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Direct Measurement of Xenon Flashtube Opacity* NASA CR 56917

by

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ABSTRACT

The optical transmission of a xenon flashtube has been measured at wavelengths from 2500 Å to 10,000 Å and at currents up to 5000 amperes per cm^2. It is found that the absorption increases with current and with wavelength. Above about 5000 Å and a current of 4000 amperes per cm^2, a discharge tube 1 cm thick is nearly opaque. At shorter wavelengths or lower currents, the discharge is fairly transparent.

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INTRODUCTION

The xenon flashtube, almost exclusively, is used as the pump source for pulsed solid state optical masers. The great demands placed by high power optical masers on the flashtube have initiated several investigations into the more detailed nature of these devices.[1-7] In the design of pumping geometries for high power optical maser systems it is important to know how opaque the flashtube is to its own radiation. From the point of view of efficiency one would also like to know the diameter and current density at which a flashtube becomes "black" in a given region of the spectrum. There has also been much recent interest in doping xenon flashtubes to enhance the radiation in a given region of the optical spectrum. Doping could be effective only if the flashtube were relatively transparent at the wavelength of interest.

Presently there are many types of xenon flashtubes in use. These range from large helices, with arc lengths up to several meters, down to small linear lamps with a few centimeters of arc length. These flashtubes are operated under a wide range of conditions. Peak current densities vary from 500 amperes/cm^2, for large helical tubes operated at low voltages, to 30,000 amperes/cm^2 in short linear lamps operated at high voltages. The wide range of current densities in use, and the many different optical maser materials of interest, dictate that the opacity of the xenon plasma should be measured both as a function of current density and of wavelength. It is the purpose of this paper to

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present opacity measurements of the xenon flashtube as a function of both these variables.

EXPERIMENTAL

It was decided that a direct measurement of the transmission would be advantageous inasmuch as measurements of light output with and without mirrors behind the flashtube are sometimes difficult to interpret. A direct measurement could be made by passing a beam of fairly monochromatic light through the operating flashtube and comparing the intensity of this probe beam to the intensity of the probe beam when the flashtube is not operating (Fig. 1). This technique requires a small, extremely high intensity pulsed light source. Several types of pulsed light sources were tested and all found to be insufficient for the purpose. Finally, a xenon cw short arc lamp was used as a pulsed light source by superimposing a high voltage capacitor discharge on the continuous dc arc. Previous measurements had suggested its use as a high intensity pulsed source.[8,9] The lamp used was a PEK X-80 Xenon short arc, which was developed for this purpose by replacing the usual molybdenum foil seals with tungsten rod seals to withstand the high current pulse of the capacitor discharge.[10] It was found that discharging a 0.05 μf capacitor, charged to 16 kv, by means of a triggered spark gap through the X-80 provided, with quartz collecting lenses and monochromators, a suitable probe beam. The signal at the detector from the probe lamp during its 5 microsecond pulse, was approximately as large as that from the lamp under test.

The flashtube on which the measurements were made was an XE-17-$6\frac{1}{2}$ ($\ell = 6\frac{1}{2}$", d = 12 mm) modified by PEK Laboratories. The center one inch of the flashtube was approximately 10.5 mm square in cross section to facilitate passage of the probe light beam. This flashtube had tungsten electrodes and was filled to a pressure of 300 Torr, as this pressure is most commonly used in commercial flashtubes. The current was measured with a device, developed in this laboratory, which allows the accurate measurement of large pulse currents with rates of rise in excess of 10^{10} amps/sec. This unit consists of a completely symmetrical Faraday shielded loop placed between the conductors of a coaxial line and used in conjunction with the Tektronix type O operational amplifier as an integrator. This current probe will be described in detail elsewhere.[11]

The experimental layout is shown in Fig. 1. The flashtube is operated from a 480 μf capacitor bank in series with a 100 μhy inductor to limit the rate of rise of current, so that a stable arc can be formed. The experiment is initiated by triggering the flashtube in the usual manner. A trigger pulse from the inductor starts one sweep of the dual beam oscilloscope (Tektronix 555). This channel displays the current pulse through the flashtube. At the peak of the current pulse (approx. 370μ sec after initiation), the delayed trigger output of the oscilloscope triggers the second beam and pulses the X-80 by triggering the spark gap switch. The second beam then shows the intensity of the probe light pulse transmitted through the flashlamp. This sequence is then repeated without operating the flashtube, and the results are compared. The light output of the pulsed X-80 is monitored with a second oscilloscope to insure uniformity of the two pulses.

Two monochromators are used in this experiment. The first is used to select a small portion of the broad spectrum of the pulsed X-80, so as to avoid heating the plasma in the flashtube by absorption of the entire output of the probe lamp. The second monochromator was used to improve the signal to noise ratio at the receiving photo diode. The signal to noise ratio was further improved by using a 25 kc high pass filter, modified to improve its pulse response, to discriminate between the 5μ sec pulse of the probe beam and the 700μ sec pulse of the flashtube being measured. With the filter, the probe light intensity was a factor of 10 greater than the minimum needed. Both photo diodes used in this experiment were checked for linearity over the range of interest.

To determine if this measurement was dependent on the past history of the discharge, the dependence of opacity on current was obtained by two methods:

(1) As described above, the measurement of opacity was done at the peak of the current pulse through the flashlamp. The capacitor bank was charged to successively higher voltages and the higher peak currents allowed the transmission to be plotted as a function of current.

(2) A series of equal high current pulses were

discharged through the flashlmap. On each succeeding pulse the measurement was delayed an additional 50μ sec. This also allowed the transmission to be plotted as a function of current.

These two techniques produced equivalent results and lend credence to the statement that, under the conditions of this experiment, the opacity is not dependent on the past history of the discharge on these time scales. With much higher currents or longer pulses, vaporization of the quartz envelope might occur, and this would produce a time-dependent absorption.[4] The intensity of the probe beam was changed by a factor of 10 without change in the absorption constant. The diameter of the probe beam was varied from 0.3 to 1.0 cm and the plasma was found to be homogeneous throughout this cross section.

