Heated cell for electron beam pumped VUV experiments

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The design of a high-temperature cell appropriate for electron beam pumping of species emitting in the vacuum ultraviolet is described. The apparatus is capable of maintaining a temperature as high as 750 °C at a cell pressure of up to 6 atm which is suitable for a variety of investigations of atomic and molecular vapors, such as alkali metals and alkali-metal, rare-gas mixtures. The performance of this apparatus with rubidium vapor in a buffer gas is described.

INTRODUCTION

Recently, there has been considerable interest in developing vacuum ultraviolet sources. Except for some excimers, very little work in this field has been done using electron beam excitation, although this excitation method is capable of producing the high pumping power densities needed for short wavelength generation and large pumping volumes. Laser-produced plasmas and conventional discharges have primarily been used as pump sources because they are compatible with experimental geometries that require a heated medium such as alkali-metal vapors.[1,2] These techniques have relied largely on conventional heatpipe technology[3] which produces a well-defined vapor column at typically a few Torr of pressure; however, electron beam excitation, using MeV electrons, requires high-pressure buffer gases to effectively absorb the delivered energy in a small volume. The experimental apparatus cannot rely, therefore, on heatpipe technology since, generally, a high pressure of a noble gas such as Ne must be added to the few Torr of the active medium in order to absorb the electron beam energy. Previous heated electron beam cells[4,5] have been designed for operation with dye vapors and metals for visible or near UV wavelengths and have been limited to temperatures of 600 °C or less. In this article, a high-pressure heated cell, capable of an operating temperature of 750 °C is described. This cell will be employed in spectroscopic studies of electron beam pumped short wavelength laser candidates.

I. CELL CONSTRUCTION

A cross-sectional view of the vapor cell coupled to the electron beam machine is shown in Fig. 1. The cell consisted of the electron-beam-pumped region, shaped as a half-cylinder with a diameter of 3.4 cm and 16.5 cm long, and two water-cooled end tubes separating the pumped region from the windows or detection equipment. The end tubes had an inner diameter of 3.4 cm and were 8.6 and 11.6 cm long. The half-cylindrical region was braised to a backplate with an oval opening for coupling the electron beam into the cell. The body of the cell was constructed of type 316 stainless steel because it has a sufficiently high tensile strength to withhold pressures of several atmospheres, even at 750 °C, and because of its corrosion resistance, particularly against reactants such as F_2 or alkali metals.

The cell was heated by two 17.8×6.4-cm plate heaters (Thermcraft #315) fitted to the back of the cell as shown in Fig. 1, and by four small rod heaters (Hotwatt Inc.) inserted longitudinally in holes drilled at the end of the electron-beam-pumped region. An additional half-cylindrical heater could be used to reach even higher temperatures but was not necessary for operation up to 750 °C. By omitting the half-cylindrical heater, the Inconel foil used to couple the electron beam transversely into the cell remained approximately 40 °C hotter than the cylindrical section of the cell, preventing condensation of the alkali metal. Condensation of alkali metal on the foil would severely decrease the foil lifetime. Over 700 electron beam shots could be taken before changing the Inconel foil in this configuration. The heaters supplied 1200 W to the cell over the 10-cm-long active region.

