JAPANESE JOURNAL OF APPLIED PHYSICS
VOL. 26, NO. 3, MARCH, 1987, pp. L206–L208

A Transverse Electron Beam Source for the Excitation of CW Lasers

Xiaoguang GUO,* Tamio HARA, Atsuo SANDA,†
Manabu HAMAGAKI, Takao FUSAYAMA, Pil Hyon KIM
and Susumu NAMBA

The Institute of Physical and Chemical Research, Wako, Saitama 351-01
†Faculty of Engineering, Saitama University, Urawa, Saitama 338

(Received January 13, 1987; accepted for publication February 21, 1987)

A novel transverse electron beam gun for the excitation of cw ion lasers is reported. The electron beam is extracted from glow discharge plasma using a short gap of electrodes. Electron beam energy and current can be controlled independently.

We report a novel transverse electron beam source with a beam energy of 500 eV, at current densities up to 1.67 A/cm^2. This source operates at helium pressures up to 2.2 Torr. Recently, we reported an electron beam pumped Ar$^+$ laser,[1] of which the electron beam energy and current can be controlled up to 300 eV and 11 A independently. We found that laser output power of Ar$^+$ 488.0 nm line showed a peak value at the electron beam energy of 120 eV. This relates to the fact that ionization and excitation cross sections of many upper laser levels have maxima around the electron energy of 100 eV. The separate adjustment of electron beam current and energy is important for the laser excitation with high efficiency. Many ion lasers are operated in the gas pressure of a few Torr. It is difficult to excite longitudinally the laser medium with a low energy electron beam, because the mean free path of beam electrons is short in such a laser. To avoid this problem, a transverse excitation scheme is necessary. Rocca et al. reported a compact Hg II laser which was pumped by a 10 cm long transverse electron beam glow discharge;[2] however, the beam current and energy in their experiment could not be controlled independently. In the transverse excitation scheme described below, the electron beam current and energy can be controlled independently. The combination of an operating pressure in the Torr range without complex differential pumping and no magnetic field allows a compact laser geometry.

The present electron beam source is schematically shown in Fig. 1. The electron beam is extracted from glow discharge plasma using a short gap of electrodes.[3] Cathode K is a tantalum pipe which is set into a molybdenum one, and the main role of the latter is to restrict a discharge to the front edge of the cathode. A$_1$ and A$_2$ are the anode and the acceleration electrodes, respectively. These are made of copper pipes each of which has a slot 30 mm long and 0.5 mm wide. The slot of A$_1$ is covered by molybdenum mesh M$_{\mathrm{mo}}$ (#100) in order to make the effective width of the slot small. A$_2$ which has an inner diameter of 8 mm is situated inside A$_1$. The electrodes A$_1$ and A$_2$ are separated by two pieces of machinable ceramics on their ends with the gap width of 0.5 mm. The outside of electrode A$_1$ is covered with ceramics except for the edge of the slot in order to concentrate the electron current in the neighborhood of the slot. The common axis of A$_1$ and A$_2$ plays the role of an optical path. It is obvious that this facility can make an easy matching of electron beam-produced plasma volume with the corresponding volume of the optical resonator. Electrode S is an additional anode. Using this electrode, there is no need to use a high voltage power supply for the breakdown. S is disconnected from the electric circuit just after the breakdown of the gas. All of these electrodes are water-cooled.

A stainless steel mesh M$_{\mathrm{sus}}$ (#20) disconnected from any electric circuit is located above the molybdenum mesh M$_{\mathrm{mo}}$. It should be pointed out that the presence of the mesh M$_{\mathrm{sus}}$ is a key factor in obtaining a uniform plasma distribution along the slot. It was observed that without M$_{\mathrm{sus}}$ the discharge plasma on the slot of A$_1$ concentrates. This means that there is a strong distortion of the potential distribution in the neighborhood of the A$_1$ electrode. To overcome this problem, we used the conductive mesh M$_{\mathrm{sus}}$, because M$_{\mathrm{sus}}$ forces the equi-potential surface of the plasma to be parallel to the surface of the A$_1$ slot. The optimum distance between M$_{\mathrm{sus}}$ and M$_{\mathrm{mo}}$ is about 1.5 mm. Using this mesh, a stable uniform plasma is realized

