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VUV Production from a Ferrite-Driven Flash-Pumped System

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Abstract

The relative spectral emission as a function of wavelength in the 1200-2900 Angstrom region is neasured for a vacuum UV flash device whose discharge is initiated by a high resistance formed-ferrite od. The device is studied because of its usefulness in the optical pumping of large volume laser systems.

Introduction

Lasers pumped photolytically by broadband vacuum ultraviolet radiation have been extensively tudied by Basov, Zuev and co-workers at the P.N. Lebedev Physics Institute, Russia for many years. he early broadband VUV sources were exploding wire light sources having blackbody radiation emperatures estimated at 30,000 °K. Reviews of gas lasers pumped by broadband VUV incoherent ources are given by Basov, Zuev, Mikheev and Stoilov for gas lasers in general[1] and for blue green aser systems in particular[2]. Efficiencies of 1% are reported for the B-X and C-A transitions of XeF[3,4]. n order for the technique to be useful, however, devices need to be developed which are capable of eing repetitively pulsed. Sliding arc discharges on high index dielectric surfaces is one such possibility. tudies carried out by Beverly, Barnes, Moeller and Wong[5] and Berverly [6,7] show the surface discharge o be extremely rich in VUV content associated with broadened line spectra of the dielectric surface naterial. The surface discharge temperature was derived from the broadening of argon spectral lines to be etween 10,000 to 20,000 °K and do not radiate like an ideal blackbody[7]. Devices of this type have een developed at the N.E. Bauman Higher Technical College, Russia for very high energy loadings [8] nd have been used by Zuev, et al. to obtain XeF (C-A) lasing at 485 nm obtaining specific energy utputs of 5 J/l and total energy per pulse of 100 Joules[9]. As this technique ablates material from the ielectric surface and under most operating conditions create carbon deposites on the dielectric surface hat causes channeling and , thus, degradation of the discharge, the lifetime of the device is estimated to e limited to a few thousand shots before a complete clean-up of the system is required. Recently, Vatanabe et al.[10] introduced the interesting technique for creating an intense vacuum ultraviolet thermal ght source that approximates the exploding wire but is capable of repetitive operation. The source is alled a "formed-ferrite plasma source" (FFPS) and works in the following way[11]. An amorphous line is rst written on the ferrite which has a measurable high impedence but orders of magnitudes less than the npedence of the untreated ferrite. When voltage is appled across this high impedence filament, the urrent ohmically heats the filament to very high temperatures causing it to emit thermal electrons and ons. Subsequently a threshold is reached where a gaseous plasma develops using the thermal electrons nd ions as a seed source. The gas impedence now collapses and the bulk of the stored energy is eposited into the gas. As the filament has a high impedence very little energy is actually deposited in the errite and the device can be used repeatedly. The light source is exactly similar to that of an exploding

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wire source. Gross, Schneider and Amimoto[12] used a flash-pumped device based on this technique to pump XeF_2 and obtained 8 J in the XeF B-X transition.

This paper describes the development of a long-lived formed ferrite plasma source device using high temperature cheap ferrites. We will briefly discuss the process of writing the amorphous ferrite line on such materials and the ability to control the impedence of the line. Relative spectral emission of the light scurce is obtained for various pressures of argon gas and for various energy deposition levels. The temporal behavior of the emission is presented for different wavelengths.

The Formed Ferrite Plasma Source

The ferrites used by Watanabe, et al.[10,11] and Gross, et al.[12] are (Ni-Zn)Fe_2O_3 ferrite rods. The amorphous line was formed by first depositing an aluminum thin film by either vacuum evaporation or by exploding a thin wire onto the ferrite. The discharge is then fired at relatively low voltage and energy, and the current through the aluminum film heats the ferrite material underneath to the melting point with subsequent reformation into an amorphous line. The amorphous line on these ferrites, however, gets broader and broader as the device undergoes repeated pulsing under high energy loading to generate the VUV flash until the resistance of the line decreases to levels where the thermal electrons and ions are no longer created efficiently and the device cease to work. Thus, these formed ferrites made of (Ni-Zn)Fe_2O_3 also have lifetimes limited to a few thousand shots.

