

CsBr Photocathode at 257nm: A Rugged High Current Density Electron Source

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There is a continuing need for high intensity electron sources that will operate in demountable vacuum and can be externally modulated. Materials with wide bandgap, e.g. diamond, are rugged but need photon energies exceeding the bandgap to emit efficiently and this rules out the use of CW lasers. We have found that a photocathode of CsBr is both adequately intense ($>150\text{A}/\text{cm}^2$) and rugged and can be excited with photons of energy of 4.8eV (257nm). This is below the energy gap of CsBr (7.3eV) but such operation can be explained by the presence of intraband states about 4eV below the conduction band minimum.

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The need for a high performance electron source (high current density, low energy spread and long lifetime) in electron beam lithography[1] and microscopy[2] is well established. High current density photocathodes also have very important applications in future ultra fast X-ray laser sources[3, 4]. Previous research[5] has demonstrated a high brightness (10^8 A/cm²-sr at 3 KeV), and an energy spread as low as 50meV at room temperature for a GaAs based negative electron affinity(NEA) cathode in a sealed-off tube. However the GaAs cathodes suffer very fast decay in a demountable vacuum system ($1/e$ decay in several minutes at a 10^{-9} Torr vacuum). More rugged operation[6] can be found with wider bandgap semiconductors but these require higher energy photon for excitation.

CsBr is one such material and has a bandgap of 7.3eV[7] suggesting that photon energies greater than 7.3 eV would be needed. But in previous work[1, 8], we demonstrated that current densities greater than 100 A/cm² can be obtained with a CsBr planar photocathode under 257nm (4.8eV) laser illumination. Such sub bandgap photoemission suggests the existence of intragap states in the CsBr films.

In this letter, we report the operation at >150 A/cm² current density of a photocathode structure with 15nm CsBr on 5nm Cr film. The photocathode performance under short time exposure to 10^{-8} torr vacuum and after one month vacuum storage at 4×10^{-8} torr is evaluated in this letter. In addition, photoluminescence is utilized to characterize the intragap states in the thin film CsBr photocathodes. As a result, an emission band centered at 330nm is detected. We present an electron emission model to explain the sub-bandgap photoelectron emission in CsBr and to provide possible guidelines for future alkali-halide cathode improvements.

The apparatus[8] consists of two connected vacuum chambers: one for deposition and one analysis, with base pressure in 10^{-10} to 10^{-11} torr range. An underlayer of 5nm thick Cr film is deposited on a single crystal sapphire substrate patterned with Cr bars (15 μ m wide, 80 μ m spacing, 80 nm thick) to provide electrical contact. This is followed by a 15nm thick CsBr film deposited using an MBE high temperature effusion cell at 400°C. The thickness of the Cr and CsBr films is monitored in-situ with a crystal oscillator. The cathode is then transferred from the deposition chamber to the analysis chamber under vacuum where the photocurrent can be measured in both transmission and reflection modes. As shown in Fig. 1 for the transmission mode, a quartz UV lens focuses the expanded laser beam on the sample substrate to a minimum spot size of about 1.25 μ m utilizing a shear plate. An Ocean Optics (USB2000) spectrophotometer is utilized to collect the photoluminescence signal (180nm-870nm). The electron collector (+1kV) is about 1mm away from the sample. Furthermore, the cathode holder is mounted on a piezoelectric driven flexure stage. This enables scanning the cathode surface across the laser beam, thus a photocurrent map (up to 80 μ m x 80 μ m) can be obtained.

Fig.2 shows a photocurrent map of a CsBr photocathode in the transmission mode under 20mW 257nm laser illumination. No photoelectrons are emitted from the 15 μ m wide Cr bars predeposited on the sapphire substrate. We show the photo current curve and the derivative of the current curve at $y=60\mu\text{m}$ in fig. 2(b) and fig. 2(c) respectively. Since the laser beam scan across the Cr bar, we can use the peaks of the derivative curve to estimate the spot size of the laser. The full widths at half maximum (FWHM) are 1.3 μ m and 1.4 μ m. The average laser spot size is $1.5 \pm 0.2\mu\text{m}$. This is only slightly larger than the diffraction limit for the projection lens obtained from the design data. Under

such a condition, we can operate the CsBr photocathode with more than 3.0uA ($>150\text{A}/\text{mm}^2$) for over 50 hours. A photoyield up to 200nA/mW ($\sim 0.1\%$ quantum yield) at 257nm can be achieved.

The photoluminescence spectrum from the CsBr film featuring an emission band centered at 330nm (3.8eV) with FWHM of 30nm (0.35) is shown in figure 3. Although, the crystal structure of the film is not measured, previous studies [9, 10] have reported a poly-crystalline or crystalline structure using a similar deposition technique.

