Chapter Five

Discussions

5.1 : Output Energy

This study shows that the new arc array discharge circuit can also lead to laser output due to its fast discharge characteristics. More importantly, it has demonstrated a new way of electrical discharge pumping of gases that can be scaled up to higher energy coupling through arc discharge. Further work is needed to scale up the input energy needed to pump gases to higher states of ionization to obtain output in the VUV and soft x-ray regions.

From Figure 4.7 and Figure 4.8, it is clearly shown that when higher charging voltage is applied, the output energy will be larger. Therefore, if a Marx generator is applied to this system, then the output energy will be much larger. Theoretically, higher output energy will be obtained when more energy is being dumped into the laser channel. However, this is out of the scope of this thesis. The objective of this experiment is to investigate whether an arc array can produce laser action.

The output energy is the average of several pulses measured with a joule-meter. The conditions such as plasma temperature and current density may be different for every pulse. Thus, the output pulses are slightly different for different shots. A few pulses are measured and their energies are averaged. For the same conditions (same pressure and voltage) the differences of the output detected are about 0.01mJ. The maximum output pulse energy is 1.70 ± 0.01mJ.

The output pulse energy is rather low when compared with other commercial nitrogen lasers, which can produce up to 5mJ energy pulses. This is because in all the commercial nitrogen lasers, the discharge is uniform along the laser channel. However, in this experiment, there are gaps between each arc discharge. Losses occur due to the refraction along the electrode gaps. In addition, the laser channel in this experiment is not pumped high enough to produce very high temperature plasma. Since this system is not optimized, the maximum output pulse energy is 1.70 ± 0.01mJ.

5.2 : The current density

The current density of this arc discharge can be calculated. However, some assumptions and approximations have to be made. We assume that the plasma formed during the arc discharge is cylindrical between the two electrodes and has a constant volume. The diameter of each of the plasma column is approximated as 0.8 cm. This can be verified from the burn marks along the copper rod electrode. The size of the burn mark gives the approximated size of the plasma. The gap between the cathode and anode is 12 cm. Therefore, the total volume is 6.03 cm^3 and the cross section area is 0.5 cm^2. The peak current measured from the Rogowski coil is 2.13 ± 0.01kA (refer to Figure 4.10). By dividing the peak current with the cross-section area, the current density can be obtained. The current density calculated is approximately $4.26 \pm 0.01 kA/cm^2$. From this current density, it is shown that the discharge is an arc discharge because the density of the discharge is more than $0.1 kA/cm^2$ and thus is defined as arc discharge. Therefore, there are all together 64 arcs along the laser channel, which discharge simultaneously.

However, from the optical pulse (Figure 4.11 and Figure 4.12) for two different electrode profiles, the laser lase at 16ns and 20ns respectively after the laser channel breakdown. The current at 16ns and 20ns is 1.53±0.01kA (refer Figure 4.9) and 0.85±0.01kA (refer Figure 4.10) respectively.

This shows that not all the energy from the peaking capacitor is contributing to the laser. Most of the energy is wasted. This may be due to the slow discharge of the peaking capacitor. If the peaking capacitor is fast enough to dump all the energy before the laser lase, then the system will be very efficient and the output energy will be much larger. In addition, the inductance of the circuit, especially the inductance across the laser channel will determine how fast the peaking capacitor discharge. Thus, reduction of the inductance across the laser channel is essential in order to have higher output energy.

5.3 : Inductance of the discharge circuit

The inductance of the laser channel can be calculated from the voltage waveform measured at one of the pin electrode. From Figure 4.9 and Figure 4.10, the inductance across the laser channel has been calculated by using equation 5.1.