In the present device we utilized a cheap, low-cost RMX ferrite material which proved to have very high temperature characteristics. We were not able to form an amorphous line using the above technique as the temperature simply was not high enough to melt the ferrite underneath. We were, however, able to use the focused beam of a quasi-cw YAG laser to write the amorphous line. Figure 1 gives an example of lines written on this ferrite material. We have written lines from fractions of a mm wide to a few mm at many different power levels. Generally, for a given width the higher the YAG power the deeper the penetration into the ferrite and the lower the impedence of the line. Figure 2 gives the resistance per cm as a function of the average YAG laser power for a one mm wide ammorphous line. Although the curve shows that we can control the impedence by nearly an order of magnitude for a given amorphous line width, the data was obtained on a single piece of ferrite. Variations from ferrite to ferrite is less predictable and variations from batch to batch from different orders at different times is even more unpredictable. We found that if the YAG power is too high imperfections in the ferrite can cause a piece to flake off. This generally renders the ferrite useless. We also find that the exact impedence is not very important if only one line is fired. If more than one ferrite line is to be fired at once with the lines connected to a single energy source, the ferrite line resistances need to be very close to prevent all the energy being deposited across only one line. The solution is to have a separate power source for each line.

Figure 3 is a 3-D schematic of the device. The ferrites are reinforced by enclosing them in a ceramic sleeve to counteract forces created by rising and falling magnetic fields created by the discharge. Figure 4 shows the device. In Fig. 5 we show the flash across the ferrite rod. The flash is taken at 5 meters distance with 10^4th attenuation.

Spectra of VUV Flash in the 1200-2800 Angstrom Region

Gross, et al.[12] have looked at the absolute light flux emitted by an FFPS using several bandpass filters to estimate an approximate flux density at various regions of the ultraviolet and the visible regions of the spectrum. They concluded that the blackbody temperature in the VUV was 35,000 ^{o}K at 140 nm and 20,000 ^{o}K in the visible and does not behave with a Plank type distribution. This data is for a gas mixture of 450 torr of argon, 50 torr of nitrogen and from 0 to 12 torr of XeF_2. The absolute measurements were made assuming the source was a Lambertian emitter. The energy stored in the capacitors was 3.5 KJ. As this is the only estimate of spectral emmision from a FFPS device that we know of, we undertook to study the relative spectral emission in the vacuum ultraviolet region of 1200-2800 angstroms in some detail.

Figure 6 gives the experimental set-up of the spectroscopic study. The formed ferrite flash source device is connected to a 1/2 meter McPherson vacuum spectrometer via a 1 meter pipe. Light is detected by a solar blind R1220 Hammamatsu photomultiplier with a CsTe photocathode and MgF_2 windows. With a 1mm output aperture for the spectrometer, the resolution of the spectra is approximately 17 angstroms. Figure 7 gives the temporal responses of the voltage and photomultiplier at various wavelengths. We note that the temporal behavior is quite differently at different wavelengths. Certain wavelengths have large light contributions late in time due to recombination mechanisms. Thus, the best data to plot is the peak light intensity at early times when the contributions are definately caused by the discharge. Figures 8 and 9 give the relative light intensities from the flash source for 600 torr and 400 torr of argon respectively and for various values of charging voltage. The pulse power is a spark gap switched capacitor system with a capacitance of 4.4 μF. The data have been corrected for the photomultiplier and grating responses. We see that the intensity is continuously rising as we go to shorter wavelengths and should peak substantially below 1200 angstroms. From the rate of rise of the spectra in going toward shorter wavelengths we see the discharge for 400 torr argon is hotter than that for 600 torr argon. This is interpreted as due to higher electron energies in the lower pressure discharge as mean electron energies should go proportionately with E/N. An equivalent blackbody temperature appears to be substantially higher than that estimated by Gross et al.[12]

Discussions

From this spectroscopic study of light produced in the region from 1200-2800 angstroms we find that the estimated blackbody temperature appears to be substantially hotter than the 35,000 ^{o}K estimated by Gross et al. Optimization of the peak, or effective temperature appears possible and should vary as the inverse of the argon buffer gas pressure (E/N). For optimal coupling to the peak absorption of XeF_2 at 150 nm one need to go to much higher pressures.

