CONCENTRIC HEAT PIPE CAVITY
FOR E-BEAM EXCITED LASERS*

F. B. Haller and M. M. Hessel
Division 277, National Bureau of
Standards, Boulder, Colorado 80302

and

W. Neef, W. Lai, and H. Lohr†
Lawrence Livermore Laboratory
Livermore, California 94550

SUMMARY

A concentric heat pipe oven for metal vapor-noble gas mixtures has been designed and constructed as a high power laser cavity for laser fusion applications. A 1 MeV, 100 KA, 50 ns e-beam is injected into this oven through a stainless steel foil window, .125 mm thick. Details of the construction and design considerations of the heat pipe oven, foil window and safety features are given.

INTRODUCTION

Noble gas-metal vapor mixtures are of interest as a laser medium for possible high power lasers for fusion. Uniformity of the noble gas-metal vapor mixture is necessary for efficient laser operation. Homogeneous metal vapor-gas mixtures have been produced by heat pipe techniques and used for spectroscopic studies. The successful application of heat pipe technology[1] to spectroscopy provided the impetus to develop a heat pipe laser cavity compatible with e-beam excitation.

Discussed in this paper are the design and development of a concentric heat pipe cavity for e-beam excited lasers and some of the solutions to problems which arose during its construction. The design goals for the heat pipe laser were as follows:

1. The laser cavity is to permit transverse injection of an e-beam over a 2 cm by 50 cm rectangular area.
2. The laser medium is to have independent control of noble gas pressure (up to 10 atm) and metal vapor (maximum vapor pressure governed by a maximum temperature of 600°C).
3. The laser cavity is to function reliably for hundreds of hours.
4. The system is to be designed with emphasis on protection of personnel from accidental leaks of possibly toxic metal vapors.

LASER CELL

The heat pipe was developed as a heat transfer device at the Los Alamos Scientific Laboratory, useful in nuclear energy and other applications.[1] Later, the principle of the heat pipe was adapted to spectroscopic measurements by Vidal and Cooper[2] at the National Bureau of Standards, who named this new device the heat pipe oven. The heat pipe oven utilizes an open ended heat pipe to produce homogeneous vapors of well defined temperature, pressure and path length; the oven terminates in optical windows protected by inert gas boundaries. The gas boundaries allow direct vapor pressure measurement and result in deposit-free windows, facilitating all types of spectroscopic measurements of metal vapors.

Using the unique properties of the heat pipe to produce an isothermal zone of variable length, the heat pipe oven was modified to a concentric heat pipe oven.[3] The concentric oven consists of an outer tube functioning as a heat pipe surrounding a similarly constructed inner tube which may or may not function in the heat pipe mode. This arrangement contains all the advantages of the original heat pipe oven, plus the ability to mix vapors of elements with other gases at well defined total and partial pressures and optical path lengths. A further modification[4] allowed production of homogeneous mixtures of a saturated vapor with an unsaturated vapor at arbitrary ratios.

The laser cell described herein utilizes the concentric heat pipe configuration as illustrated in figure 1 to provide the appropriate gas-metal mixture for the lasing medium. The mesh lined inner cell is heated by the outer heat pipe, which acts as a uniform temperature oven of variable length. This outer pipe is designed to operate with potassium, sodium or lithium as the liquid-vapor medium; the choice of the metal dependent on the desired vapor pressures of the metal used in the inner cell.

The outer pipe, made of type 304 stainless steel tubing, has a 12.7 cm o.d., 1.65 mm wall, and is 133 cm long. The inside boundary is the 10.16 cm o.d. of the inner cell. There is a centrally located slot approximately 57 cm long, to accommodate a flanged fitting through which the e-beam drift tube can reach the lasing medium in the inner cell. This flange is vacuum tight welded to the tube around this slot. The outer

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*This project was managed by Paul Hoff, present address, ERDA, Washington, DC. L. Schlitt, Lawrence Livermore Laboratory provided the necessary guidance in e-beam technology.

† The heat pipe cavity was designed and developed under contract of Lawrence Livermore Laboratory to the National Bureau of Standards, Boulder, Colorado. Design of the e-beam window, drift tube and safety equipment was initiated by W. Neef and completed by W. Lai. H. Lohr provided the mechanical design.