$$T_{1/2} = \pi\sqrt{LC} \qquad (5.1)$$

therefore,

$$L = \frac{T_{1/2}}{\pi^2 C} \qquad (5.2)$$

where, $T_{1/2}$ = half period of the oscillatory voltage waveform

L = inductance of the circuit

C = capacitance in the circuit = 2nF

$T_{1/2}$ for the laser channel is measured from the voltage waveform of the peaking capacitor in Figure 4.9 and Figure 4.10. Both the electrode profiles give the same value of $T_{1/2}$ is 80ns. This is consistent with what is expected because the inductance of the discharge merely depends on the separation gap and pressure in the laser channel. If these parameters are fixed, then the inductance should be the same. The inductance across each peaking capacitor is 324nH. From Figure 4.4 and Figure 4.6, it is observed that the $T_{1/2}$ measured at various electrode along the channel is also the same. The value $T_{1/2}$ is measured to be 80ns for each of the isolated electrode. Therefore, it can be concluded that the inductance at each isolated electrode is the same. By laying the wires close to the ground plate to reduce the cross section area of the loop, the same inductance for each of the separated loop of discharge can be

obtained. Therefore, the total inductance of the discharge channel is L_{64} = (324/64) nH = 5nH.

Besides, the inductance of the circuit loop from the storage capacitor to peaking capacitor can be calculated from the voltage waveform measured across the spark gap. Referring to Figure 4.2, $T_{1/2}$ is 500ns. By using equation (5.2) and the capacitance is 56nF when the spark gap is on, the inductance calculated is 452nH. This large inductance is due to the large dimension of storage capacitor and also the inductance of the spark gap. There is also a big loop from the storage capacitor to peaking capacitor.

In addition, from Figure 4.4 and Figure 4.6, the discharge waveforms at the laser channel show that there is a sharp drop at the first 20ns. This is due to the stray capacitance created when wires are laid close to the ground plate. This can be further shown in Figure 4.9 and Figure 4.10 where the current pulse seems to be a combination of the two pulses. In other words, the stray capacitance, which is very small compared to the peaking capacitors, discharge in a faster time before the peaking capacitor discharges.

Moreover, this has caused the discharge circuit to be more complex as the stray capacitance is very hard to be determined. Since the stray capacitances generated in this experiment is small and is negligible, no further study of this phenomenon is carried out.

5.4 : The optical pulse and energy dumped

The energy dumped into the laser channel can be calculated by equation (5.3).

$$E = \frac{1}{2} CV^2 \qquad (5.3)$$

where E = energy in joule

C = capacitance of the circuit

V = voltage apply to the capacitor

Since the peak of the optical pulse occur 15ns and 20ns after the laser channel breakdown, the voltage that is effectively pumped into the laser channel is the amount of voltage drop when the optical pulse comes to its peak.

Both Figure 4.11 and Figure 4.12 shows that the ΔV is 5.0 ± 0.5kV and 8.0 ± 0.5kV respectively. Therefore, the energy used to pump the laser is 25 ± 5mJ per arc and 64 ± 5mJ per arc. There are 64 arcs and thus, the total energy is 1.600 ± 0.005J and 4.096 ± 0.005J. Although such high energy has been pumped into the laser channel, the laser output is only 1.70 ± 0.01mJ. That means a lot of energy is wasted as heat and other emissions. In addition, due to the separation of each electrode, there are gaps between each of the arc. This gap will cause the beam to be absorbed, scattered and refracted. The absorption, scattering and refraction of the beam will reduce the laser output

Due to all these losses, the laser output energy measured is only 1.70 ± 0.01mJ to 1.50 ± 0.01mJ. Optimization of the system can still be carried out by reducing the gap between each arc.

5.5 : Comparisons of two different electrode profiles

From the three different electrode profiles, it is found that the flat and cylindrical electrodes may provide better discharge voltage. This is because the sharp end profile cannot hold high voltage for a long period. Corona effect occurs at the sharp edges, whereas the other two profiles have less corona effects. The results and waveforms obtained from this experiment show that there are not much difference between the flat and cylindrical electrode profiles.

5.6 : Impurity in the laser channel

Impurity of gases in the laser channel will reduce the nitrogen laser output energy. Besides absorption and scattering of the beam, the impurity gases in the laser channel may be excited instead of the nitrogen gas. These other gases may compete with nitrogen molecule to be excited. These impurities will emit photon with its own wavelength but amplification will never occur. Therefore, it is a waste of the pumped energy. In the present system, the vacuum of the laser channel is not very good and can only be pumped down to 2 to 5 mbar. Due to this limitation, nitrogen gas is purged into the laser channel a few times before starting the discharge. Better vacuum design should be employed in the future.