RESULTS AND CONCLUSIONS

The results of these measurements are shown in Figs. 2-9. From 2500 Å to 3500 Å the passband of the monochromators was 32 Å, from 4000 Å to 6500 Å, 64 Å and from 7000 Å to 10,000 Å, 128 Å.

Figure 10 is a composite to summarize a portion of the data at low current densities where the discharge is not yet opaque. It will be noted that there is a dip in the transmission curve near 9500 Å. This can be attributed to the presence of several strong xenon lines near this wavelength.

The continuum absorption is produced by free-free and bound-free transitions in the xenon plasma.[12] In this plasma, atoms and ions in highly excited states are fairly numerous, and these have large absorption cross-sections. The continuum absorption coefficient is found to be approximately proportional to the square of the current density, and to vary with a power of the wavelength between 1 and 1.5. It is not clear how generally these approximate relations will hold. At low current densities, where the continuum absorption is weak, there remain atomic absorption lines.

It is quite important to note here that in a large region of the spectrum the discharge becomes nearly black at quite modest current levels. This implies that doping of the xenon discharge at these pressures and currents could not be expected to result in a very large gain of intensity in the visible and infrared portions of the spectrum. If high power outputs from this system are desired, they can be attained only by raising the temperature of the plasma. If the discharge were black at all wavelengths, the output would increase as T^4. However, in a fixed pumping band in the red, the output would rise only linearly with T at sufficiently high temperature, or as the fourth root of the total radiated power. On the other hand, the violet and ultraviolet output rises very rapidly,[3] especially for real lamps which are not completely black. Thus, an increase in plasma temperature greatly increases the pumping light output only if the short wavelengths can be used. A really large increase in output in the red region could only be expected from a different system which radiates but does not absorb, or from a system which is transparent everywhere except at the radiating region.

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FIGURE CAPTIONS

Fig. 1. Functional diagram of the absorption apparatus.

Fig.2-9. Transmission through 1 cm of xenon flashlamp, as a function of current density and wavelength.

Fig. 10. Current density for constant transmission, as a function of wavelength.