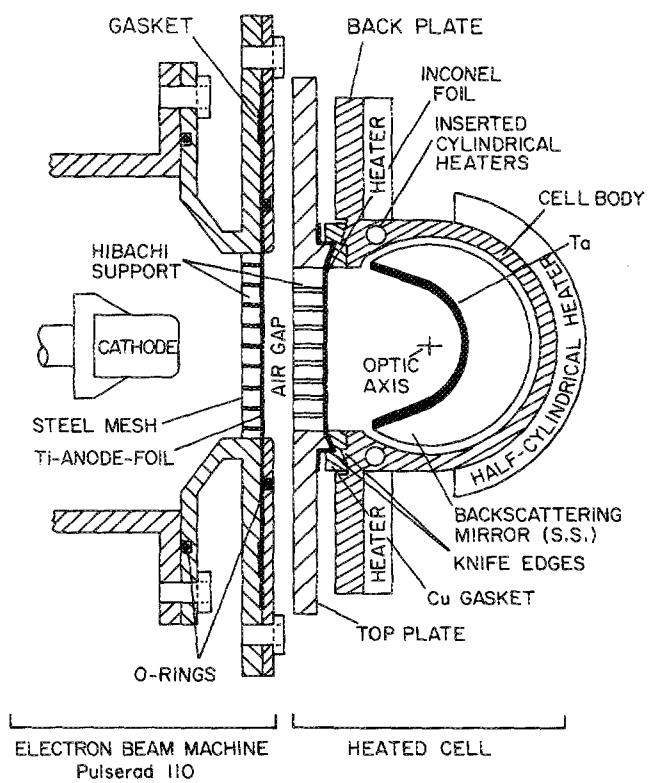

FIG. 1. Cross-sectional view of heated cell and electron beam cathode. Heated cell is sealed with Inconel foil, and the cathode region is sealed with titanium foil. The small air gap acts as a thermal insulator.

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The temperature was monitored in three locations using Chromel-Alumel thermocouples. One thermocouple was located close to the 50-μm-thick Inconel foil.

The Inconel foil sealed the oval shaped opening (90×25 mm) of the half-cylindrical heated region of the cell. The seal had to be capable of high temperatures and pressures and yet still allow electron beam penetration into the cell. The method chosen was to use a knife-edge groove in the backplate designed to mate with a copper gasket as shown in Fig. 1. The seal was completed by the top plate which has a knife-edge groove similar to that of the backplate, and had a series of holes forming a Hibachi-like structure. This top plate was held against the Inconel foil by a set of bolts around the oval opening. The Hibachi-like structure provided support for the foil at high pressures while allowing the maximum electron beam deposition inside the cell.

The cell was designed for transverse excitation by the electron beam largely for simplicity of operation. Many probe techniques require that external laser beams be introduced into the cell to perform absorption or gain measurements. Transverse excitation simplifies such experiments by avoiding the complications of coupling both the electron beam and the laser probe beams longitudinally into the cell; also transverse excitation does not require the intense, pulsed-magnetic guiding fields that are necessary for longitudinal excitation. For a heated cell, a buffer gas must be present at the cold ends of the cell in order to contain the vapor and to protect the windows and spectrometer. This necessary cold zone would result in an energy loss for a longitudinally inserted electron beam.

There is also an energy loss associated with transverse excitation of a heated cell because of the necessity of insulating the heated cell from the electron beam assembly. Figure 2 shows a top view of the heated cell attached to the electron beam source. In this work, a Physics International Pulserad 110 electron beam accelerator generated a 1-MeV electron beam with a pulse width of 10 ns (FWHM). Electrons were accelerated from the carbon cathode of 7.5 cm in length, towards a highly transparent steel mesh serving as the anode. This steel mesh was supported by a Hibachi structure similar to that of the hot cell and sealed to the diode housing by a 50-μm-thick titanium pressure foil. As shown in Figs. 1 and 2, the electron beam had to penetrate two foils in this configuration. The heated cell was isolated from the first titanium foil by about 1 cm of air to provide thermal isolation between the heated cell and the diode housing. This was necessary in order to prevent extensive heat loss to the diode housing. The air gap and the use of two foils effectively insulated the cell thermally from the diode housing but introduced additional energy loss to the electron beam.

In order to compensate for the decrease in electron-beam-pumping density, a backscattering mirror or concentrator was employed inside the heated zone.[6] This concentrator, as shown in Fig. 1, consisted of a 10-cm-long piece of stainless steel machined into a parabolic shape. This device was then fitted to a similarly shaped tantalum shield. Because tantalum is a high Z material, the shield served to effectively backscatter the incident electrons into the focus of the parabola. The approximate focal point was located along the optic axis of the reaction cell. Due to the electron beam divergence, the imperfect parabolic shape of the mirror, and the relatively broad angular distribution of backscattering, the backscattered electrons did not converge to an ideal line focus, but rather contributed to an enhanced energy density in a finite volume of several millimeters diameter centered around the focal line of the parabolic mirror. The absorbed energy per unit volume at 6 atm of Ar was determined to be 22 mJ/cm^3, compared to 110 mJ/cm^3 for a cell coupled directly to the diode housing without the second additional foil or air gap.[7] The concentration of backscattered electrons at the optical axis can probably be improved further by the use of a magnetic guiding field to reduce the electron beam divergence.

