Quantum Electronics Letters

A Continuous Discharge Improves the Performance of the Cu/CuCl Double Pulse Laser

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Abstract—**A continuous glow discharge was applied to a Cu/CuCl double pulse laser. Maximum laser pulse energy was observed to increase as much as 35 percent at low buffer gas pressure and 3.5 percent at optimum buffer gas pressure. Minimum and optimum time delays decreased with increasing glow discharge current. The greater pulse energy may be due to increased rate of current rise of the pumping discharge pulse, and decreased contribution to the population of metastable copper from ion recombination.**

THE COPPER laser has received much attention in recent years as a source of intense optical pulses [1]-[5]. Unlike the conventional copper laser which requires a tube temperature of about 1500°C to obtain sufficient copper vapor from pure copper [4], the use of copper chloride (CuCl) as a source enables optimum tube temperatures to be near 400°C [1]. To obtain laser action from CuCl vapor, at least two discharge pulses are required. The first discharge pulse dissociates the CuCl, producing copper atoms. The second discharge pulse pumps the copper atoms, producing the laser pulse. The discharge pulses are typically 1-20 nF at 12-20 kV charging voltage.

Because a large fraction of the copper atoms emerge from the dissociation in the metastable lower laser level, there is a minimum time delay between discharge pulses which must pass before enough copper atoms have collisionally relaxed to permit oscillation. Copper atoms are continually reassociating to form the parent molecule, and there is a maximum time delay between discharge pulses beyond which threshold cannot be reached because the copper atom density is too low. Between the minimum delay (a few to tens of microseconds) and the maximum delay (tens to hundreds of microseconds) there is an optimum time delay for which the output pulse energy is maximum.

The afterglow period between discharge pulses is of interest primarily for two reasons. The first is that during this period thermal collisional processes occur (e.g., reassociation, charge exchange, collisional deactivation) which determine the availability of ground state copper. The second is that initial conditions are provided for the pumping discharge pulse. It has been shown that for otherwise fixed discharge conditions, the optimum laser pulse energy is proportional to the rate of current rise of the pumping pulse [6], and that the rate of current rise is a function of time delay [7].

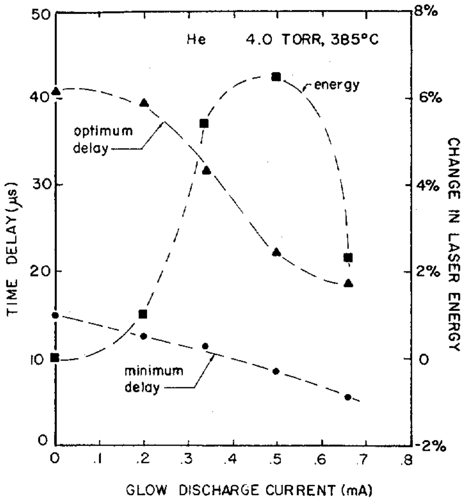

Fig. 1. The change in optimum laser energy, the minimum delay, and the optimum delay as a function of glow discharge current. There is an optimum glow discharge current for the increase in laser energy while the minimum and optimum delays decrease monotonically with increasing glow discharge current. The results are typical for a large range of buffer gas pressures and tube temperatures.

A continuous discharge should maintain the interpulse afterglow, eliminating the necessity for the second pulse to break down the gas. Consequently, the rate of current rise in the pumping pulse should be increased. We have studied the influence of a continuous glow discharge sustained in the laser tube simultaneously with the double discharge pulse excitation. The results of that procedure are reported here.

The laser was a Pyrex tube with a 12 mm diameter and pin electrodes separated by 60 cm. The double pulse power supply is described elsewhere [6]. Charging voltage and capacitance for both discharge pulses were 15 kV and 5 nF. The optical cavity consisted of a 2 m, 99 percent reflecting mirror, and a quartz optical flat. The dc power supply used for sustaining the glow discharge was homemade and unregulated. The laser energy was recorded with a Korad KDI photomultiplier.