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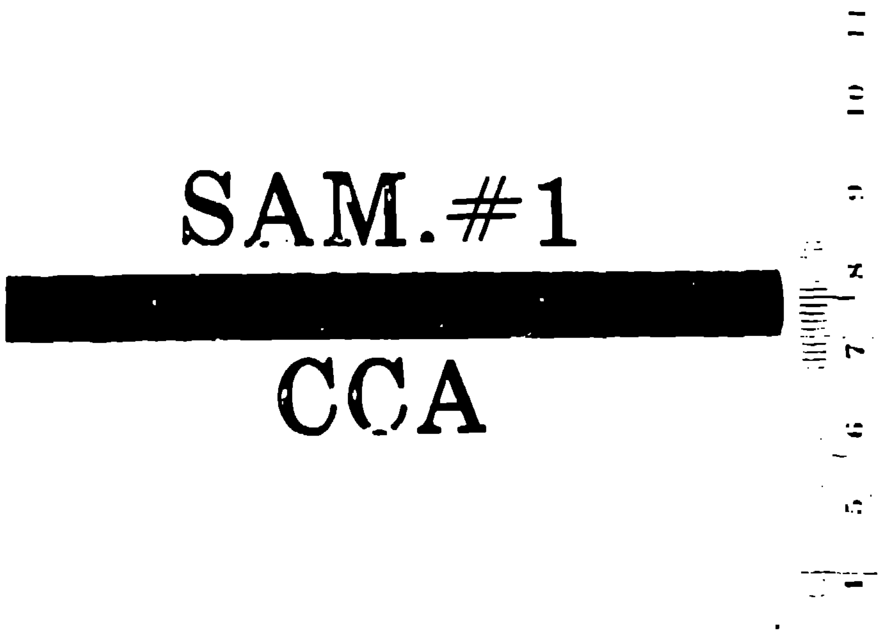


Figure 1. 1 mm lines written by YAG laser on RMX ferrite.

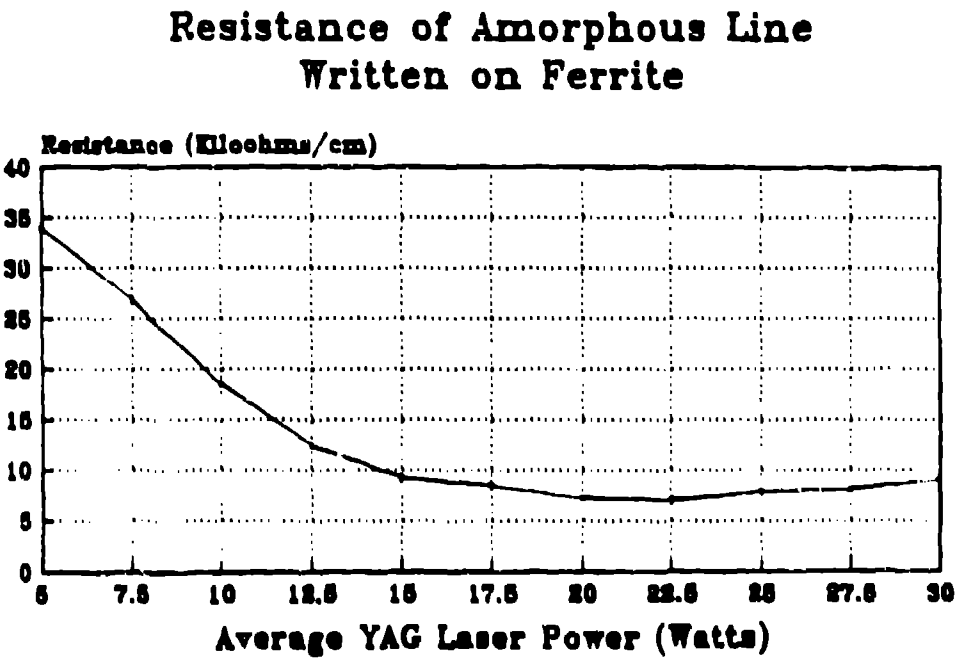
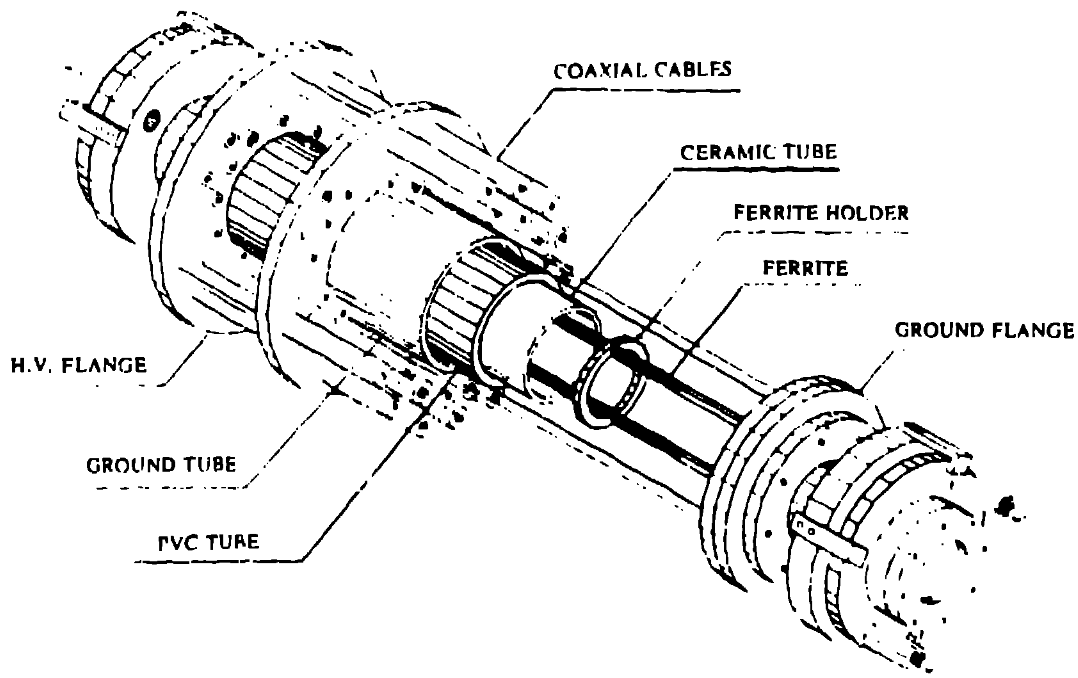