Considering the 7.3eV band gap of CsBr, these intraband absorption states are located at the mid-gap region. The Cr has a work function of 4.6eV and the CsBr has a band gap plus electron affinity of 8.2eV [11]. If we assume there is no interaction between the Cr and the CsBr films, the vacuum level of the two materials should be aligned. This will place the detected intraband absorption states at (or below) the position Cr Fermi level as shown in the figure 3. We believe that this matching between the Cr Fermi level and the intraband absorption levels plays an important role in the sub-band photoemission. As the film is illuminated with the focused UV laser, the CsBr surface gradually becomes a Cs rich surface through Cs migration or Br desorption[8]. Thus the energy barrier at the CsBr surface is reduced. The electrons that have been excited from the intraband states [12] to the conduction band will have a better chance to escape from the surface. At the same time, electrons can be efficiently injected from the Cr film to the intraband states (below the Fermi level) to sustain the electron emission. The Cs migration (or Br desorption) caused by the UV laser illumination can maintain a Cs rich surface on the CsBr cathode. Therefore, a high current density continuous photoelectron emission is achieved without the need of cesiation with external Cs sources. It should be

pointed out that direct electron injection from the Cr film to the conduction band as discussed by Spicer et al [9] may also play an important role for very thin CsBr films.

In the future, we should be able to engineer the position and density of the absorption states by doping the CsBr film. For example, a series of absorption bands are formed if Au is added in the CsBr film[13, 14]. With the proper doping, it may be possible to reduce the excitation photon energy and increase the photoyield.

The performance of CsBr under different vacuum conditions is also investigated. Figure 4 (a) shows the photocurrent map obtained at a base pressure of 1×10^{-10} torr. The cathode is scanned with the flexure stage and the photoelectron current is recorded in a 60um by 80 um field. The Cr bars and small square Cr marks on the sapphire substrate are shown in black (low photoemission yield). The activated area is shown as a bright spot. Intensity cross-section profiles along two perpendicular directions of the activated areas are also shown in the figure. When the gate valve between the load lock and analysis chamber is open, the chamber pressure jumps to 3×10^{-8} torr and stays above 1×10^{-9} torr for 15 minutes. The residual gas analyzer shows that the main contaminants are CO and moisture. The photoelectron current map obtained after a 3×10^{-8} torr pressure burst is shown in figure 4 (b). Comparing the cross-section intensity profiles, we find that the photocurrent of the activated region drops from 1.6uA to 1.4uA. However, the photocurrents of the other adjacent regions are not affected. These results demonstrate that the surface contamination caused by the pressure increase is localized at the activated region, and the unactivated region is not affected by the pressure burst. This is consistent with the fact that only the activated spot is Cs rich[8], and therefore it is more vulnerable than the unactivated surface. Unlike GaAs and other NEA photoemitters, in which the

degradation due to poor vacuum will cause an irreversible damage to the whole cathode, the photocurrent of the activated CsBr region gradually recovers after the vacuum burst. This behavior is consistent with photolysis caused by the focused UV light removing the contaminants and rejuvenating the cathode with a fresh Cs rich surface. It is remarkable that a CsBr cathode stored for a month in the system load-lock chamber under a relatively high pressure of 4×10^{-8} torr can be reactivated to a photoyield comparable to a freshly grown cathode.

In conclusion, a robust CsBr photocathode that can be operated at $>150 \text{A/cm}^2$ current density under 257nm laser illumination has been presented. An emission band centered at 330nm is observed using the photoluminescence technique, and a model is presented to explain our findings. The performance under short time exposure to 10^{-8} torr vacuum and after one month vacuum storage at 4×10^{-8} torr demonstrates the robustness of the CsBr photocathodes. The contaminations caused by such conditions are localized to the activated region, and the photocurrent recovers to the original value after UV exposure. Based on the proposed model, we believe that improvements in photoyield and a reduction of the excitation energy may be possible by properly doping the CsBr film.

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Figure captions

Figure 1: Schematic view of experimental apparatus. The spectrophotometer is located behind the final objective lens to collect the fluorescence light from a large solid angle. The cathode (not in scale) can be operated in both transmission (as shown) and reflection.

Figure 2: The photocathode is operating in transmission mode. The photocurrent map of the cathode surface is shown in (a). The current cross-section curve and the derivative curve of the current at $Y=60\mu\text{m}$ are shown in (b) and (c) respectively. The laser spot size is estimated with the width of the derivative peaks in (c).

Figure 3: Photoluminescence spectrum of CsBr cathode. An emission band centered at 330nm (3.8eV) is observed under 257nm excitation. The proposed energy diagram for the CsBr/Cr photocathode is shown in the insert.

Figure 4: a). The photocurrent map of the sample before it is exposed to 3×10^{-8} torr pressure burst. b). the photocurrent map of the sample after it is exposed to 3×10^{-8} torr pressure burst.