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tube terminates in stainless steel coaxial spacing flanges with O-ring vacuum seals. A 30 cm long, 10 kilowatt resistance heater surrounds the center section, exclusive of the flange and O-ring sealed water cooling chambers are placed just inboard of the spacing flanges.

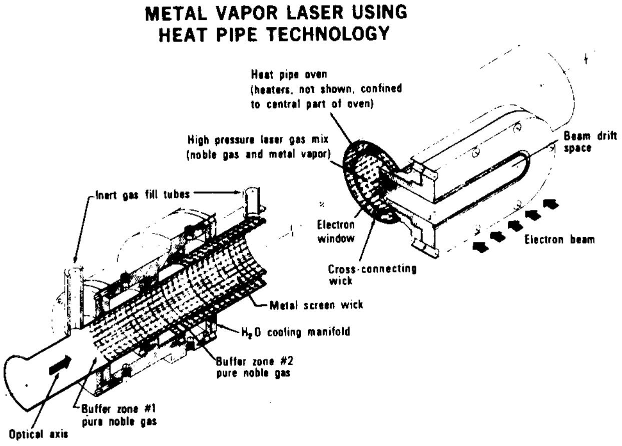

Fig. 1. Heat pipe oven with the E-beam window.

The inside of the outer tube and the outside wall of the inner cell are lined with 280 by 70 woven stainless steel mesh. There are two layers on the inner cell wall and four layers on the outer tube. These layers are cross connected at two points along their entire length with similar mesh. (fig. 1). Figure 2 shows the heat pipe oven and inner wall mesh prior to assembly. The mesh length is approximately 100 cm, with the ends terminating under the water cooling chambers. Slots are cut in the mesh for passage of the aforementioned flanged fitting and all the mesh is spot welded in place.

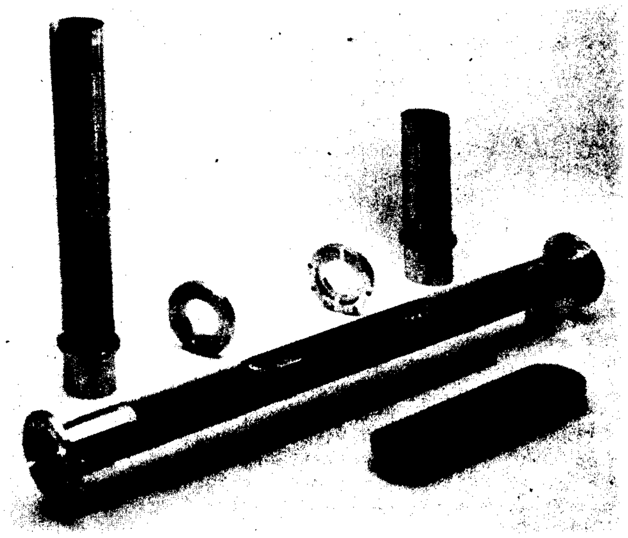

Fig. 2. Pre-assembly view of the concentric heat pipe oven with mesh welded to outer surface of inner cell. Below is the flanged fitting. Above, the severed outer tube prior to welding is shown.

In operation, heat applied at the center evaporates the metal; the vapor travels between the walls toward the cooled ends, where an equilibrium boundary is established with a previously admitted noble gas of known pressure. The vapor condenses at the cooled boundary region and returns to the evaporator section via capillary action in the mesh. Condensation on the wall of the inner cell returns to the evaporator section via the cross connecting mesh, thus avoiding depletion of the material in the hot zone. Any condensation on the flange wall will drain to the mesh and also return to the evaporator.

To reduce radiation losses, the outer pipe is surrounded by a 63 cm long heat shield, consisting of three formed sheets of stainless steel spaced about 1.5 cm apart and filled with two layers of quartz wool. Spacing of the metal is accomplished with screws and springs to allow for differences of thermal expansion during heating.

The laser cell (figs. 2 and 3), made of type 304 stainless steel tubing, is nominally 190 cm long, 10.16 cm o.d.; with a 4.76 mm wall thickness. The flanged fitting welded to the outer pipe penetrates the center area of the laser cell and is fastened with a vacuum tight weld. The ends of the cell are symmetrically equipped with removable flanges, O-ring vacuum seals, pumping ports and window mounts. O-ring sealed aluminum water cooling chambers provide cooling for condensation of the metal vapor inside. A woven wire mesh of suitable wetting and corrosion resistance characteristics for the chosen metal vapor lines the interior wall of the cell and terminates under the cooling chambers. The mesh is slotted where the e-beam window enters the tube and the mesh is spot welded in place.