Figure 2. Resistance of amorphous line written on RMX ferrite by a YAG laser. Resistance is for a 1 mm line written with various YAG laser power. Lines are written on a single piece of ferrite.



SURFACE DISCHARGE PUMPED LASER

Figure 3. Three dimensional view of formed ferrite flash device.

Figure 4. Photograph of apparatus operating.

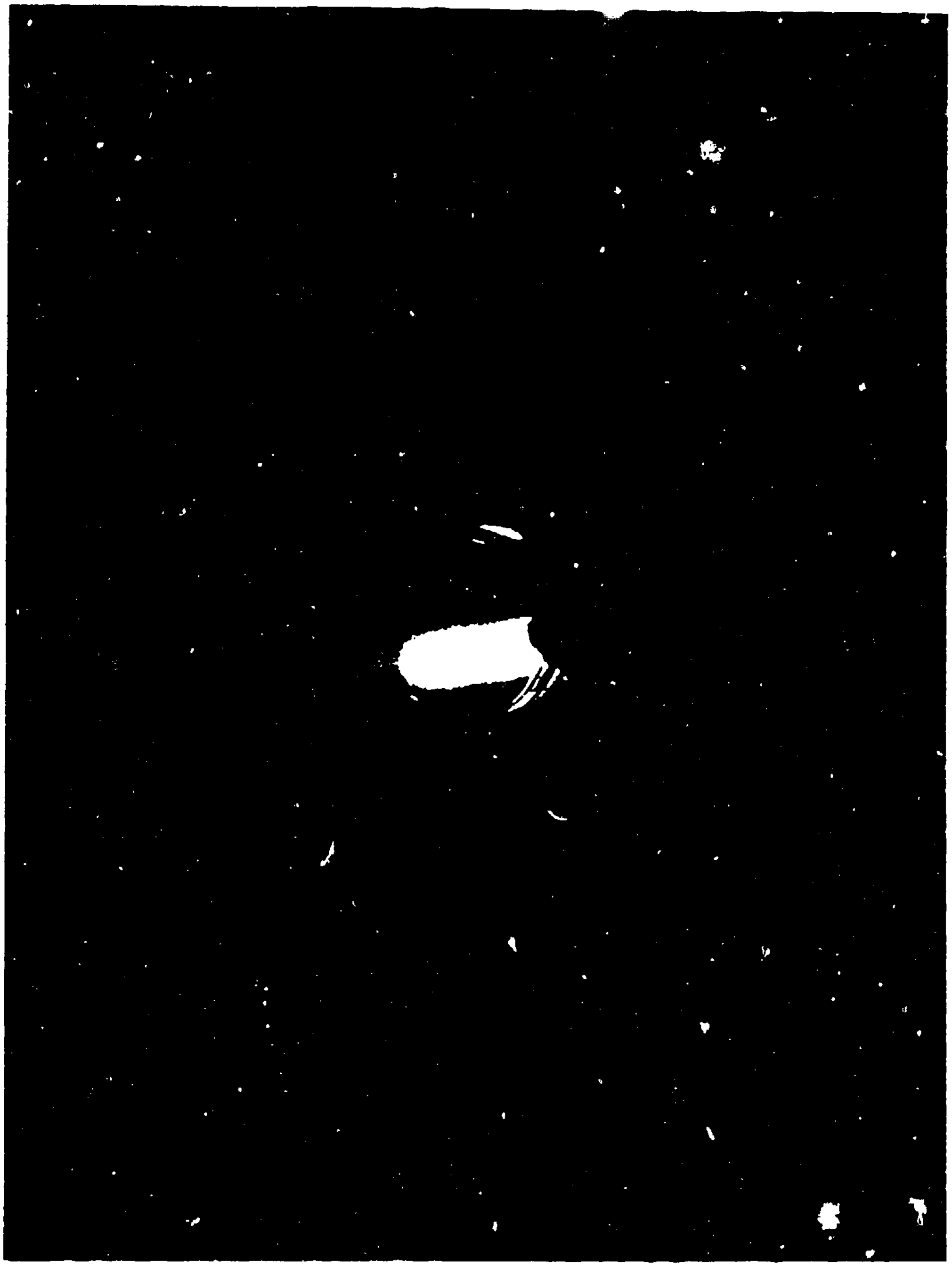


Figure 5. View of the VUV flash taken with 10^4 th attenuation and at a distance of 5 meters.

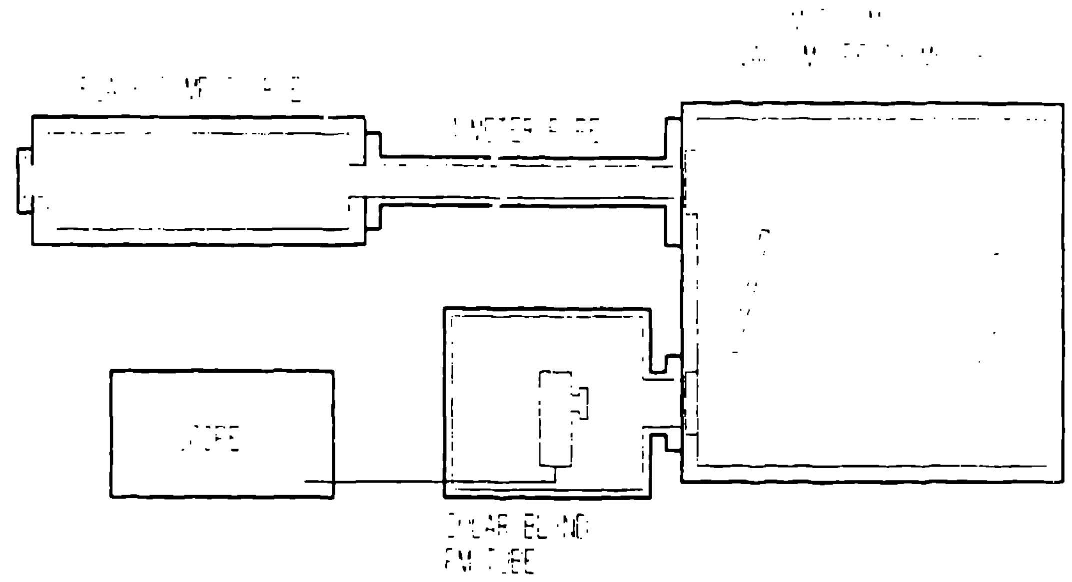


Figure 6. Experimental set-up for VUV flash spectral content in the 1?00-2800 angstrom region.

