could be used to good effect for absorption studies in the grazing incidence region from 60 to 180 Å, and that it was particularly useful when a pulsed source was required. However, it was found that the tungsten continuum became strongly contaminated with lines, both emission and absorption, above about 180 Å, thus limiting its usefulness as a background source. Tantalum was also studied but was found to be as strongly contaminated with lines as tungsten, particularly at wavelengths longer than about 150 Å. Following the promising use of the tungsten continuum for absorption work a study was made of other high-Z target materials with a view to obtaining, if possible, a continuum that would be stronger, more extensive in wavelength coverage, and, in particular, freer from atomic lines.

In a survey of most of the heavier elements from tellurium to uranium, it was found that the higher rare earths ($Z > 62$) emitted strong, and, over wide spectral regions, relatively line-free continua. The experiments were carried out from 30 to 500 Å with a 2-m grazing

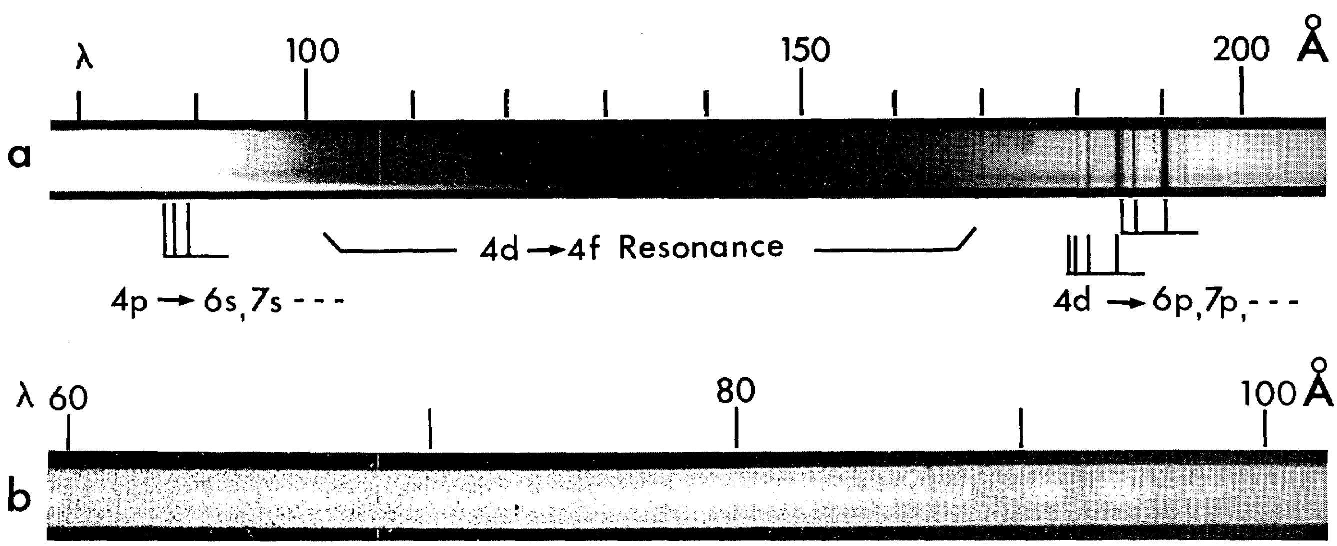

Fig. 1. (a) Absorption spectrum of xenon from 80 to 200 Å. The xenon pressure in the spectrograph was 0.05 Torr, and the number of laser pulses used was 30. For details of the xenon spectrum in this region see Madden and Codling.[5] The unmarked weak lines near 200 Å are due to O v. Oxygen present in the target gives rise to some emission lines as well. (b) The ytterbium continuum from 60 to 100 Å. The number of laser shots was 20. As in (a), the spectrum was obtained on a Kodak SC5 plate.

