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[AMN01] Investigation on a longitudinal discharge ultra-violet gas laser

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Introduction

Longitudinal discharge refers to a method of electrically discharging an elongated confined geometry, in which the discharge current moves coaxially with the axis of the elongation geometry. Longitudinal discharge has always been employed to obtain visible and infra-red laser emission in the early days of laser research. Laser light is emitted coaxially with the discharge current through the tube end opening.

Short wavelength lasers research employing longitudinal discharge had started many years ago. With the success on visible and infra-red gas lasers such as helium-neon and carbon dioxide gas laser, and also the increasing demand of higher photon's energy coherent source, laser researchers turned to ultra-violet region of the electromagnetic spectrum for new type of lasers. Many ultra-violet lasing lines were reported in various types of gas species using high current longitudinal discharge. (Cheo & Cooper, 1965) These pioneering works on ultra-violet lasers does not create much impact because scaling to more practical device had been met with much difficulty. Efficient pumping of ultra-violet gas laser needs high current density and fast discharge duration, which is beyond technical capability at those times. The advent of ultra-violet gas lasers were more attributed to a new type of discharge configuration introduced later on called transverse excitation laser, whereby the laser emitted perpendicularly with the discharge current.

Longitudinal discharge lasers actually do have some inherent advantages to be used in the short wavelength lasers research. The discharge tube, usually a glass or ceramic tube provide a confined geometry to the discharge plasma, this will force the discharge current to pass through the tube's bore, which is usually small in cross section. This will enhance the current density. Today modern high voltage switching technology already enables high peak power discharge with very fast discharge circuitry. The confinement also helps to maintain a homogenous plasma condition. The elongated tube geometry will also provide adequate length for gain amplification of certain low gain lasers. This will help laser scientists to discover new lasers.

Recently, revived interests in the short wavelength lasers have been mounting tremendously, owing to the new technological applications of such laser source in advance photolithography for next generation integrated circuit chips and also micro-machining of micro-electromechanical systems. In search of better laser source for industrial applications, researchers in Japan have been able to demonstrate longitudinal discharge laser in nitrogen, krypton fluoride and fluorine. (El-Osealy et al., 2001; El-Osealy et al., 2002) Their research had displayed some favorable characteristics of longitudinal discharge laser as compared to the more conventional transverse types. In line with the research focus of our laboratory, we had initiated some works in this particular technological field to study this type of longitudinal discharge laser and further enhancing its performance.

Experimental Setup

The longitudinal discharge gas laser used in this experiment essentially consists of a quartz discharge tube enclosed by two side-flanges. The quartz tube is 100mm in length and has a 6mm outer diameter and 3mm bore. The two side-flanges are made of stainless steel SS 316 material, so that different types of gases could be used in the future, including highly corrosive halogen gases. The choice of stainless steel also will minimize the contamination of the discharge tube. One of the flanges housed a 25mm highly reflective aluminum mirror while the other housed a 25mm CaF_2 transmission window, which will be transmitting wavelength deep down into the vacuum ultra-violet region.

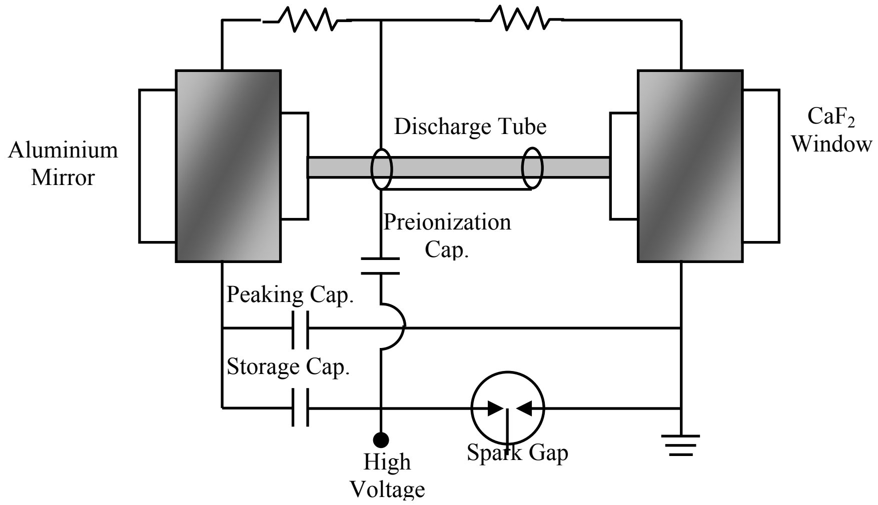

FIGURE 1 Schematic showing the setup of the longitudinal discharge gas laser.

In order to excite the lasing medium with fast pulsed power input, special capacitor configuration need to be employed in this experiment. We used a C-to-C charge transfer circuit to excite the laser. In this case, a 2nF ceramic high voltage capacitor, as a storage capacitor is being charge up by the high voltage charger. Upon triggering of the spark gap, the storage capacitor will discharge and transferring its charges to a second capacitor called peaking capacitor, which is a 0.7nF ceramic high voltage capacitor. As the peaking capacitor is being charged up, the holding voltage of the discharge tube with respect to ground potential will be increased. Ideally, the discharge tube will breakdown once the peaking capacitor is fully charged, then the peaking capacitor will dump all its energy into the discharge tube. In our experiment, we have constructed a high voltage power charger which step up our normal line voltage to become a 25kV, 30mA high voltage capacitor charger.

