CHAPTER V

LUMINOSITY AND SPECTRAL ANALYSIS OF AN OPERATING MgO CATHODE

5.1 Luminosity Studies

The presence of the distinctive blue glow of an operating MgO cathode and its variation in intensity with the emission current suggested that it would be of value to measure these phenomena in detail. These measurements can be distinctly classified under two headings, viz.,

(a) Luminosity vs emission current density, and

(b) Luminosity vs temperature.

5.2 Luminosity vs Emission Current Density

At low values of emission current (of the order of a few μa), luminescence is observed only at a few discrete points along the cathode surface. However, at currents of the order of 1 ma, luminescence spreads, and the whole cathode glows with a pale blue color.

Measurements of the absolute value of luminosity of an operating cathode as a function of anode current were made to determine whether any definite relationship holds between luminosity and anode current. Luminosity
measurements were made with a sensitive "Spectra" luminosity meter. The photomultiplier tube in this instrument had S4 emission characteristics. Figure 20 shows the behavior of luminosity as a function of anode current. The I-V characteristic of the tube was also plotted on the same graph paper for comparison.

We observe from these curves that the current rises exponentially with the voltage, between $10^{-6}$ amp and $2 \times 10^{-3}$ amp. With further increase in voltage, the curve exhibits a negative resistance characteristic. The luminosity curve also follows a similar pattern over a fairly wide range. We can therefore relate them by an empirical law:

\[
\text{Luminosity} = \text{constant} \times \text{voltage} \quad (64)
\]

5.3 Luminosity vs Temperature

The temperature of the cathode increases with increasing current density due to electron energy dissipation in the coating, therefore it was felt that an investigation of luminosity as a function of temperature alone (keeping the emission current density constant) would furnish useful information.
Figure 21 illustrates the variation of luminosity with temperature. These measurements were made by stabilizing the tube each time at 200 μa. Increasing the cathode temperature caused the anode current to increase, therefore, it was necessary to reduce the anode voltage each time to maintain the current at a steady value of 200 μa. We see from Figure 21 that the luminescence has a tendency to decrease beyond 200°C. The drop in luminescence is pronounced in the region between 200-500°C, beyond which it flattens off until around 750°C where the cathode "pops out." The S4 response of the luminosity meter is insensitive to thermal radiation in the temperature range investigated.

Use of this luminosity meter enabled to sample an active area that was small compared to the total surface area of the cathode.

5.4 Spectral Analysis

In order to investigate the physical processes associated with this emission it was felt that a determination of spectral distribution of this radiation would be useful in understanding the self-maintenance of an MgO tube. Our model predicts that some of the primary electrons, while
penetrating the barrier by avalanching, recombine, producing a continuum in the UV region, thereby maintaining the MgO layer a p-type semiconductor. The effect of recombination radiation is believed to be a link in the feedback mechanism which sustains emission in an operating MgO cathode. However, because electrons from the avalanching region are both very energetic and widely dispersed in energy, it would be expected that radiation from the avalanching region would appear as diffuse lines in the far UV. Another source of radiation would be from radiative recombination of electrons from the NiO layer with holes accumulated at the NiO-MgO interface.

Spectral data were obtained in the visible and the UV region. In order to undertake measurements in the UV, it was necessary to fabricate a cathode structure in an envelope with a window transparent to the UV.

The cathode structure, the sustaining grid, and the mica mount were carefully removed from a standard tube by breaking open the soft glass envelope. A fresh zirconium getter was installed in this structure and the whole assembly was immediately transferred to a type 7052 Corning glass envelope which had a 1-inch diameter sapphire window
sealed to it. The thickness of the sapphire window was 0.12 mm. The transmission was better than 60% at 2000 Å. The cathode was positioned in the tube in such a way that it was parallel to the plane of the window.

The assembled tube was then mounted on a vacuum system, evacuated, and processed in the usual manner. It was sealed-off the system at a pressure of 5 x 10⁻⁷ mm Hg, and the previously outgassed getter was flashed. The tube was aged at 2 ma for a week before spectral measurements were undertaken. Figure 22 shows the actual photograph of the tube on which these measurements were made. Also, a color photograph of an operating cathode is shown in Figure 23.

A Littrow auto-collimating (Bausch and Lomb) quartz spectrograph was used for photographing the spectrum. The spectrum from this instrument extended for a length of 700 mm between 2000 Å and 8000 Å, and was recorded on three 10-inch plates between the ranges 3440 to 6938 Å, 2500 to 3470 Å, and 2100 to 2900 Å. The dispersion of the instrument was 0.6493 mm per Å at 2180 Å, and 0.0198 mm per Å at 7298 Å.
The intensity of luminescence of the MgO cathode being relatively weak, it was necessary to use a short focal length quartz lens between the tube and the entrance slit of the spectrograph. It was also necessary to use a special wide slit which had a separation of about 200 microns. The exposure time had to be extended to 15 hours before any observable impression could be obtained on the photographic plate. An iron arc comparison spectrum was used for calibrating the plates.