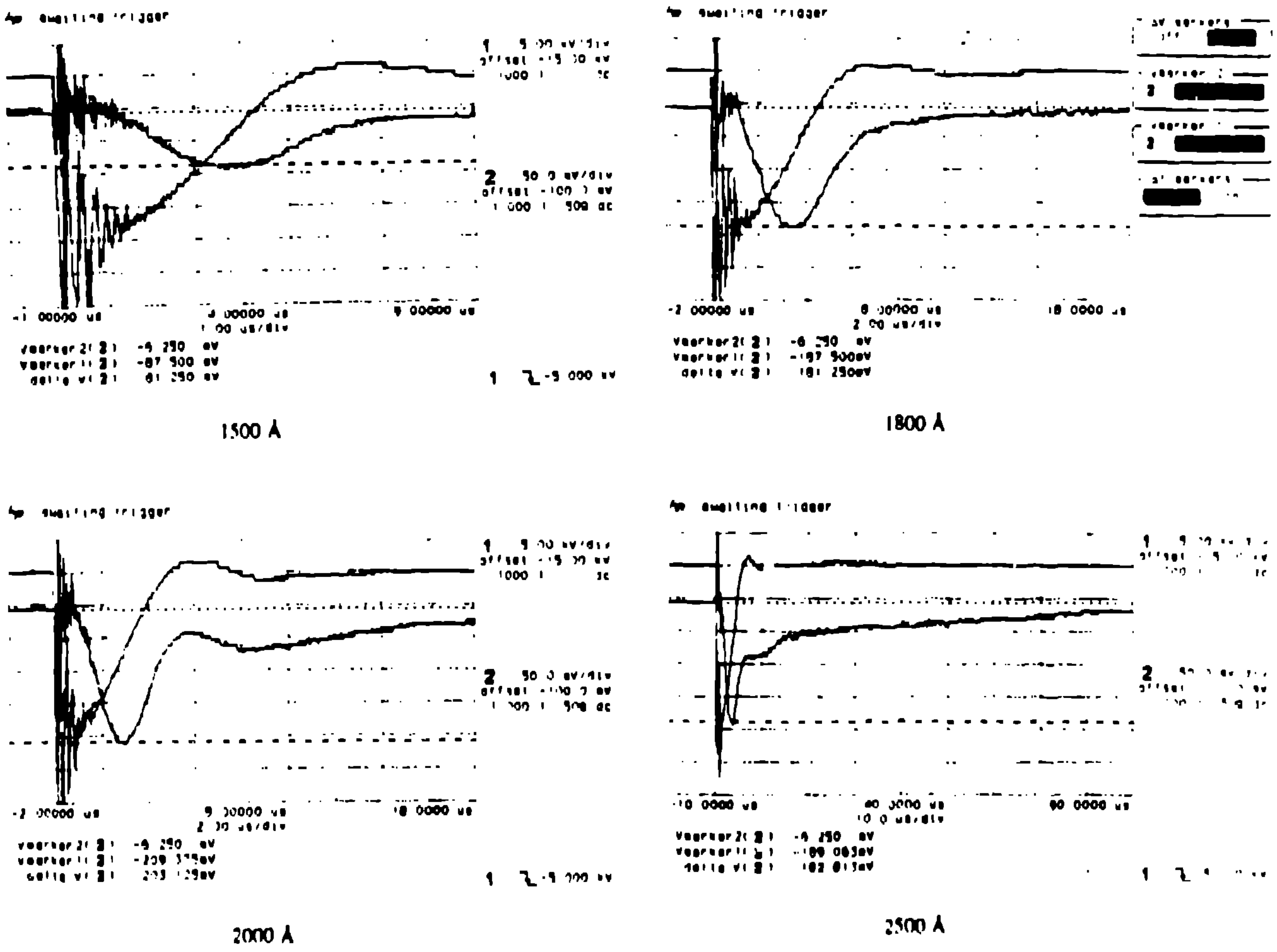


Figure 7. Temporal behavior of VUV flash at various wavelengths.