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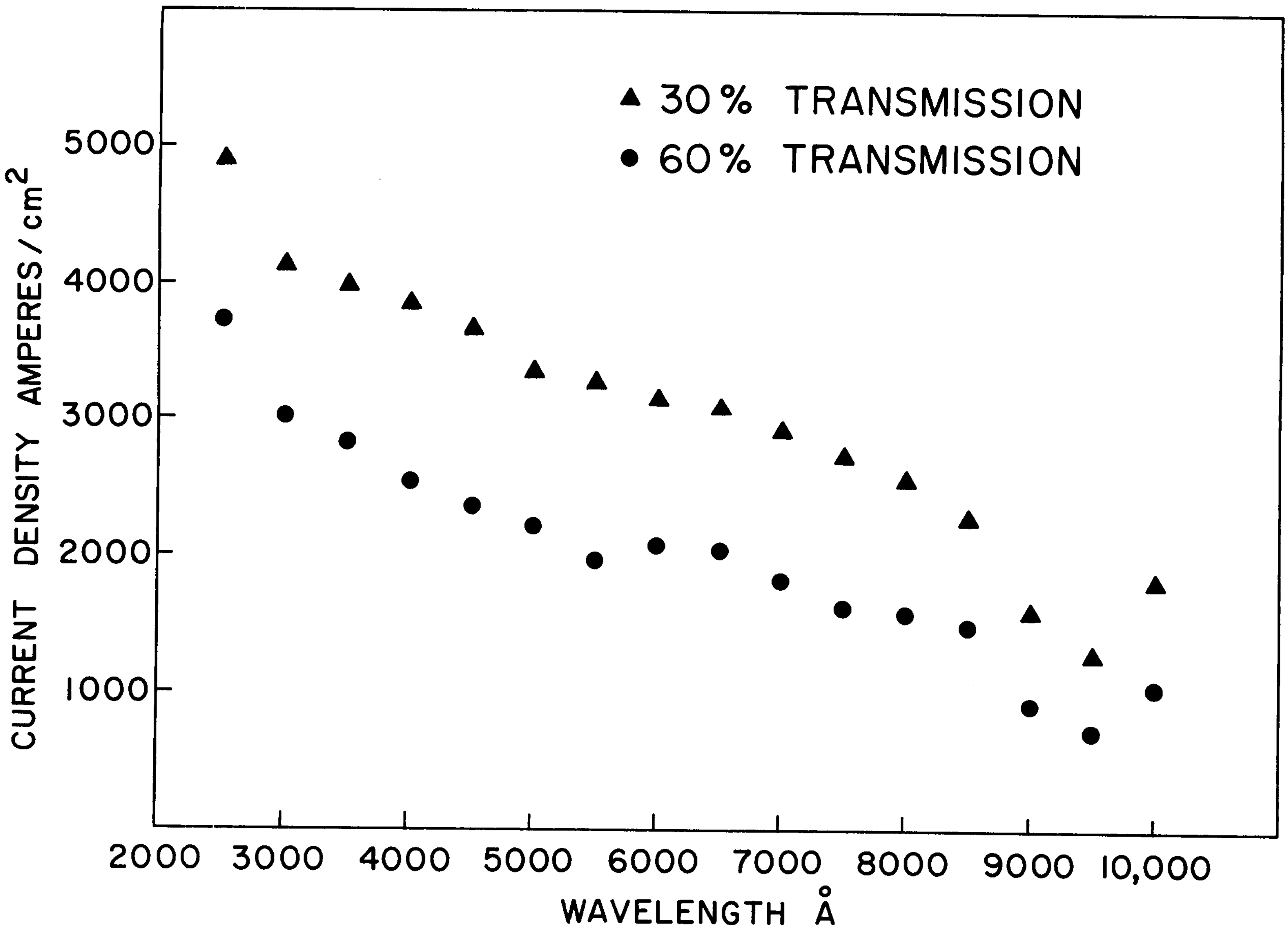