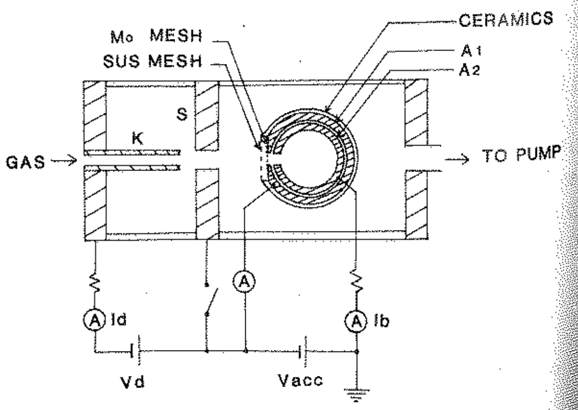

Fig. 1. Schematic diagram of the transverse electron beam source.

---

*Present address: Changchun Institute of Optics and Fine Mechanics, Academia Sinica, P. O. Box 1024, Changchun, PEOPLE'S REPUBLIC OF CHINA.

along the slot of A_1.

The present facility has two modes of operation. One is the high impedance mode, or electron beam mode. In this mode, when the potential of A_2 is biased positively against A_1, electrons fed from the discharge plasma into the electron accelerating region between A_1 and A_2 are accelerated and injected inside A_2. Electron beam currents are of the order of hundreds of milliamperes. However, it is found that when the ambient pressure or discharge current as well as acceleration voltage is increased, the current to electrode A_2 increases abruptly up to several amperes. This means that the mode of operation changes into the other mode, i.e., the low impedance mode, in which a stable discharge takes place between cathode K and the acceleration electrode A_2.

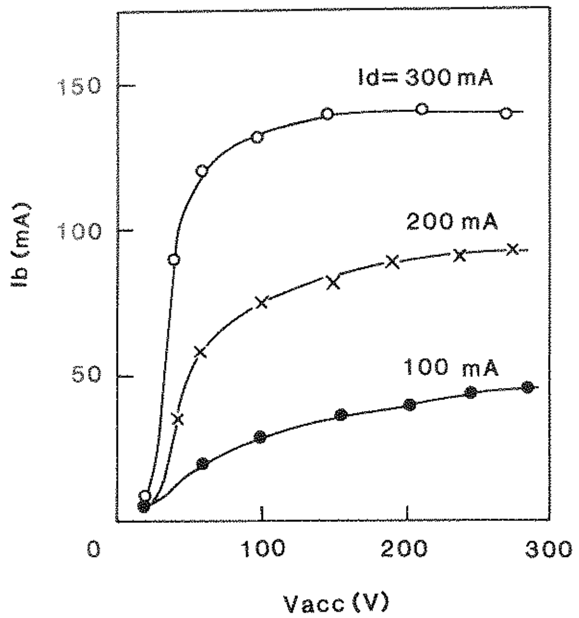

Fig. 2. Electron beam current as a function of acceleration voltage. The helium pressure is 1.7 Torr.

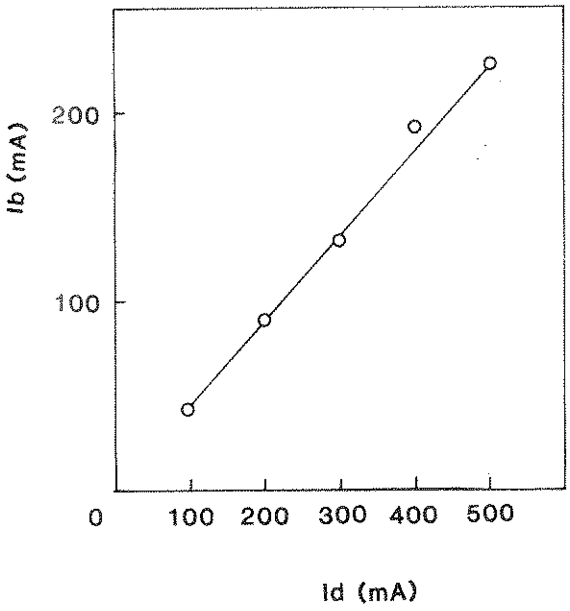

Fig. 3. Electron beam Current as a function of discharge current. The helium pressure is 1.7 Torr. The electron beam accelerating voltage is 200 V.