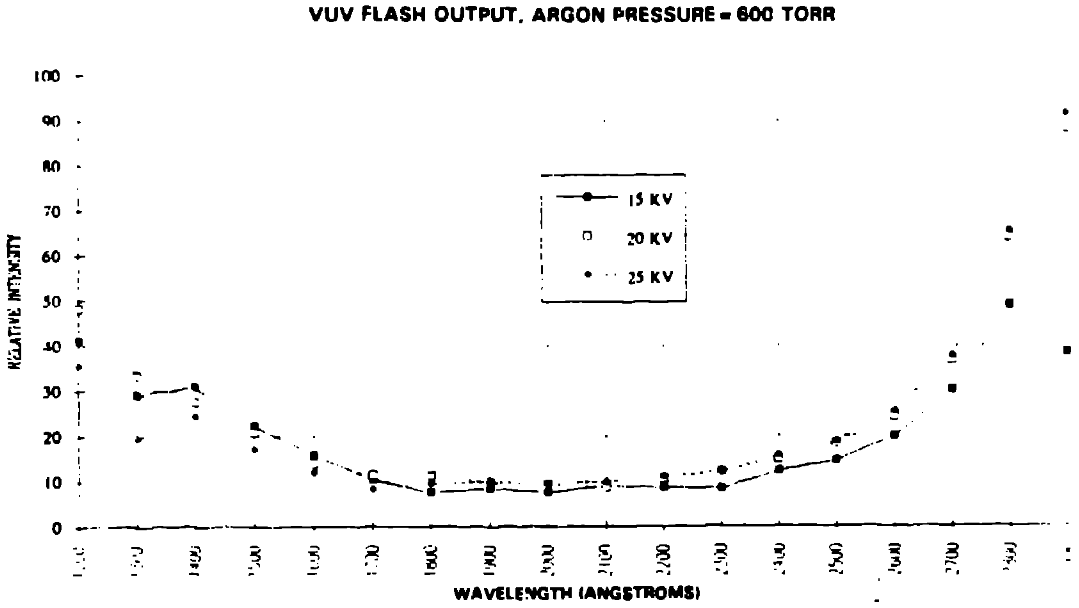


Figure 8. Relative VUV output as a function of wavenelgth and for different charging voltages with 600 torr of argon buffer pressure.

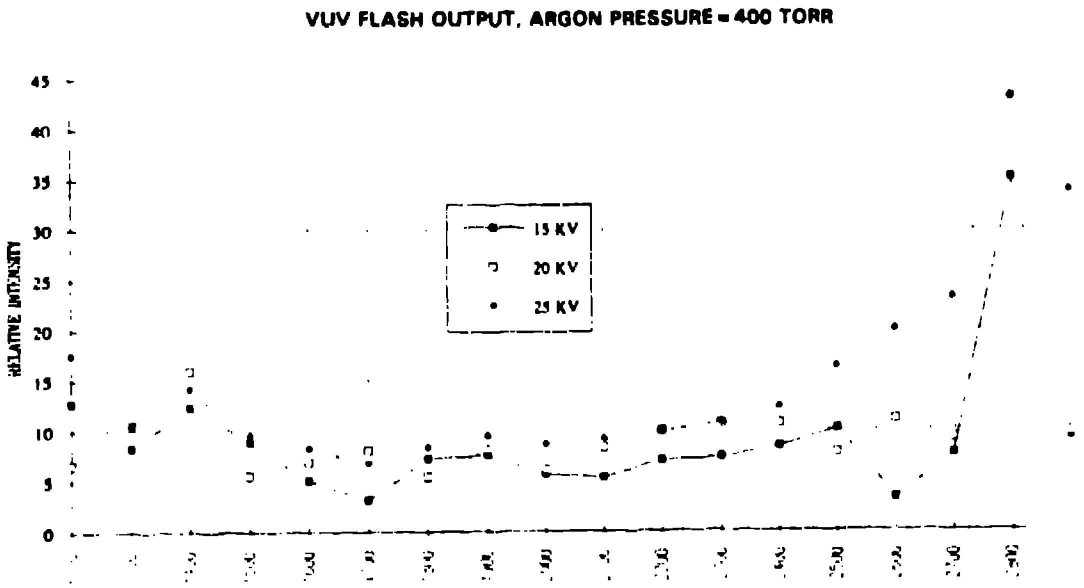


Figure 9. Relative VUV output as a function of wavenelgth and for different charging voltages with 400 torr of argon buffer pressure.