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# A Gold-Vapor Laser Using Ne–$H_2$ as Buffer Gas

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**Abstract.** A small amount of hydrogen was added to neon buffer gas in a discharge-heated gold vapor laser. It was found that the output power and efficiency of the gold-vapor laser dramatically increased. The average output power and efficiency increased as much as 60%, when 0.5–1.0 Torr of hydrogen was added to neon. Maximum average power of 8 W was obtained using a plasma tube with 30 mm$^{\varnothing}$ × 100 cm active volume.

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The gold-vapor laser (GVL) has a high average and peak power in the red spectral region, and is attractive due to its possible application to photodynamic tumor destruction and hyperthermia [1]. Neon or helium has been employed as buffer gas in the GVL. In the past, a variety of rare gas and other molecular gases were used as buffer gases or as additives into neon in the attempt to improve the output performance of copper-vapor lasers (CVL). Recently, several authors reported the effect of hydrogen on the output characteristics of CVL [3–6]. They found that the molecules which contain hydrogen atoms could increase the output power and efficiency of CVL. The most prominent effect was obtained when hydrogen was added. The addition of a little amount of hydrogen into neon could considerably increase the average output power and efficiency, and also improved the radial intensity distribution of the laser beam [6]. They attributed these effects to the improvement of the de-excitation of the lower laser level $^2D$. This suggests that the same positive effect can be expected for other metal vapor lasers. In this letter, we report the effect of hydrogen on the output characteristics of a discharge-heated GVL. We found the output power and efficiency of the GVL dramatically increases when a small amount of hydrogen is added into neon buffer gas.

## 1. Experimental Equipment

We have constructed a GVL, as shown in Fig. 1. It has three concentric cylinders: an inner alumina discharge tube, a quartz tube and an outer stainless steel water jacket. A fibrous ceramic insulation fills the annular region between the alumina tube and the quartz tube.

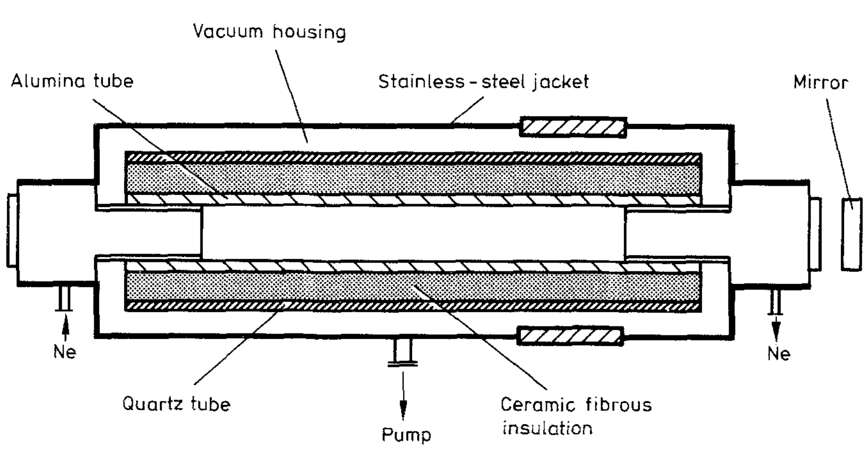


Fig. 1. Schematic diagram of the gold vapor laser

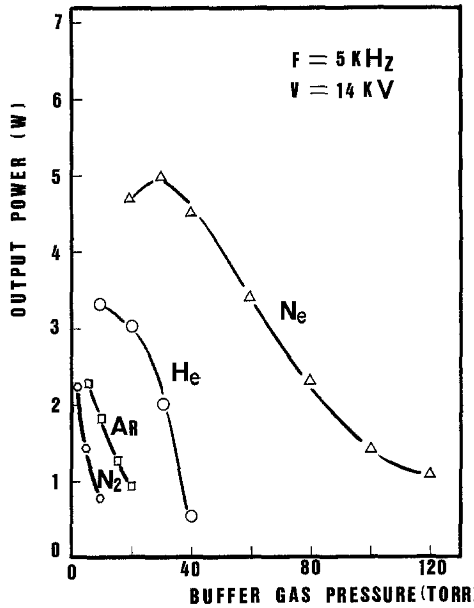


Fig. 2. The output power dependence of the GVL on the pressure of several buffer gases