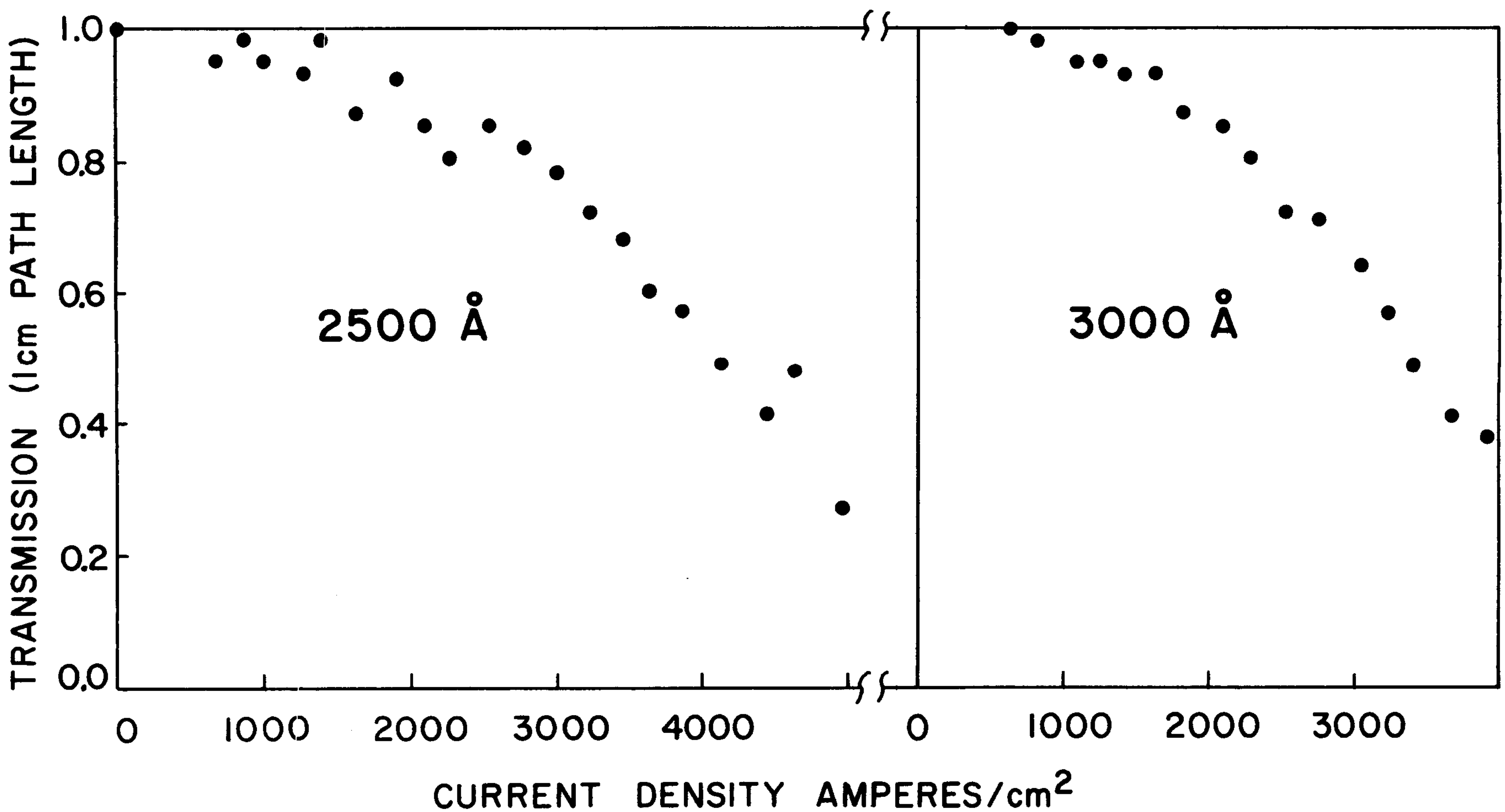
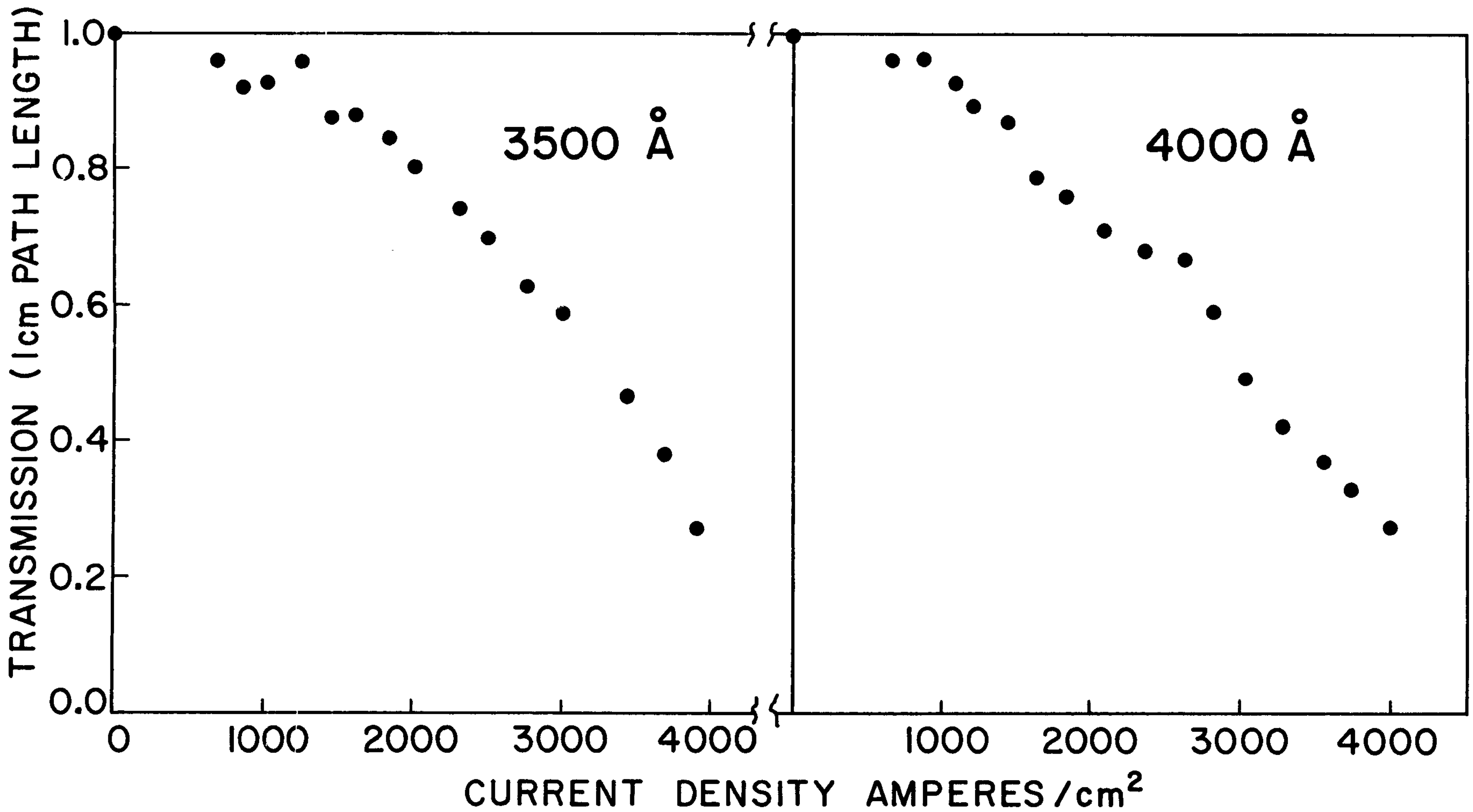
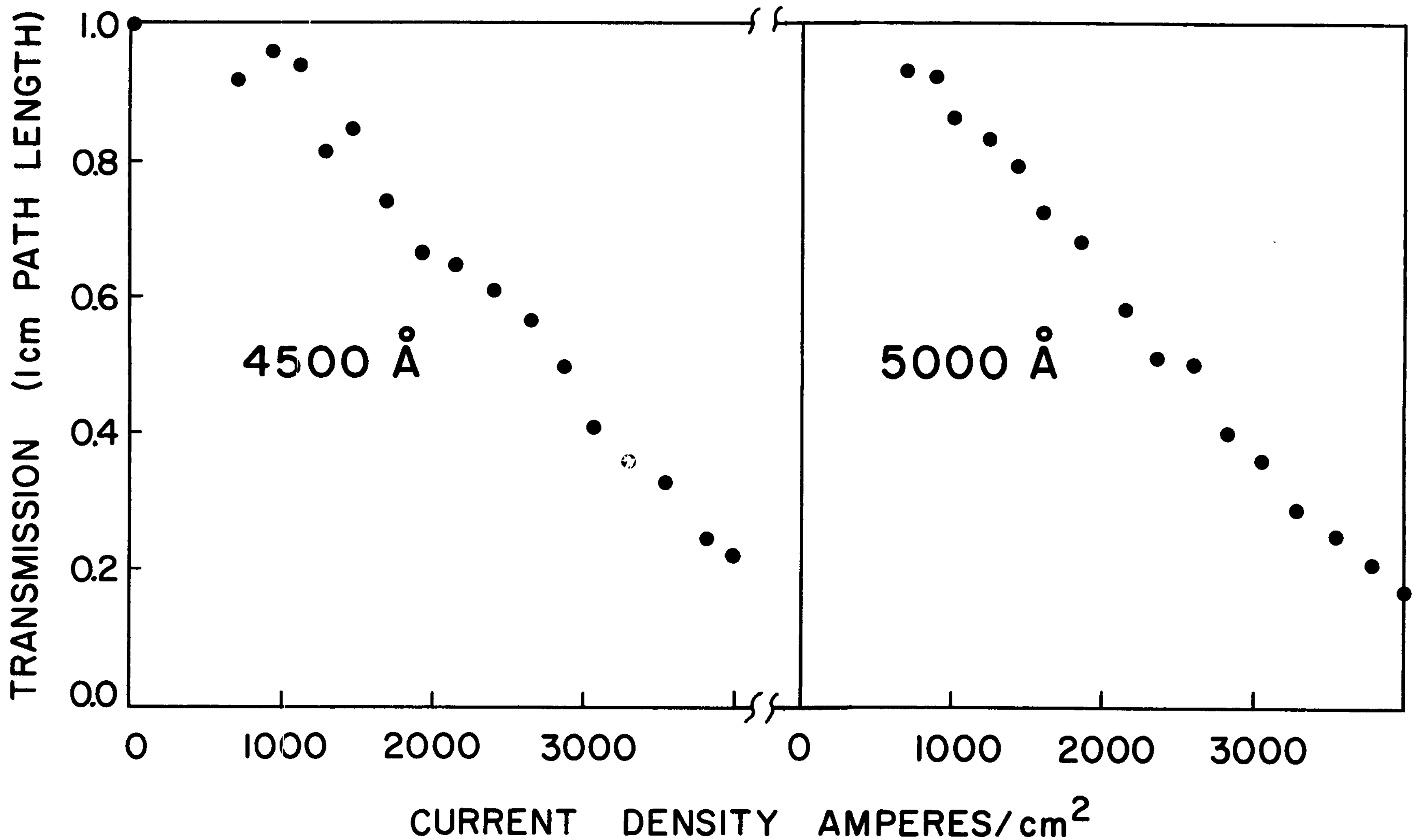