The cell does not operate in the heat pipe mode, but uses the outer heat pipe type of construction to continuously generate a homogeneous mixture of metal vapor and gas. Metal vapor, evaporated by the surrounding heat pipe oven, mixes with the high pressure noble gas, eventually condenses at the cooler ends and returns to the heated area by capillary action. The vapor pressure of the metal in the cell is controlled by the temperature of the outer oven; the temperature of the outer oven is precisely controlled by the measured pressure of the confining inert gas. Gas pressure variations in both the inner cell and outer heat pipe are minimized by connecting them to suitable reservoirs. Connections to pumping apparatus and gas sources are accomplished by connecting both ends of the respective units to tee connectors by means of flexible lines, necessary to accommodate the thermal expansion of the tubes and to increase operational stability of the heat pipe.

A high temperature flanged transition section, carrying the e-beam window, a heater and thermocouples, mates with the flanged fitting welded to both tubes and is sealed with a hollow, inconel X-750, nickel plated O-ring. A one kilowatt coaxial heater is installed in a channel in intimate contact with the e-beam window support. Its function is to heat the window sufficiently to prevent metal vapor condensation on the window.

To accomodate the thermal expansion of the heated sections, the total structure is supported on rollers; as shown in fig. 3, the rollers are on top of two vertically adjustable posts which permit easy and precise leveling of the cell.

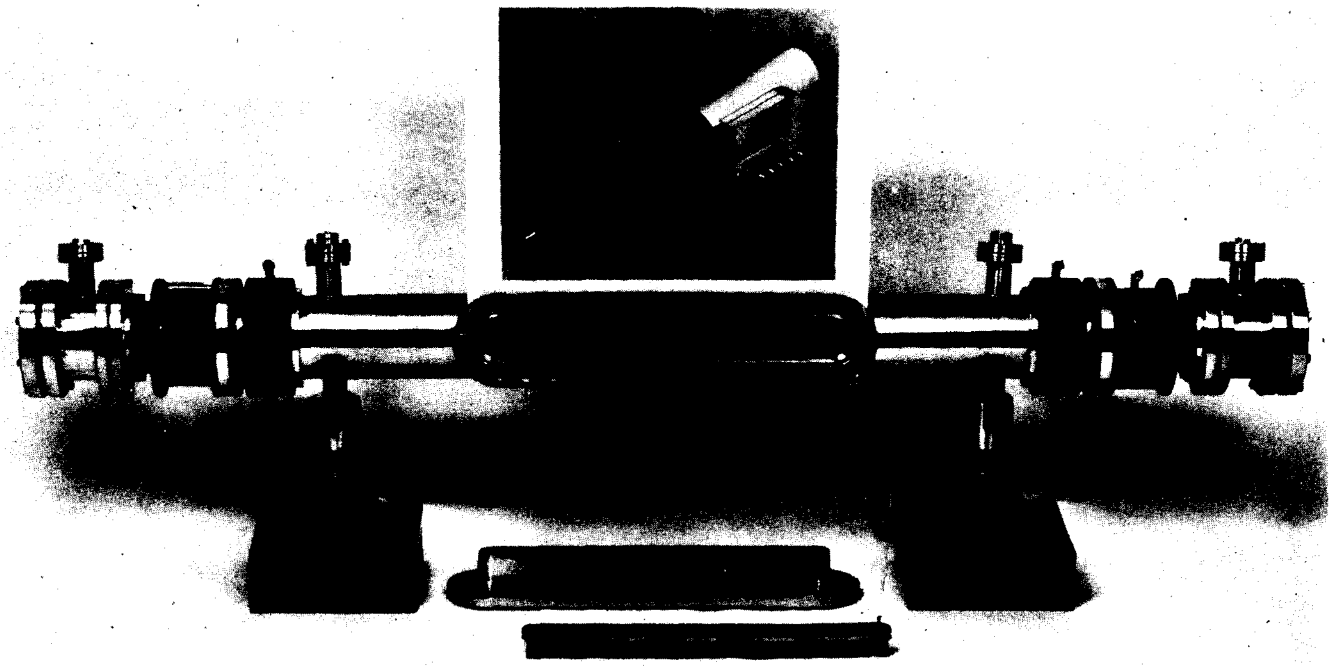

Fig. 3. Assembled laser cell on adjustable support, without heater or heat shield. Included below are the flanged high temperature drift tube and foil assembly.