The concentrator is particularly useful for increasing the energy deposition into buffer gases with low stopping powers such as helium. It has been shown to increase the pumping density in gases such as He or Ar by at least 40% at gas pressures of 1 atm.[6] For electron beam experiments in the VUV region of the spectrum, the heated cell must often be directly coupled to a spectrometer since no transmitting windows are available in this region. Since most VUV spectrometers are constructed for vacuum operation, coupling a

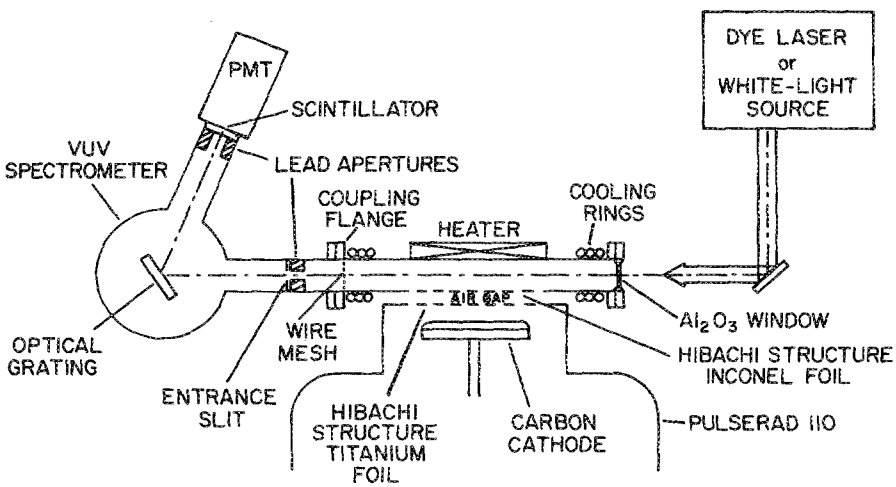

FIG. 2. Top view of heated cell, VUV detection apparatus, and electron beam machine. The dye laser or white-light source can be used to measure population densities in the hot vapor.

high-pressure windowless heated cell to such an instrument presents a problem. For the apparatus described in this article, the operation of the windowless cell was limited to a pressure of 1.2 atm due to the pressure constraints of the spectrometer. The concentrator was therefore especially effective for increasing the power deposition at this low pressure.

As shown in Fig. 2, the detection apparatus consisted of a fast photomultiplier (RCA 8575) with a sodium salicylate scintillator and an optical multichannel analyzer (Princeton Applied Research OMA I 1205 series D, with a 1205D/01 UV Scintillator) coupled to an Acton 0.2-m vacuum spectrometer (VM502). One end of the cell was sealed with a sapphire window while the other side employed a 1-in.-diam MgF_2 window to separate the high pressure in the cell from the vacuum in the spectrometer. In this configuration, the cell could be operated up to about 6 atm of buffer gas pressure. For experiments below the transmissive region of the MgF_2 window, the window was removed and both the cell and the spectrometer were kept at the same pressure by flooding the spectrometer with a buffer gas up to a maximum pressure of 1.2 atm. Possible exposure of the spectrometer to the metal vapor was minimized by an automatic shutter which opened the input port of the spectrometer for only 250 ms during the firing of the electron beam. A wire mesh shown in Fig. 2 was also incorporated in front of the spectrometer slits to facilitate the trapping of alkali metal particles that might penetrate into the cold zone of the cell. To protect the detectors from electron-beam-generated x-ray radiation,the entire detection system was encased in lead shielding. Also due to the high x-ray sensitivity of the photomultiplier tube, two lead apertures of 0.5-cm diameter were employed. Further suppression of the x-ray noise on the data was accomplished using background subtraction techniques.