30% TRANSMISSION
60% TRANSMISSION
CURRENT DENSITY AMPERES/cm2
5000
4000
3000
2000
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
WAVELENGTH Å

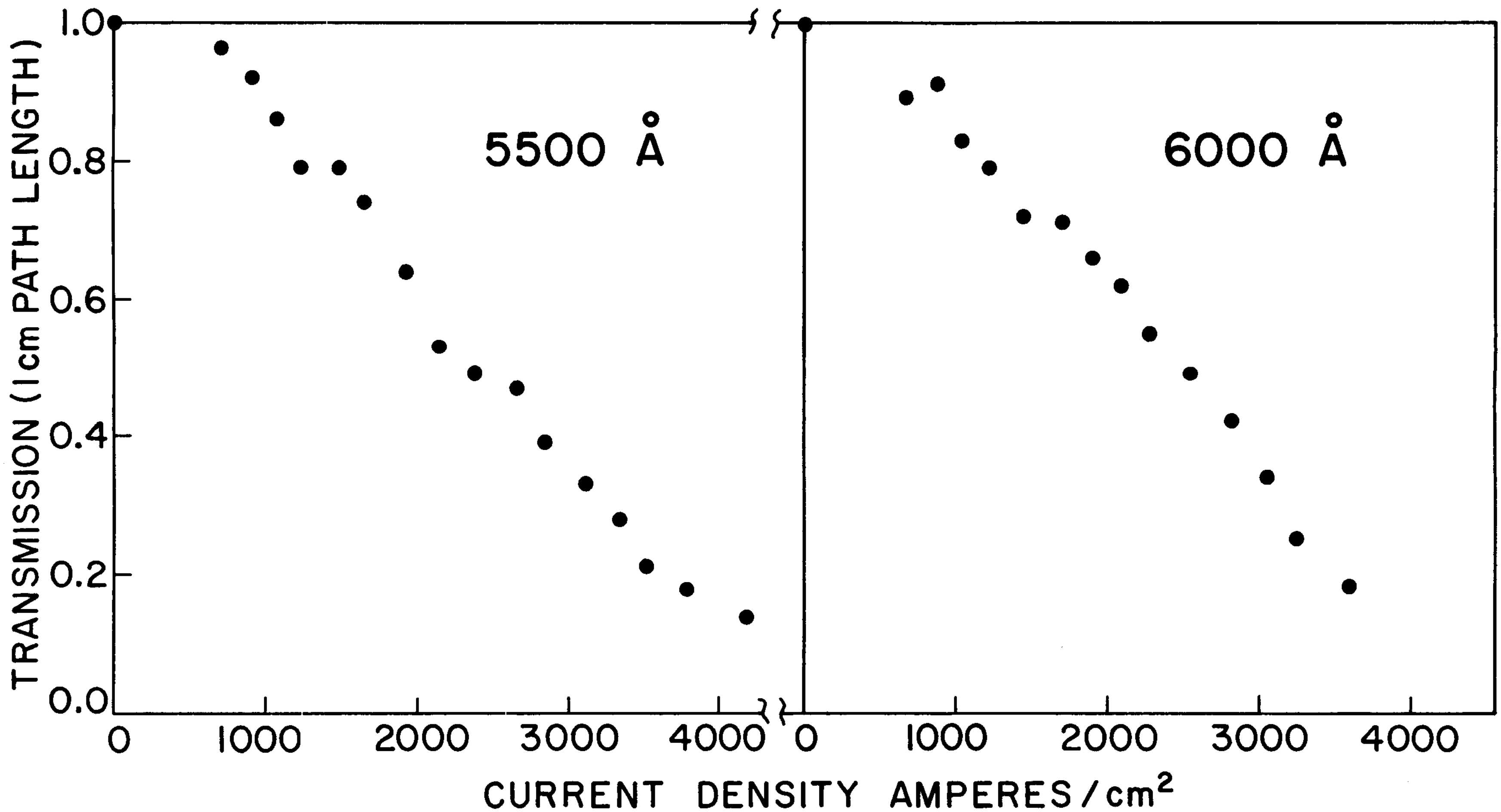

TRANSMISSION (1cm PATH LENGTH)
1.0
0.8
0.6
0.4
0.2
0.0
2500 Å
3000 Å
0
1000
2000
3000
4000
0
1000
2000
3000
CURRENT DENSITY AMPERES/cm2



TRANSMISSION (1cm PATH LENGTH)
1.0
0.8
0.6
0.4
0.2
0.0
3500 Å
4000 Å
0
1000
2000
3000
4000
1000
2000
3000
4000
CURRENT DENSITY AMPERES/cm²



TRANSMISSION (1cm PATH LENGTH)
1.0
0.8
0.6
0.4
0.2
0.0
4500 Å
5000 Å
0
1000
2000
3000
0
1000
2000
3000
CURRENT DENSITY AMPERES/cm2