E-BEAM TRANSPORT CONSIDERATIONS

The laser medium is to be excited by a nominally 50 ns, 1 MeV, 5000 J e-beam which originates in a vacuum. The transition section, which connects the laser cavity to the e-beam machine and is designed to serve several functions, will now be discussed. In brief, the transition section consists of an e-beam window, a drift tube, a high temperature transition tube, a cutoff valve, and a settling chamber. The latter two items were included to minimize the hazards of toxic metal vapors; one of the selected metal vapors, Cd, and its compounds, are highly toxic.[5] The safety aspects were designed with cadmium in mind.

The E-Beam Window

The e-beam window is to withstand the high temperature, high pressure, and reactive metal vapor environment and is to have high e-beam transmission. The window should not condense metal vapor on its surface which would cause local changes in transmission characteristics. The design selected (Fig. 4) was a compromise among the opposing parameters.

Figure 4 shows that the design is basically a grill reinforced foil structure. The window was fabricated from type 304 stainless steel. The grill has a total thickness of 4.4 mm and has a hexagonal close packed hole pattern which provided ~ 54% geometric transmission while supplying the desired strength. The hole diameter, 4.8 mm, was determined from a hoop stress type analysis for .125 mm foil.[6] The theoretical transmission of the e-beam is ~ 90% for 0.125 mm thickness of stainless.

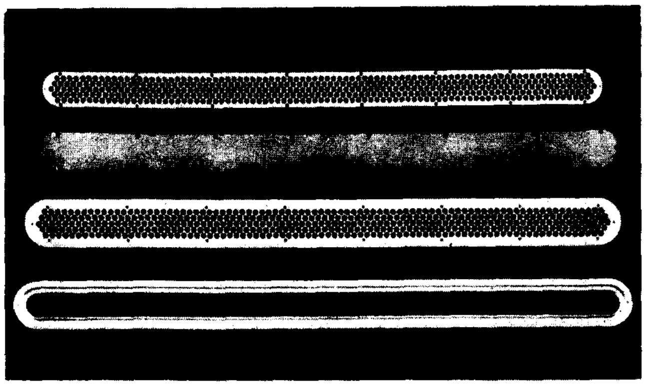

Fig. 4. Component parts of the 50 cm e-beam window. Frame is grooved for the one KW heater.

Predicted life for the foil is between 10 and 100 hours. The large range in the predicted life of the foil arises from two sources, 1) the uncertainty in extrapolating high temperature creep data, especially to foil structures, and 2) the unknown reactivity of dilute mixtures of high temperature, high pressure Xe-Cd.

Fabrication methods tried were brazing and machining. A cross section of the foil assembly, with brazed and machined foils, is illustrated in Fig. 5. Two leak tight units were brazed. The machined unit, though leak tight, contained several foils that were less than 0.125 mm thick; these were caused by unpredictable gouging by the end mill cutter. It would appear that brazing is better adapted to producing windows with predictable characteristics.

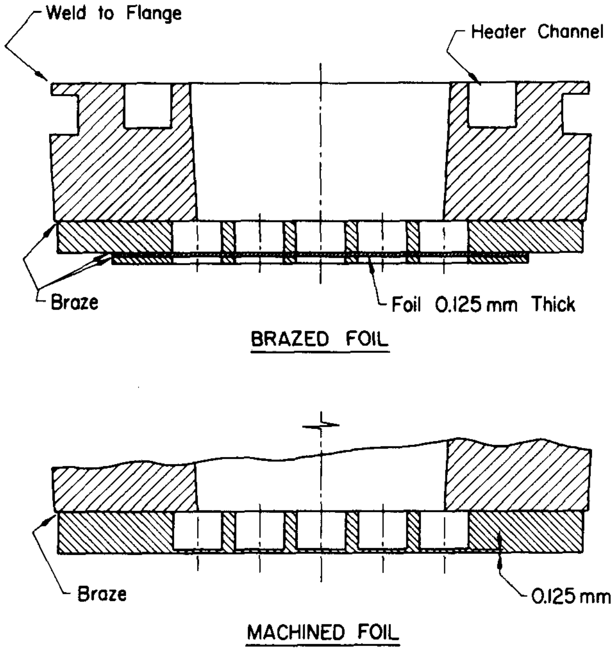

Fig. 5. Cross section view of the foil window assemblies.