II. CELL PERFORMANCE

To test the heated cell performance, measurements were made of the metal vapor pressure inside the cell using a mixture of Ne or He with Rb. These measurements were made by analyzing the equivalent width of the absorption from a spectrally broad light source on the 4202 and 4216 Å resonance lines of Rb.[8] Because the cell is not operated in a heatpipe mode, this measurement is only approximate, since the uniformity and length of the vapor zone were not independently measured. Uniformity of heating can be improved using a concentric heatpipe configuration, but this adds considerable complexity to the cell construction.[5] Using the configuration shown in Fig. 2, the measured equivalent widths and the corresponding vapor pressures deduced from these widths were consistent with the measured cell temperatures near the Inconel foil. The excellent agreement of the measurements, shown in Fig. 3 for a He buffer gas pressure of ~100 Torr with the tabulated vapor pressure of Rb,[9] was probably largely due to the small thickness of the foil which therefore gave an accurate indication of the inside cell temperature. The vapor pressure inside the cell leveled off above 10 Torr, as indicated in Fig. 3. Although a steel wick was incorporated in the cell to provide recirculation as in

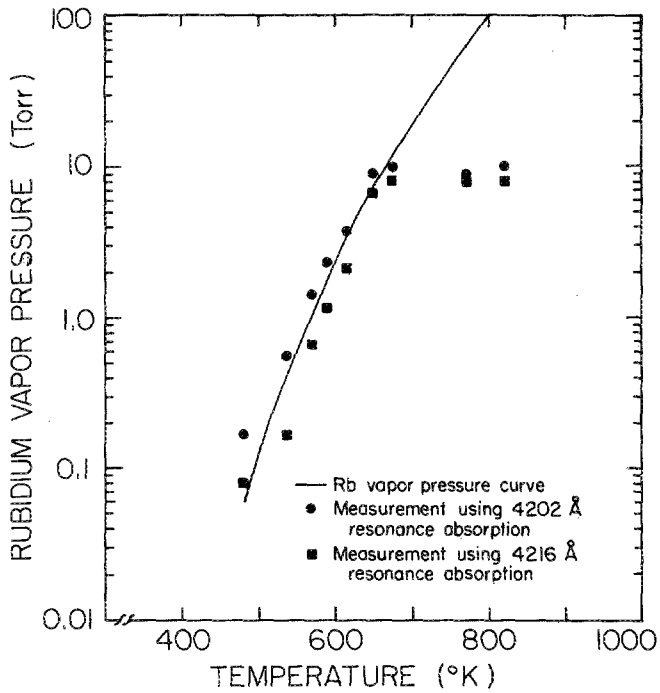

FIG. 3. Measurement of Rb vapor pressure inside the heated cell as a function of temperature for ~100 Torr of He buffer gas pressure. Resonance line absorption was used to measure the ground-state density of Rb, and thermocouples were used to measure the temperature. The Rb vapor pressure curve is taken from Ref. 9.

standard heatpipes, the Rb depleted from the vapor zone to the cold zones around the cooling rings as the cell was heated above 750 °C, resulting in the vapor pressure limit shown in Fig. 3. By increasing the cooling transition zone lengths of the cell so that the Rb could be more effectively recirculated, the operational range of the cell could probably be extended substantially. For buffer gas pressures of higher than 100 Torr, the 4202 and 4216 Å absorptions were so broadened that the overlap between these absorptions made the analysis more difficult. At 1 atm of He buffer gas pressure, the calculated Rb pressures agreed to within a factor of two with the results shown in Fig. 3.

In summary, a heated cell appropriate for electron-beam-excited VUV experiments has been described which can produce metal vapor pressures up to 10 Torr at a high buffer gas pressure. Since this cell can maintain temperatures of 750 °C and is corrosion resistant, the cell can be used with a variety of materials such as alkali metals and alkali earth metals. In addition, this cell allows for simple transverse excitation while still achieving a high pumping density by using an electron backscattering concentrator. This apparatus will be utilized for future studies of VUV light sources using electron beam excitation.[10,11]

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