5500 Å
6000 Å
TRANSMISSION (1cm PATH LENGTH)
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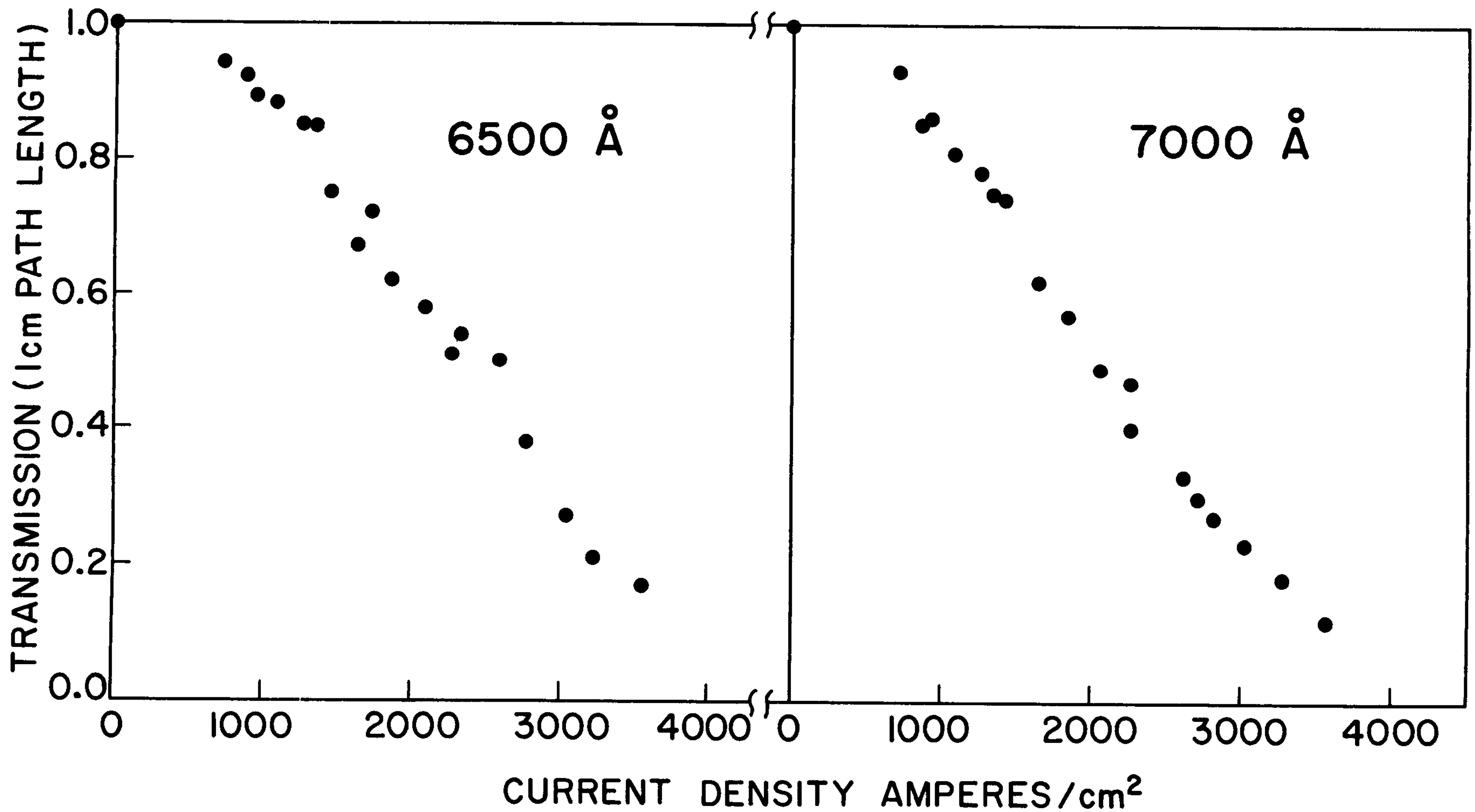
