Hollow-Cathode Transverse Discharge
He–Ne and He–Cd + Lasers

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Abstract. An all-metal hollow-cathode laser tube consisting of a perforated cylindrical cathode surrounded by a coaxial cylindrical anode has been operated as a He–Ne laser at 0.6328, 1.15 and 3.39 µm, and as a He–Cd laser at red, green and blue visible wavelengths, using both dc and pulsed-plus-de excitation. Laser oscillation in He–Zn, Ne–Cd, Xe–Cd and Ar–Cd mixtures has also been obtained. The hollow-cathode discharge consists primarily of an intense cathode glow inside the cathode cylinder, giving a quiet, stable, low-voltage, positive-resistance discharge. Results for the He–Ne and He–Cd laser output versus partial and total pressures and discharge currents are presented. The un-optimized laser performance for the He–Ne case approaches but does not yet equal the conventional positive-column case, while the He–Cd performance for the charge-transfer-pumped green 5378 Å line appears particularly promising.

Index Headings: Gas laser – Hollow-cathode laser – He–Ne laser – He–Cd + laser

The cathode glow discharge occurring inside a slotted or end-excited hollow-cathode structure has been used by several earlier groups [1–9] as an excitation medium for various gas lasers. The potential advantages of this type of discharge over the more usual positive column discharge for laser excitation can include lower discharge voltage, positive discharge impedance, lower discharge noise, a potentially more favorable electron energy distribution, reduced catephoresis problems, and all-metal discharge tube structures.

We report here experimental results for laser operation in a new all-metal hollow-cathode structure using a perforated Kovar or stainless-steel hollow-cathode cylinder surrounded by a coaxial stainless-steel anode cylinder and vacuum envelope. Laser action in this structure has been obtained with Ne–He mixtures at 6328 Å, 1.15 µ, and 3.39 µ, and with He–Cd + mixtures at 4415, 5337, 5378, 6355 and 6360 Å. Laser action at the longer infrared Cd wavelengths could almost certainly have been obtained also, but was not looked for; nor was the ultraviolet 3250 Å transition studied. Simultaneous three-color laser operation at the blue (4415 Å), green (5378 Å), and red (6360 Å) Cd transitions was readily obtained using broad-band mirrors. Blue-green laser oscillation at 4912 Å and 4924 Å in a He–Zn discharge has also been briefly examined; and some interesting results using Ne–Cd, Xe–Cd and Ar–Cd discharges have been observed, too.

1. Laser Tube Structure

Our hollow-cathode structure (in the only form studied to date) consists of a 47 cm long, 7.5 mm inner diameter Kovar tube with 1 mm wall thickness held inside a 2.5 cm inner diameter stainless-steel anode cylinder and vacuum envelope. The cathode cylinder is perforated with 3 parallel rows of 3 mm diameter holes spaced 120° apart azimuthally and 6 mm apart axially along the entire length of the cathode, as shown in the inset to
Fig. 1. (It appears that many fewer holes could probably be employed with equal success.) The cathode tube is supported concentrically inside the anode tube either by flexible pins from side-mounted vacuum feedthroughs in the anode tube at each end of the cathode, or by concentric boron nitride collars near each end. Longitudinal thermal expansion of the cathode tube is a serious problem requiring either flexible pins or a sliding fit in the insulating collars. Arcing caused by metal vapor build-up on or near the vacuum feedthroughs or cathode support insulators is an occasional problem. The overall length of the outer envelope, including water-cooled O-ring flanges and Brewster window projections at each end, is \( \approx 70 \) cm. The tube is evacuated and gases are admitted through side tubings near the ends of the outer envelope.

The outer anode tubing is also lined on the inside with approximately 5 layers of fine stainless-steel mesh (\( \approx 40 \) mesh/cm) which we intended to serve as the wicking to provide a form of partial heat-pipe operation [10]. It was hoped that a limited degree of heat-pipe operation might provide a more uniform temperature and Cd-vapor distribution in the center region of the tube, together with capillary transport of condensed cadmium from the cooler ends of the tube back to the hotter middle region, since the condensed Cd metal on the wick should be liquid (melting point \( \approx 320 \)°C) at the usual operating point of our He–Cd laser (temperature \( \approx 340–370 \)°C, vapor pressure \( \approx 0.2–0.6 \) Torr). There is some considerable uncertainty as to the actual efficacy of this heat-pipe action in our structure. The tube in operation did provide an apparently very uniform discharge along its length, with minimal transport of Cd into the end regions, but it was not clear whether the mesh had been completely wetted by the cadmium metal even after sustained periods of operation.

Electric heating tape can be placed around the outside of our anode tube, but is not required for sustained operation in most experiments, the tube heating being provided by the laser discharge itself.

2. Discharge Characteristics

In operation an intense cathode glow fills the inside of the hollow cathode tube except for a narrow annular cathode-fall region around the inside periphery of the cathode. Tenuous plasma columns extend out through the cathode holes and carry the discharge to the anode. It is difficult to make visual observations of the discharge in our structure during operation, but the condition of the cathode after sustained operation indicates that a large part of the discharge current may be carried by only a small number of holes with the active holes being spaced \( \approx 5 \) cm apart along the cathode.

Figure 1 shows typical dc voltage-current characteristics of the discharge, measured using a dc supply with a ballast resistance of a few hundred ohms, for various gas mixtures. The discharge is characterized by its low sustaining voltage of 200 to 300 volts d c and its positive-slope V–I curve with a positive dynamic impedance of a few hundred ohms. These characteristics are preserved down to very low currents where the discharge is extinguished. For He–Cd mixtures the sustaining voltage increases as the Cd vapor pressure increases, which is exactly the opposite behavior to the positive-column He–Cd discharge.