0146-9592/78/0300-0072$0.50/0

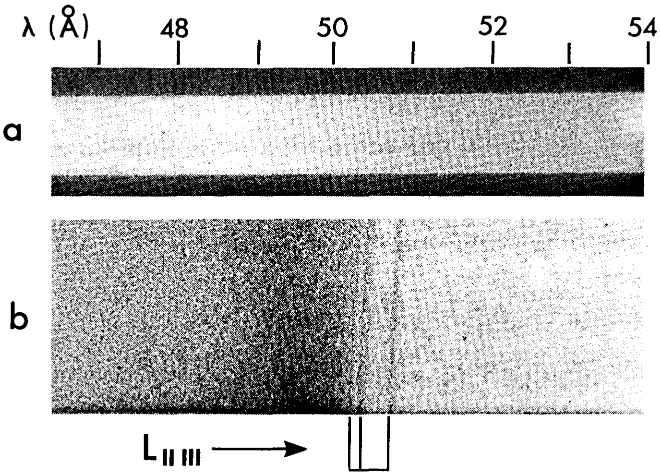

Fig. 2. (a) Terbium continuum from 46 to 54 Å obtained with 30 laser shots. (b) Argon L edge absorption corresponding to the transitions $2p^6 3s^2 3p^6\ ^1S$–$2p^5 3s^2 3p^6 ns,nd$. (See Nakamura *et al.*[6]) The argon pressure was 0.2 Torr, and 30 laser shots were used. As in Fig. 1, the spectra were recorded on Kodak SC5 plates.

incidence vacuum spectrograph blazed at 65 Å; from 500 to 2800 Å the observations were made with a 3-m normal incidence instrument blazed for 1500 Å. In both spectrographs Bausch & Lomb gratings having 1200 grooves/mm were used. The target was located 4–10 cm from the spectrograph slit and irradiated with a Q-switched ruby laser that gave an output of about 1 J in a pulse that had a FWHM of 25 to 30 nsec. A planoconvex lens of 5-cm focal length was used to focus the laser beam onto the target metal. The slit widths used were typically 10 to 15 μm.

The continua emitted by the rare earths were remarkable for their intensity, relatively slow variation with wavelength, and, in particular, the absence over substantial spectral ranges of atomic lines emitted by the target element. Thus, in the case of ytterbium, an intense, quasi-uniform continuum was emitted from 35 to 600 Å. At this point relatively strong emission lines appeared, although the underlying continuum was still present. Again, in the case of samarium, although the intensity was less uniform than in the case of ytterbium, the continuum extended from 35 to 2000 Å with only a few target lines appearing at longer wavelengths. The short-wavelength limit of our observations was set by scattered light from the grating.

It appeared from these results that the continua would be well suited for absorption work throughout the whole vacuum region from 2000 Å to soft x rays at about 40 Å. This proved to be the case, and the results of a number of experiments are shown in Figs. 1–3. Figure 1 shows the absorption spectrum of xenon from 45–200 Å, in which region autoionizing transitions from inner-shell excitations are prominent. Also shown (at larger magnification) is part of the ytterbium continuum itself, from which its cleanliness and relative uniformity may be seen.

Figure 2 illustrates the argon $L_{\mathrm{II,III}}$ edge at 50 Å observed with the terbium continuum as background. The $L_{\mathrm{II,III}}$ edges of chlorine at 62 Å and the K edge of carbon at 44 Å were observed in other experiments.

Although well-established continua are now available for work above 600 Å, the rare-earth sources may be useful for particular types of experiments. In Fig. 3 is shown part of the N_2 absorption spectrum, again obtained with the terbium continuum. The plates were taken on the 3-m normal incidence instrument, and the results indicate that the new continua can be used in work of intermediate and high resolution.

In the above experiments, as well as in others not reported here, the absorbing gas was present in the source as well as in the body of the spectrograph; its presence, at least up to moderate pressures, does not appear to inhibit the emission of the continuum. Again, preliminary experiments indicate that the emission time of the continuum corresponds fairly closely to the length of the optical output pulse of the laser—a result similar to that obtained by Ehler and Weissler[2] with tungsten. This characteristic is of obvious value for experiments requiring time resolution.

The system is simple to set up and is easy to operate, and its performance is essentially as reliable and consistent as that of the exciting laser. It is also a relatively clean source in the sense that little debris from the laser-produced plasma is thrown onto the slit, especially