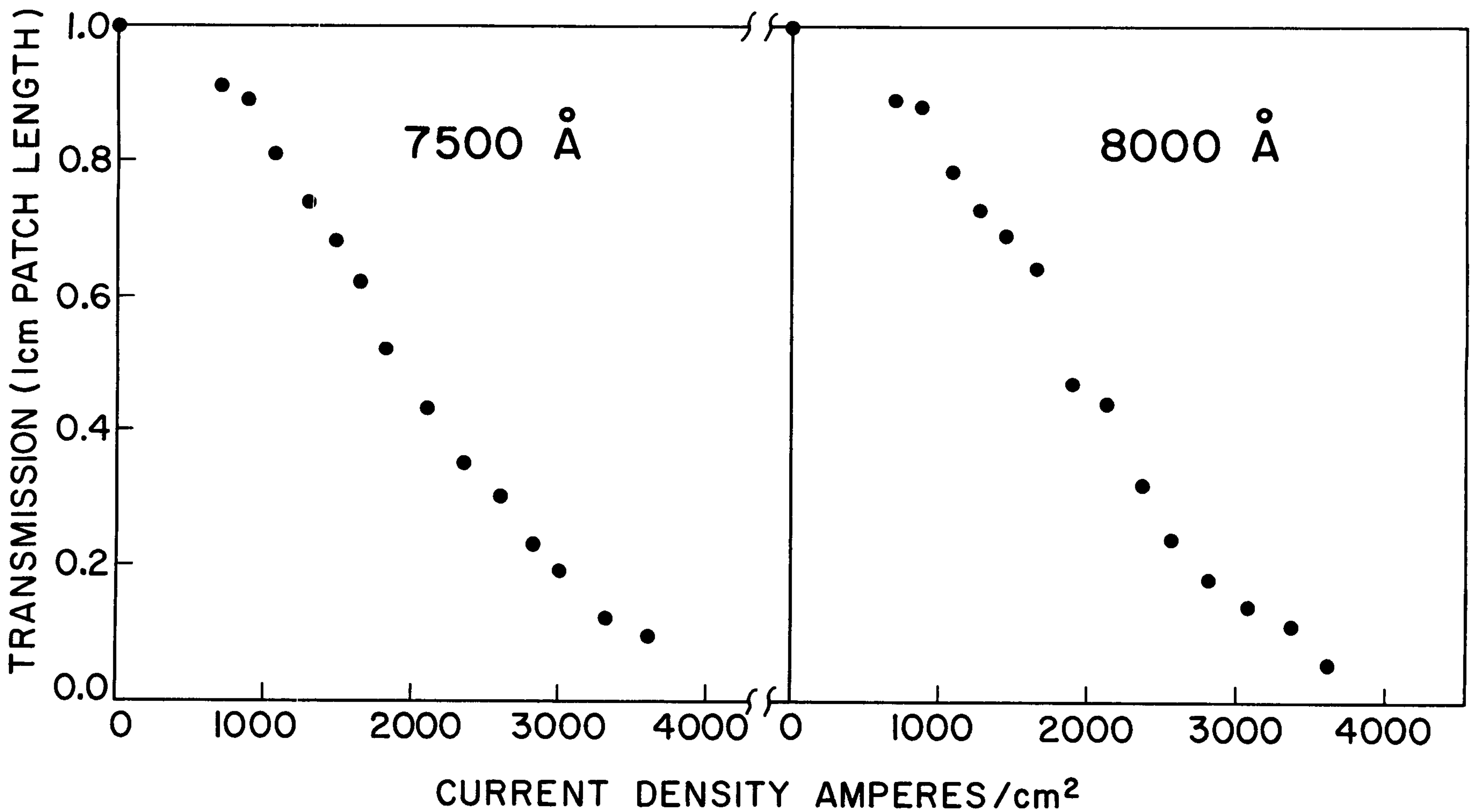
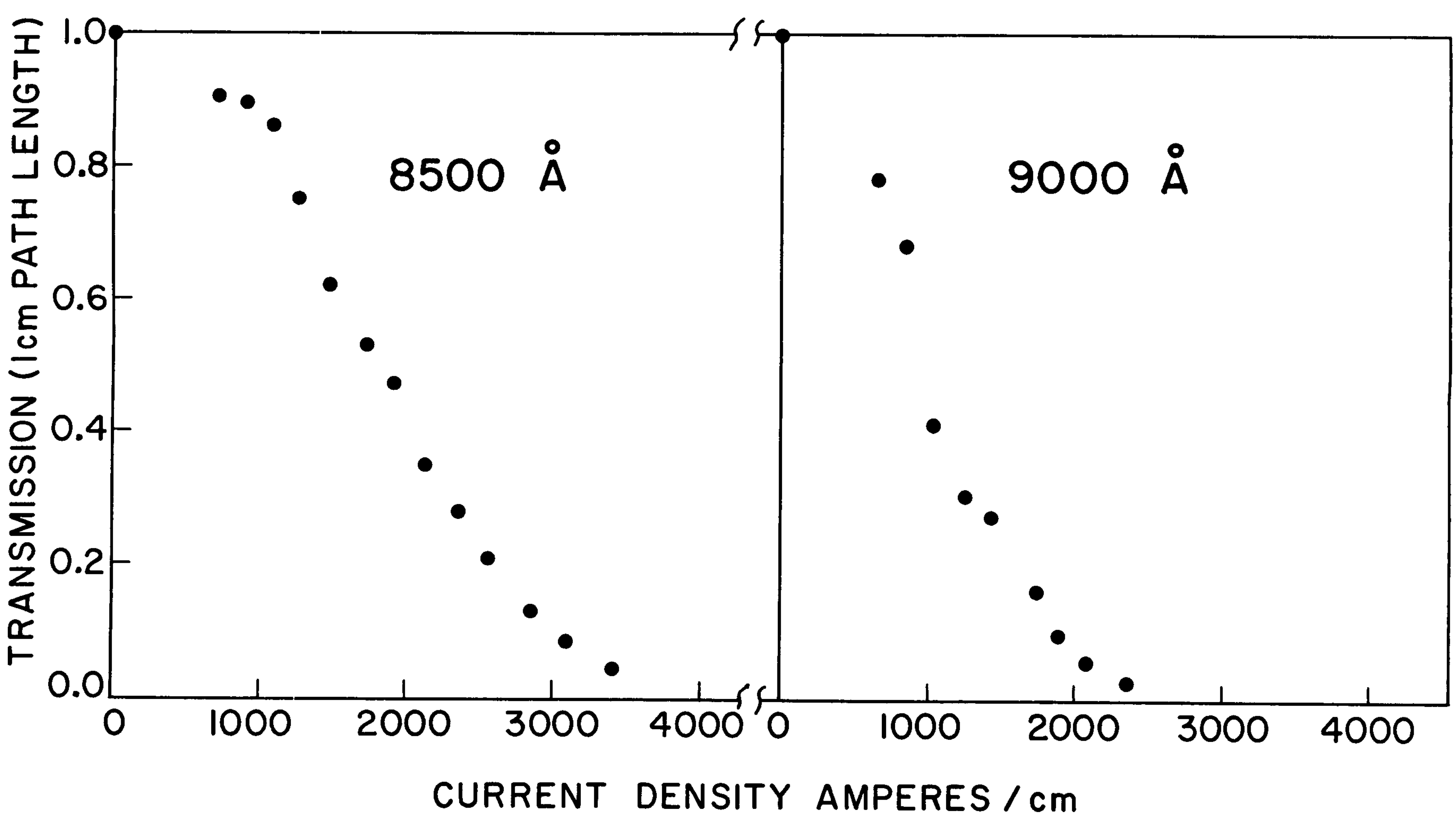
0.8
0.6
0.4
0.2
0.0
0
1000
2000
3000
4000
CURRENT DENSITY AMPERES/cm²