The change in optimum laser pulse energy as a function of glow discharge current in 4 torr of helium and CuCl at its vapor pressure at 385°C (≈0.04 torr) is shown in Fig. 1. Note that the optimum laser energy is increased by as much as

Manuscript received March 15, 1979; revised May 1, 1979.

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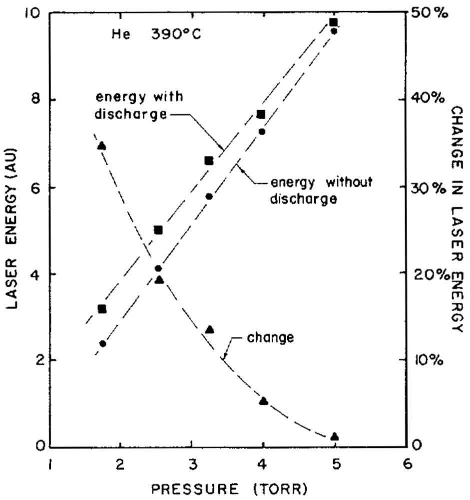

Fig. 2. Laser energy and the change in laser energy optimized with respect to time delay and glow discharge current as a function of buffer gas pressure in helium. Note that as the optimum pressure is approached (≈8 torr) the change in laser energy decreases.

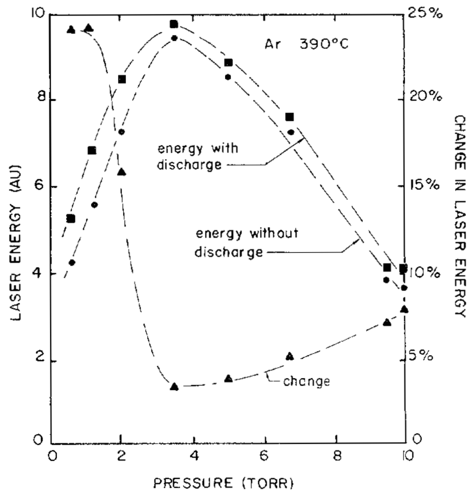

Fig. 3. Laser energy and the change in laser energy optimized with respect to time delay and glow discharge current as a function of buffer gas pressure in argon. Laser energy is enhanced by 3.5 percent at the optimum buffer gas pressure.

6 percent, and that the glow discharge current at which this enhancement occurs is less than 1 mA [8]. Note also that the minimum and optimum time delays monotonically decrease as the glow discharge current is increased. The results shown in Fig. 1 are typical for a large range of buffer gas pressures and tube temperatures. Fig. 2 shows the laser output pulse energy, optimized with respect to time delay and glow discharge current, as a function of helium buffer gas pressure. Note that at low pressures the enhancement in laser energy is as much as 35 percent, but this decreases as the optimum buffer gas pressure is approached (≈8 torr). The glow discharge became unstable as the optimum pressure was approached with helium so that the enhancement could not be confirmed at pressures greater than optimum. For the tube geometry and discharge conditions described above, the optimum buffer gas pressure for argon was low enough so that the glow discharge remained stable above the optimum pressure. Enhancement in output pulse energy was observed at and above the optimum argon pressure. The increase in laser energy was about 3.5 percent at the optimum pressure (see Fig. 3). This enhancement is not due to discharge heating. The optimum output energy is increased in the presence of the glow discharge at temperatures both less than and greater than the optimum temperature (≈400°C).

The decrease in optimum and minimum delays, and the increase in optimum laser energy observed with increasing glow discharge current is consistent with the results obtained by increasing the rate of the rise in pumping pulse current [6]. But the rate of rise increased only a few percent for the experiments reported here, much less than the value required to cause the observed change in output energy according to earlier work [6], [9]. The decrease in minimum and optimum delays are also large for the observed change in the rate of rise of pumping pulse current. The rate of current rise and peak current of the dissociation pulse were essentially unchanged by the glow discharge.