The e-beam window loses heat primarily by conduction and radiation to the transition section and the e-beam machine. A maximum loss of 0.75 kW is predicted. Incorporation of a 1 kW heater to ensure that the temperature of the window will remain at or above the cavity temperature to prevent condensation of the metal vapor was discussed previously. Figure 4 shows the location of the heater.

The Drift Tube

The drift tube guides the e-beam, provides a return path for the current, and contains all of the components required to control and match the laser cavity to the e-beam machine. Unless close coupled, e-beam instabilities affect their drift characteristics. Studies showed that a 2 cm by 50 cm beam pinches and recovers to nearly full size after drifting 38 cm.[†] The length of the drift tube, and hence the transition section, was selected to be 38 cm in order to include the control capabilites to be discussed (Fig. 6).

Fig. 6. The 50 cm e-beam drift tube with cut-off valve.

The High Temperature Transition Section

The geometry of the drift tube is sufficiently complex so that a meaningful cost reduction can be realized if fabricated from aluminum using polymeric seals wherever required. To be compatible with the high temperature, high pressure cavity, the e-beam window was welded to the snout of a stainless steel tube; this tube provided a flange connection to the heat pipe cavity and to the remainder of the drift tube which was fabricated from aluminum (fig. 3).

The walls of the stainless steel tube, located outside the heat pipe are 3.1 mm thick to limit the steady state temperature of the end flange to $< 250^{\circ}$ C. This permitted the connection to the aluminum section to be sealed with either viton or silicone rubber gaskets. Electrical feed throughs for the heater and for monitor thermocouples are silver soldered to the thin section of the tube.

The Cutoff Valve

Associated with the mass and insulation of the heat pipe is a thermal lag which will continue to vaporize Cd after shutdown. Rupture of the e-beam window foil will probably rupture the anode foil and the continuous source of Cd vapor after shutdown will contaminate the diode section and the vacuum system of the e-beam machine.

To confine the contamination, a rotating cutoff valve was incorporated into the drift tube (fig. 6). The valve is automatically activated by a pressure switch which monitors the pressure in the drift tube. The valve is designed to stop the direct flow of metal vapor and to permit gas to leak through to the settling chamber.

The Settling Chamber

The flanged end of the settling chamber with the perforated metal screen connects to the bottom of the drift tube, providing an additional volume to ensure that in the event of an e-beam foil rupture, the equilibrium pressure will be below atmospheric. In this manner, opening the drift tube for maintenance will result in an inflow of air; hence, accidental spraying of personnel by vapor laden gas cannot occur, fig. 7.

[†] L. Schlitt, private communication.

Fig. 7. Settling chamber for e-beam window failure protection.

SAFETY CONSIDERATIONS

The toxicity of Cd vapor and its compounds requires precautionary measures for personnel safety in the event of laser cavity wall failures. Because of the design of the experiment and of the heat pipe laser system, safety considerations naturally separate into contained surfaces and exposed surfaces.

Contained Surfaces

The heat pipe oven surrounds and contains any leaks that develop in the isothermal zone. Optical windows will be enclosed in line of sight pipes which will also serve as containment vessels in the event of window failures. Therefore, personnel are adequately protected from failure of contained surfaces.

Exposed Surfaces

A vented hood was designed to enclose the heat pipe laser tube to restrict contamination which may result from failure of walls that communicate directly between the cavity and the room environment. The hood has ports with removable covers for on site clean up. Adjustable vents contol the inflow velocity of air. Air, drawn in through the vents by a 1000 scf/m fan, passes through a high efficiency particulate-aerosol filter before exiting from a stack six feet above the roof apex.

PRESENT STATUS

A concentric heat pipe laser cavity suitable for Xe-Cd has been fabricated. Limited tests will be conducted to check its performance.

The transition section has been fabricated. The hood will be fabricated when required. Full-scale tests of the heat pipe laser system will be scheduled when funding permits.

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