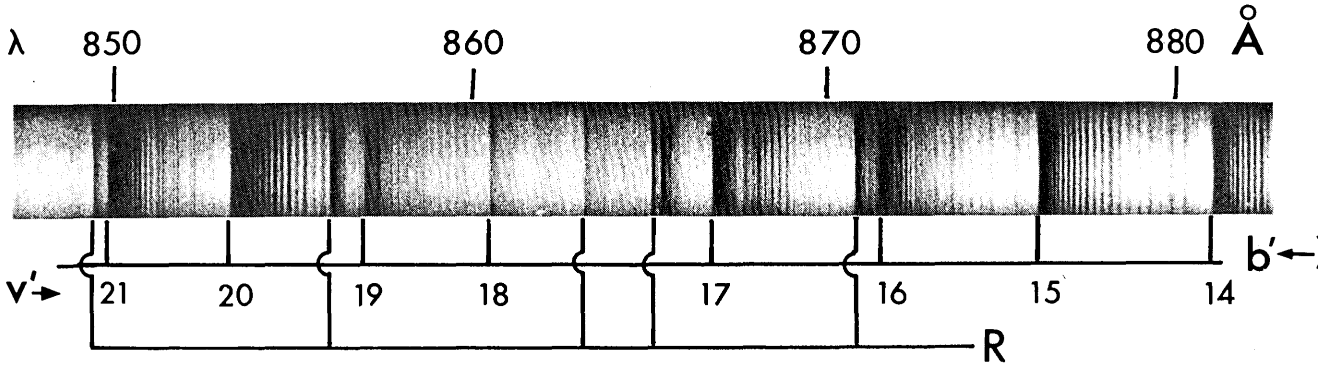

Fig. 3. The absorption spectrum of N_2 from 850 to 880 Å taken on the 3-m normal incidence vacuum spectrograph with the terbium continuum. The number of laser shots required was 200, and the nitrogen pressure in the spectrograph was 3.5×10^{-4} Torr. The spectrum was recorded on Kodak SWR plates. Part of the v'–o absorption progression of the $b'\,^1\Sigma_u^+$–$X\,^1\Sigma_g^+$ system is shown, together with a number of Rydberg bands designated R. For a high-resolution analysis of the N_2 spectrum in this region, see Carroll and Yoshino[7] and references therein.

if the plasma plume is directed in a plane parallel to the slit jaws. Furthermore, the effective intensity of the continuum, although already adequate for many experiments, could be increased by about an order of magnitude by the use of suitable condensing optics.[8] In short, the continua described here would seem to have many attractions for absorption spectroscopy from 40 to 2000 Å, particularly in the region below 500 Å.

References

1. A. Carillon, P. Jaegle, and P. Dhez, "Extreme ultraviolet continuum absorption by a laser-generated aluminum plasma," Phys. Rev. Lett. **25,** 140 (1970); A. Carillon, G. Jamelot, A. Sureau, and P. Jaegle, "Autoionizing series in the Al^{3+} ion spectrum of a laser-produced plasma," Phys. Lett. **38A,** 91 (1972); F. P. J. Valero, "Intensity anomalies in the extreme VUV spectrum of Al^{3+} obtained in a laser produced plasma," Appl. Phys. Lett. **25,** 64 (1974).
2. A. W. Ehler and G. L. Weissler, "Vacuum ultraviolet radiation from plasmas formed by a laser on metal surfaces," Appl. Phys. Lett. **8,** 89 (1966).
3. C. Breton and R. Papoular, "Vacuum UV radiation of laser-produced plasmas," J. Opt. Soc. Am. **63,** 1225 (1973).
4. P. K. Carroll and E. T. Kennedy, "Doubly excited autoionization resonances in the absorption spectrum of Li^+ formed in a laser-produced plasma," Phys. Rev. Lett. **38,** 1068 (1977).
5. K. Codling and R. P.Madden, "Newly observed structure in the photoionization continua of Kr and Xe below 160 Å," Appl. Opt. **4,** 1434 (1965).
6. M. Nakamura, M. Sasanuma, S. Sato, M. Watanabe, H. Tamashita, Y. Iguchi, A. Egiri, S. Nakai, S. Yamaguchi, T. Sagawa, Y. Nakai, and T. Oshio, "Absorption structure near the $L_{\mathrm{II,III}}$ edge of argon gas," Phys. Rev. Lett. **21,** 1303 (1968).
7. P. K. Carroll and K. Yoshino, "The $c_n\,{}^1\Pi u$–$c'n\,{}^1\Sigma_u^+$ Rydberg states of N_2; high resolution studies," J. Phys. B **5,** 1614 (1972).
8. W. A. Rense and T. Violett, "Method of Increasing the speed of a grazing-incidence spectrograph," J. Opt. Soc. Am. **49,** 139 (1959).