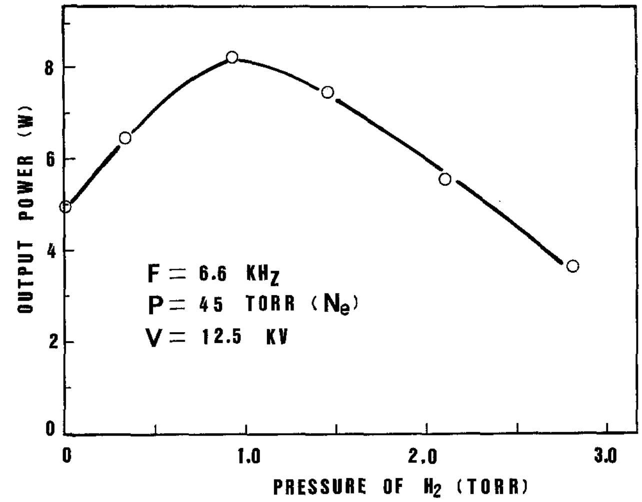


Fig. 3. Average output power of the GVL as a function of hydrogen pressure at 45 Torr neon buffer gas pressure and 12.5 kV discharge voltage and 6.6 kHz repetition rate

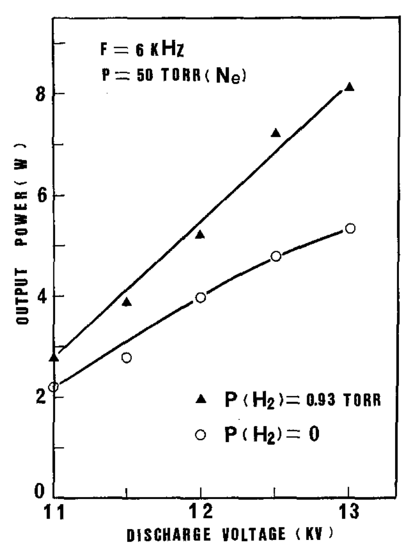


Fig. 4. Average output power of the GVL as a function of the discharge voltage without (circles) and with (triangles) hydrogen. The neon pressure is 50 Torr and the repetition rate 6 kHz

The O-ring located at each end of the quartz tube form a vacuum seal. The region between the stainless-steel jacket and quartz tube has been evacuated to $\sim 10^{-3}$ Torr. While the volume inside the quartz tube including the fibrous insulation and discharge tube is filled with 30–100 Torr neon buffer gas. The discharge tube has a 3 cm of inner diameter and a 100 cm length. The thickness of the thermal insulation is about 2.5 cm. The temperature in the discharge tube rises to 1600° C, when the input electric power is increased to 4.5–5 kW. The windows are perpendicular to the axis of the laser cavity. One of the windows works as an output coupler. The other end is equipped with a plane mirror with 99.8% reflectivity.

A 5 W average power and 0.08% efficiency in the red component (628 nm) were obtained, when $45 \sim 50$ Torr of pure neon was used as buffer gas. The discharge voltage was in the range of 10–13 kV, and the pulse repetition rate was $5 \sim 7$ kHz.

## 2. Experimental Results and Interpretation

Several rare gases (He, Ne, Ar) and $N_2$ were used as buffer gases. The output power dependence of the GVL on the buffer gas pressure was shown in Fig. 2. It can be seen that the neon is the best buffer gas. Then, a small amount of hydrogen was added to neon. The output power and efficiency were found to increase gradually with the hydrogen pressure (Figs. 3 and 4). The maximum average power of 8 W and the efficiency of 0.13% was obtained. This is almost an improvement of 60% on the output power and efficiency.

The optimum hydrogen pressure was found to be 0.5–1.5 Torr, which was higher than that for a CVL [6]. The output power decreased monotonically, when the hydrogen pressure was increased beyond the optimum value. Other rare gases and $N_2$ were also tried as additives into the neon buffer gas. However, we did not find any positive effect on the output power.