In the region 3440 to 6938 Å, three distinct lines located at 3.08 ev, 2.85 ev, and 2.3 ev were detected. These lines had been observed previously by Woods and Wright\(^{(17)}\) under slightly different conditions. (Their samples were continuously bombarded with electrons from an electron gun. In the present experiment, the MgO tube was operated under self-sustained conditions.) In addition to these lines, a background continuum extended all the way down to 2760 Å (≈ 4.5 ev).

Our experimental tube incorporated a tungsten heater inside the cathode core. Using this heater, a study of the line intensities at elevated temperatures was undertaken. The spectrum was photographed in the visible region.
with the cathode operating at 490°C, 690°C, and 740°C. It was not possible to extend these observations to higher temperatures since the tube tended to become unsteady, and emission could not be maintained over a long period of time. The exposed plates were scanned with a Jarrell-Ash Model JA-200 microphotometer. A slit height of 3 mm and a slit width of 15 microns were used for all the densitometer readings. A 100% transmission was obtained on the clear (non-exposed) area of the plate prior to taking densitometer readings. Figure 24 shows the behavior of line intensity as a function of temperature. These observations indicate that a definite bleaching of the lines occurs as the temperature of the cathode is raised. This agrees with the temperature quenching of certain MgO bands which has been observed previously by Gandy. According to him, the relative intensities of the 3.6 ev and the 2.7 ev bands decrease rapidly as the temperature is raised from 350°K to 680°K.

5.5 Initiation of Self-Sustained Emission

Not much direct information is available about the processes involved during the initial excitation stage of cathode operation. During this period, an applied plate
voltage is, by itself, unable to initiate emission; a source of external excitation is also necessary. Some of the sources of external excitation used have been UV light, intense white light, radioactivity, electron bombardment, etc. One of the most efficient methods of external excitation is bombardment of the cathode by electrons from a thermionic heater located inside the tube.

It seems reasonable to expect that one function of the external excitation mechanism is to cause a positive charge to be built up on the MgO surface by a secondary multiplication process, or other means. Direct electron bombardment is probably the best way to build up the surface charge. An additional function of the initial excitation may be to convert the MgO outer surface layer to a p-type semiconductor.\(^{(19)}\) Holes produced at the surface then drift down to an interfacial layer which, in the usual case, is NiO. As the holes accumulate at the interfacial layer, the voltage builds up. If the external excitation is relatively weak or inefficient in the production of secondary electrons, a considerable time (hours) may elapse before the barrier voltage builds up to a high enough value to
initiate avalanching. Apparently, a field of the order of $1 \times 10^6$ volts/cm is necessary to cause avalanching through the NiO layer.

Schwarz\(^{(19)}\) has suggested a mechanism for surface layer hole conduction which appears to be relevant to this discussion. In order to properly activate a cathode, it is necessary to heat it to a temperature of the order of 800°C in low pressure air or O\(_2\). This is necessary even if the Ni sleeve has already been oxidized before being sprayed with MgO. In addition, measurements by Tung Sol have indicated that a measurable quantity of O\(_2\) is retained by MgO under conditions similar to those encountered in activating a cathode. It seems reasonable, therefore, to expect that a layer of O\(_2\) must be adsorbed onto the MgO for proper operation. Undoubtedly, one of the functions of the adsorbed O\(_2\) is to make MgO an efficient secondary emitter. Another function (as suggested by Schwarz) may well be to cause surface hole conductivity. The following paragraphs are partly abstracted from the work by Schwarz.

The final surface layer has most likely a complex structure consisting of a chemisorbed layer near the (MgO) surface and physically adsorbed layers on top of it.
The bond strength between the $O_2$ atoms and the particle decreases with increasing layer thickness so that the ions of the outermost layer approach the state of free $O_2$ atoms for which the electron affinity for the second electron is negative. Although this state is not reached for adsorbed $O_2$ ions, it indicates that the activation energy for the production of holes will decrease with increasing barrier layer thickness.

The transport of electrons along a continuous layer of adsorbed $O_2$ atoms may be visualized as hole conductivity; a doubly charged $O_2$ atom loses one electron to a neighboring singly charged $O_2$ atom, thus becoming singly charged, and in turn takes up another electron.