6500 Å
7000 Å
TRANSMISSION (1cm PATH LENGTH)
1.0
0.8
0.6
0.4
0.2
0.0
0
1000
2000
3000
4000
CURRENT DENSITY AMPERES/cm²


7500 Å
8000 Å
TRANSMISSION (1cm PATCH LENGTH)
1.0
0.8
0.6
0.4
0.2
0.0
0
1000
2000
3000
4000
CURRENT DENSITY AMPERES/cm2


8500 Å
9000 Å
TRANSMISSION (1cm PATH LENGTH)
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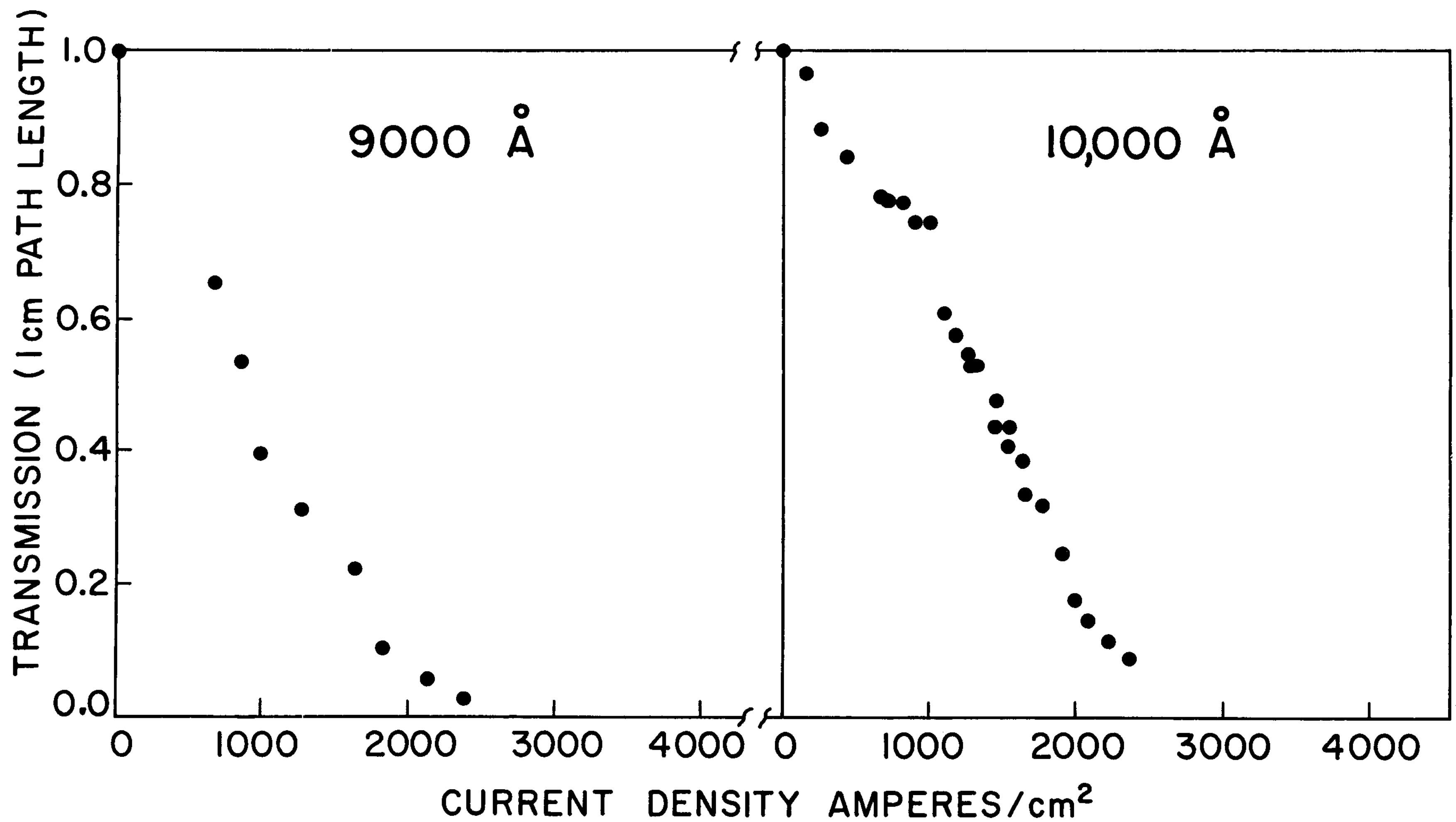
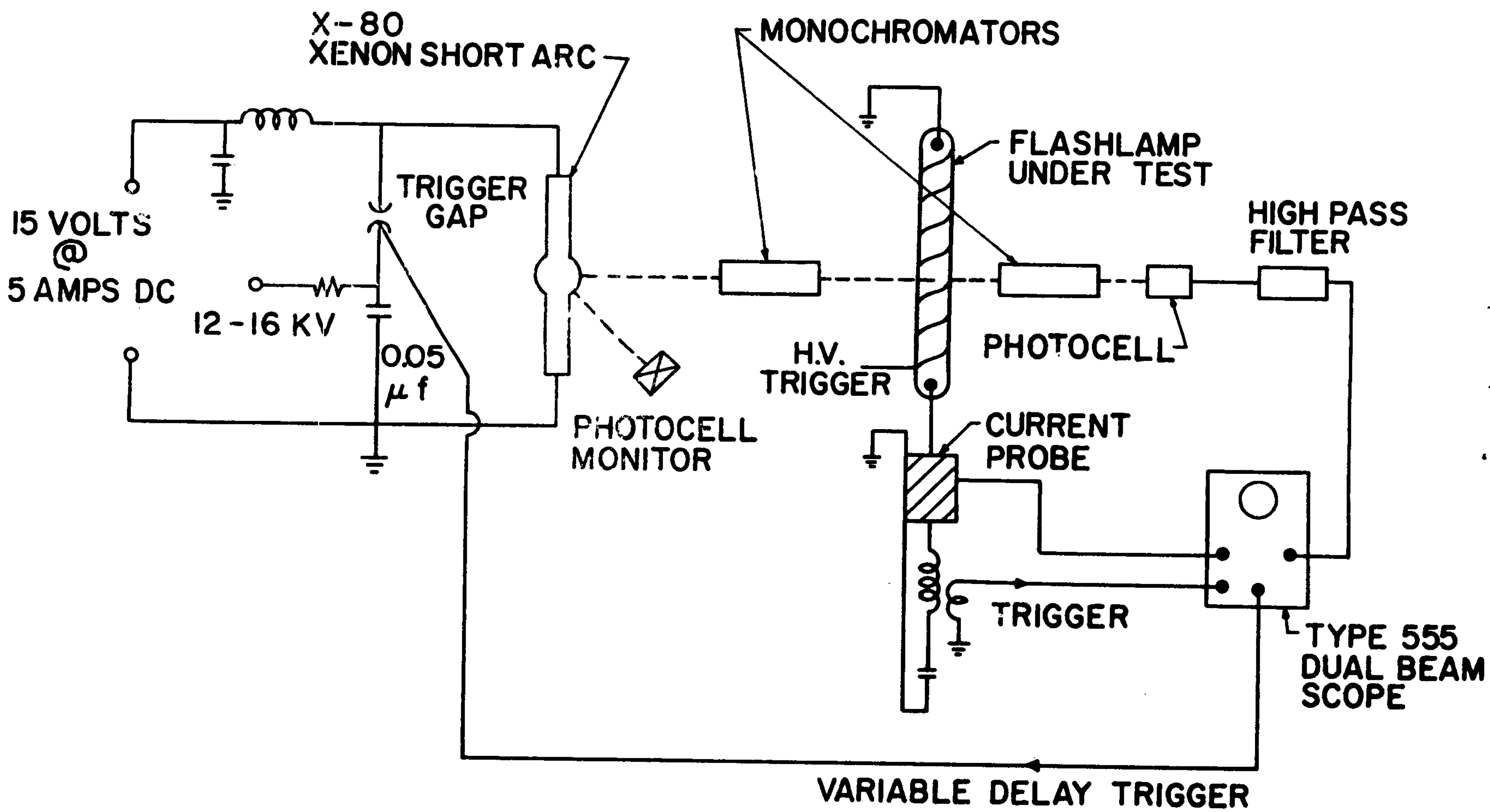
0.8
0.6
0.4
0.2
0.0
0
1000
2000
3000
4000
CURRENT DENSITY AMPERES / cm



9000 Å
10,000 Å
TRANSMISSION (1cm PATH LENGTH)
1.0
0.8
0.6
0.4
0.2
0.0
0
1000
2000
3000
4000
0
1000
2000
3000
4000
CURRENT DENSITY AMPERES/cm²


X-80
XENON SHORT ARC
15 VOLTS
@
5 AMPS DC
12-16 KV
TRIGGER
GAP
0.05
μf
MONOCHROMATORS
FLASHLAMP
UNDER TEST
HIGH PASS
FILTER
PHOTOCELL
H.V.
TRIGGER
PHOTOCELL
MONITOR
CURRENT
PROBE
TRIGGER
TYPE 555
DUAL BEAM
SCOPE
VARIABLE DELAY TRIGGER