The radial intensity distribution of the laser beam was also found to change with the addition of the hydrogen. The brightness of the laser beam in the center increased as the hydrogen pressure was in-

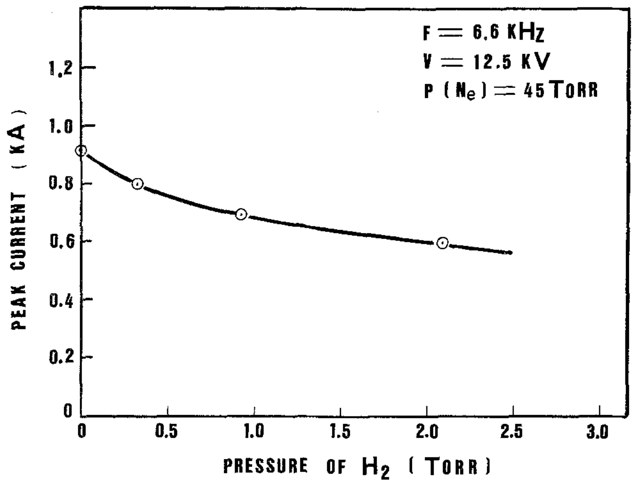


Fig. 5. Dependence of the peak discharge current on the hydrogen pressure

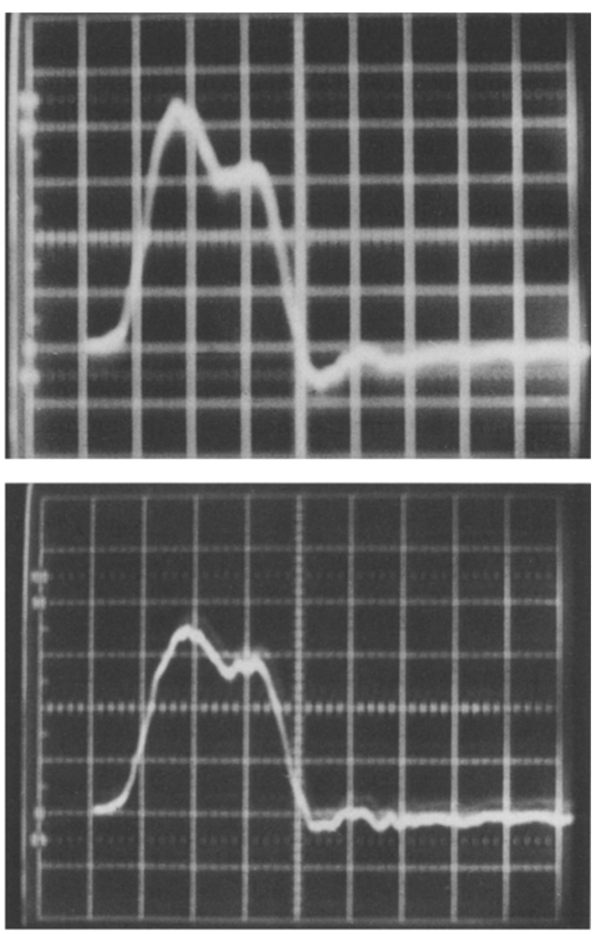

Fig. 6. The discharge current pulse shapes. Upper trace was with out hydrogen, the lower trace with 0.8 Torr of hydrogen. The pulse repetition rate is 6.6 kHz, discharge voltage 12.5 kV and neon pressure 45 Torr. The ordinate is 200 A/div, and the abscissa 100 ns/div

creased, even after the optimum pressure was exceeded. The change in the radial intensity distribution of the laser beam indicated that volume de-excitation of $^2D$ level became dominant as hydrogen atoms were introduced. Hydrogen is known to have a large elastic collision cross section with electrons and a large electron energy loss rate due to their closer mass ratio between an electron and a hydrogen atom. The addition of hydrogen effectively cools electrons after the excitation pulse has been terminated, thus, effectively decreases the population of the metastable $^2D$. The improvement of the GVL shows, at least for relatively low hydrogen pressure, the de-excitation of the $^2D$ level thorough this mechanism plays more important role than the loss of the excitation efficiency to $^2P$ level due to the cooling of electrons during the excitation pulse.

The peak discharge current was also found to decrease with the introduction of hydrogen (Figs. 5 and 6). This fact shows that the hydrogen increases the discharge plasma resistance, and thus increases the axial electric field strength. A larger electric power can be fed into the discharge plasma during the excitation pulse. This is favorable to excite upper laser level $^2P$ and to increase the population of the $^2P$ level.

## 3. Conclusion

We have constructed a high-power discharge-heated gold vapor laser. By introducing a small amount of hydrogen into neon buffer gas, the output power and efficiency of GVL was greatly increased. The effect of hydrogen can be interpreted with the improvement of the de-excitation of $^2D$ level at interpulse period and the increase in the $^2P$ level population at exciting pulse.

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