During "double pulsing" in the presence of a glow discharge, the electron temperature during the interpulse afterglow will tend to a value determined by the glow discharge and not by the gas temperature. Without the dc discharge, collisional radiative recombination is dominant, varying with the electron temperature as $T_e^{-9/2}$ [10]. With the glow discharge, this channel of ion recombination is effectively eliminated and is replaced by ambipolar diffusion. The time delays of interest here are short compared to the diffusion time required for neutral copper to return to the center of the tube after recombination at the walls. Hence, in the presence of a glow discharge, contributions to the neutral copper population by ion recombination are eliminated. The fractional ionization caused by the dissociation pulse is large compared to that caused by the glow discharge [11]. Despite this relative loss of neutral copper, the optimum laser energy increases. This can only occur if the population of metastable copper is reduced by an even larger fraction. After the electron temperature falls from its peak value, and the dissociation rate of CuCl becomes small, the only sources of metastable copper are cascading from higher lying levels and ion recombination. By eliminating this second source of metastable copper, the ratio of ground state copper to metastable copper is increased. The optimum laser energy is, therefore, also increased. In order for this explanation to be valid, ion recombination without the glow discharge, which populates the lower laser level, must be significant. The work of Gridnev *et al.* [12] indicates that this may indeed be the case.

Another effect which may be important in explaining why the output pulse energy is enhanced by a glow discharge is that copper chloride is continuously being dissociated during the afterglow. The rate of dissociation due to the glow discharge will be small compared to that during the dissociation pulse but the rate may be large enough to compensate temporarily for the loss of copper due to reassociation. Fig. 4 shows laser pulse energy as a function of time delay and glow

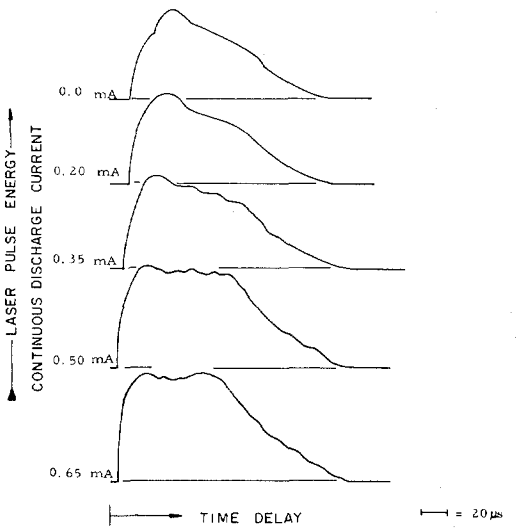

Fig. 4. Laser energy as a function of time delay and glow discharge current. Note that laser energy at long delays increases relative to the optimum delay as the glow discharge current increases. The plateau appearance suggests a quasi-steady condition between reassociation and dissociation of CuCl.

discharge current. Note that as the glow discharge current increases, the pulse energy at long delays increases relative to the optimum value, creating a plateau appearance. This suggests that a quasi-steady condition has been produced between reassociation and dissociation of CuCl.

In summary, the laser pulse energy from a Cu/CuCl double pulse laser has been enhanced by as much as 35 percent at low buffer gas pressure and 3.5 percent at optimum conditions by the application of a continuous glow discharge. This increase may be due to three causes: 1) increasing the rate of current rise of the pumping pulse; 2) eliminating contributions to the metastable lower laser level due to ion recombination; and 3) dissociating CuCl which tends to compensate the loss of copper due to reassociation. The energy input of the glow discharge is negligible compared to the energy input of the high voltage discharge pulses so that the increase in laser energy is nearly free of charge. The results discussed above, indicate that ideal discharge conditions for the Cu/CuCl double pulse laser comprise small rates of collisional radiative recombination of ionic copper; and sustained afterglow electron densities during the afterglow to reduce the impedance of the discharge and to increase the rate of rise of current during the pumping pulse.

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