The dependence of the electron beam current I_b on the acceleration voltage V_{acc} is shown in Fig. 2. When V_{acc} increases beyond a threshold, I_b increases abruptly to a high value, and then saturates over the acceleration voltage of 100 V. This feature becomes more clear with the increment of discharge current. The ratio of the saturation value of beam current to the discharge current reaches 0.4–0.6. Figure 3 shows the dependence of the electron beam current I_b upon discharge current I_d. I_b increases linearly with I_d under the condition of the constant acceleration voltage. It is concluded from Fig. 3 that this facility has the important merit that the electron beam current and energy can be controlled independently. The beam current as a function of the He gas pressure is shown in Fig. 4. Available pressure region is from 0.5 Torr to 2.2 Torr, which is typical for the operation of cw ion lasers. The ratio of I_b to I_d increases with the increase in gas pressure. Above a gas pressure of 2.2 Torr, it is hard to stably accelerate the electron beam beyond 200 V because of the breakdown between K and A_2.

A maximum electron beam energy of 500 eV and electron beam current density up to 1.67 A/cm^2 are achieved in the present facility. However, the value of I_b does not refer to the electron beam current injected to the inside of A_2 through the slot. By setting a plane probe just behind the slot of A_2, we have measured the ratio of the beam current injected to the inside of A_2 to I_b; this was estimated to be about 1/3. It is expected that this ratio could be increased by improvement of the shape of the slot. This input power per unit length is sufficient for pumping of cw ion laser.

Using a plane probe, we observed the applied voltage-drain current characteristic in the plasma inside A_2, which is shown in Fig. 5. There is not only electron current from the low temperature plasma around the probe potential of 0 V but also a clear step of electron current −100 V. The latter confirms the existence of the electron beam in the plasma. The dip of the probe current from −50 V to −10 V can be attributed to the secondary elec-

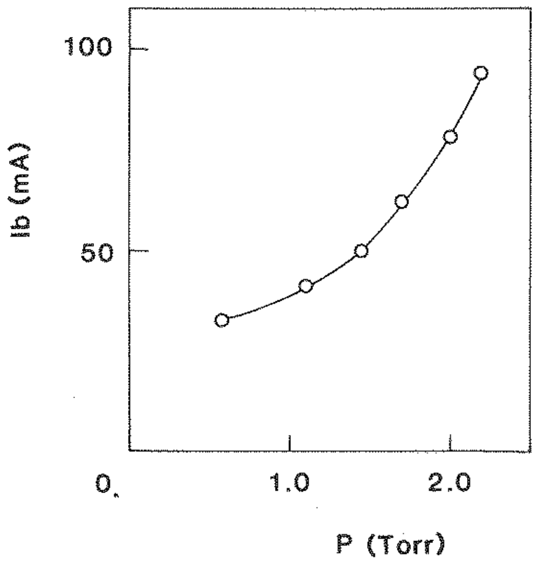

Fig. 4. Electron beam current as a function of helium pressure. The discharge current is 150 mA. The electron beam accelerating voltage is 200 V.

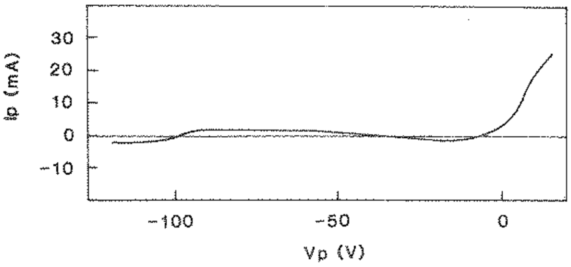

Fig. 5. Probe characteristics of the plasma produced by the electron beam. The helium pressure is 1.7 Torr. The discharge current is 100 mA. The electron beam accelerating voltage is 200 V.

trons emitted from the probe surface by the bombardment of the electron beam.

In summary, we have constructed a novel transverse electron beam source which provides reasonable operation conditions for cw ion lasers. Fundamental features of the facility are studied. It is expected that cw ion lasers including both noble gas lasers and metal vapor lasers can be pumped by such an electron beam.

The authors wish to thank Mr. M. Ishibashi and Mr. A. Tanabe for skilled technical assistance.

References

1) T. Hara, Y. Sadamoto, M. Hamagaki, T. Ohgo and T. Dote: Jpn. J. Appl. Phys. **22** (1983) L379.
2) J. J. Rocca, D. M. Mc Clure and G. J. Collins: IEEE J. Quantum Electron. **QE-19** (1983) 1485.
3) T. Fusayama: Jpn. J. Appl. Phys. **25** (1986) L406.