Most of the short wavelength gas lasers require a very fast current rise time to create the population inversion for realizing amplified stimulated emission. So special considerations were taken when we construct this experiment. The ground return path was distributed radially along the discharge tube to complete the complete the current loop back to the capacitors. This will ensure a minimal inductance circuitry, thus enhancing the discharge duration and its current density. A compact triggered spark gap was specially designed as a switch for this configuration. Point-to-plane configuration was adopted in the spark gap design to provide a stable triggering and wider operating voltage range. This spark gap can be pressurized with different insulating gas for enhanced performance. Preionization is needed to ensure smooth breakdown for such a long discharge tube. Thin wires which acted as corona wire were wrapped on both ends of the discharge tube and is excited by a small capacitor connected to the spark gap.

Electrical diagnostics were done in this experiment using Tektronix P6015A high voltage probes which offered a 1000X attenuation and a self made Rogowski's coil, which essentially is an magnetic pick-up probe that measure the magnetic field generated by the changing discharge current. The coil's signal then will be integrated to give the current signal. The laser temporal pulse shape was detected using a BPX65 silicone photodiode. All these signals were displayed and stored using a Tektronix 3034B 300MHz, 4-Channel Digital Phosphor Oscilloscope. The laser pulse energy was measured using an Ophir NOVA joulemeter with a PE-10 pyroelectric detector.

Experimental Results

In this experiment we used nitrogen gas as the active medium. Nitrogen was selected because it emits in ultra-violet wavelength of 337nm and it has stringent requirement in

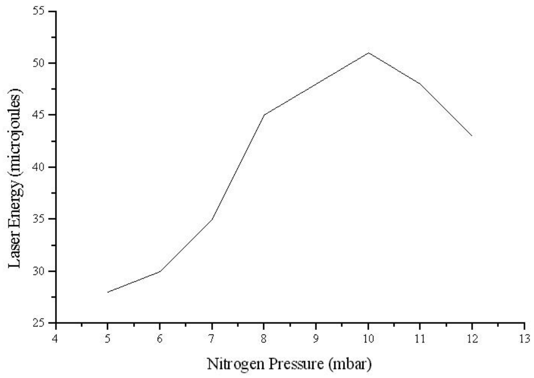

FIGURE 2 Pressure dependence of the laser energy generated by the longitudinal discharge pulsed nitrogen laser.

pumping duration. This will serve as a good indication on the performance of the laser. As shown in figure 2, the laser output pulse energy increased with operating pressure until its optimum point after which it started to decrease. With a charging voltage of 15kV, the laser pulse energy reached 52μJ when the laser is operated 10mbar. This will translate to an overall efficiency of 0.022%. If we made a comparison to earlier reported works, the Japanese groups nitrogen longitudinal laser reported 0.028% efficiency in a 15cm long tube with more than 24kV charging voltage. (El-Osealy et al., 2001)

Discharge current was measured using the self-made current probe and the signals were stored in the oscilloscope. Waveforms shown in figure 3 indicate a calibrated peak current of 0.35kA when the peaking capacitor is discharging at 15kV. Taking into consideration, the tube bore diameter of 3mm, we have a current density of 5kA/cm^2. The current waveform also showed that it has a 20ns risetime.

Conclusion

From the results we obtain from the experiments, we had demonstrated that we managed to enhance the performance of longitudinal discharge nitrogen laser by having a more compact discharge circuitry and lowering the plasma impedance of the discharge. We had done a thorough study of the laser's electrical behavior and we can conclude that such a longitudinal discharge laser is capable of pumping higher current density compared to a normal transverse discharge. This had opened up new possibility of trying other gas mixtures to obtain shorter wavelength lasers, such as rare gas or rare gas halogen excimer lasers. Excimer lasers usually require high pumping density and some of the high energy vacuum ultra-violet excimer lasers have until now only been able to realize in electron beam pumped devices. (Hughes, 1974).

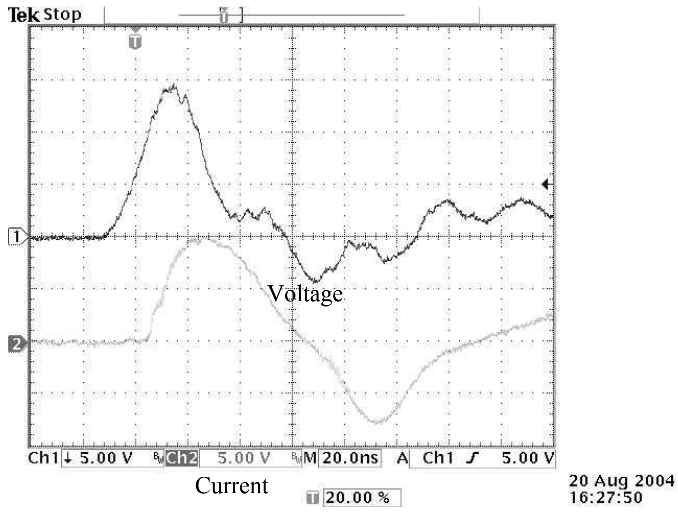

FIGURE 3 Oscillogram showing the discharge voltage and current waveforms of the longitudinal discharge laser.

The annular structure of a longitudinal discharge gas laser provides an excellent geometry to obtain good output beam profile. The high aspect ratio of the tube's length to the tube's diameter also provides low beam divergence. By operating these longitudinal lasers in ultra-short wavelength of vacuum ultra-violet region, they are the best energy source for micro-machining highly delicate devices. Its short wavelength and high beam quality will ensure extremely small feature, in term of nano-scale to fabricate precisely. This will greatly benefits the micro-electromechanical system (MEMS) industry.

The high photon energy emitted by these vacuum ultra-violet excimer laser is higher than the bonding energy of a lot of materials, including that of silicone compound. These VUV lasers will find applications in advance material research by being able to perform new experiments on photo-ablation and spectroscopy to study the characteristics of the materials of interest.

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