Chapter One

Introduction

1.1: Background of the experiment

In 1996, Rocca et. al. [1] has successfully produced a table top x-ray laser with the output of 1mJ pulses. Capillary discharge scheme has been used to obtain this laser. Such a discharge scheme has limitations in power scaling. Therefore, there is a need to develop a new discharge scheme, which is capable of producing fast and high current discharge.

A new transverse arc array discharge scheme has been developed as an alternative way of pumping shorter wavelength lasers (a patent is currently being processed for submission) [2].

Two research projects were initiated in parallel to investigate the practical implementation of such a new discharge scheme. In this present experiment, investigation has been carried out on the laser action of the transverse arc array in nitrogen gas. Electrode profiles and discharge characteristics have been studied. In this experiment, a single large capacitor acts as the storage capacitor while 64 isolated peaking capacitors are connected directly to the discharge channel to form a 'C-to-C' discharge circuit. The other project, which was carried out concurrently in developing this concept, aims to develop a faster discharge circuit. The details been discussed in K.F. Ng 's thesis [3].

1.2:Brief introduction of short wavelength lasers

Since the invention of laser in 1960 by T. H. Maiman [4], this field has undergone a rapid development with vast impacts on a wide range of science and technology. The output wavelengths of the lasers available today span from several hundred micron (far infrared) to shorter wavelength such as vacuum ultraviolet.

In Schawlow and Townes' analysis of infrared and optical maser [5], they appraised the difficulties associated with the extension of maser concept to ultraviolet or shorter wavelength. They indicated that the emission of shorter wavelength depends on the excitation power required to establish useful population inversion and optical gains at these shorter wavelengths.

The most important forerunner of the direct amplifying, self-contained laser to be developed was the molecular nitrogen laser [6]. This laser, which emits at 337.1nm from molecular electronic levels, has motivated the development of the fast-pumping circuits required for shorter wavelength lasers, as well as pointing out the utility of molecular electronic levels for UV laser.

The development of nitrogen laser led directly to the realization of the first vacuum ultraviolet (VUV) laser from H_2 molecule [7]. Further works by Waynant was able to generate lasing at 116nm from the Werner-band transitions $(C^1\Pi_u\text{-}X^1\Sigma_g^+)$ of H_2 [8].

In 1968, Molchanov etc. al. [9] proposed the possibilities that rare gases could be made to lase. Koehler and associates [10] then used high current electron beams and high pressure gaseous Xe to form excited Xe molecules (Xe_2*) called excimers. Lasing was observed at 172nm from these excimers. Later, other excimers such as

Kr_2^* and Ar_2^* have been made to lase in the 126nm-146nm region. These lasers appear to have potential for both high power and high efficiency.

Most of the pulsed gas lasers reported up to date is produced from direct electrical transverse discharge excitation scheme. These direct electrically discharge excitations have difficulties to produce the excitation power required to create population inversion for emission of shorter wavelengths such as soft X-ray and VUV. All these direct electrical pumping methods are operated mainly in the glow discharge region, which may not provide enough excitation energy for pumping of shorter wavelength output. When higher energy is pumped in during the discharge, the discharge will switch from glow to arc discharge and uniformity along the laser channel is lost. Once arcing occurs somewhere along the channel, all the stored energy will discharge through this arcing channel and no laser output is obtained. Therefore, such transverse electrical discharge lasers include means to ensure uniform glow discharge along the laser channels in order to obtain high output power.

Several short wavelength (VUV and X-ray) laser excitation schemes have been proposed. Transient collisional excitation schemes, which are pumped by picosecond lasers have produced soft x-ray amplification [11]. Other soft x-ray amplification has been obtained by utilizing high intensity ultra-short pulse laser to pump soft x-ray laser in plasma created by optical-field-induced-ionization.

In 1988, Rocca et. al. [12] from Colorado State University reported on the capillary discharge, which has produced soft x-ray amplification. In such a capillary discharge, highly ionized plasma has been created by very fast discharge. Subsequently, the plasma is cooled rapidly by heat conduction to the capillary walls. This resulted in the recombination of highly ionized species into ions of lower charge and thus creating population inversions.

In 1996, Rocca et. al. has successfully scaled the soft x-ray emission gain to reach gain saturation. He scaled the fast capillary discharge by increasing the length of the capillary discharge to 12cm long [13]. Up to date, the length of the capillary discharge has been increased to 34.5cm and the pulse energy is increased to 1mJ [1]. A four stage Marx generator has been used to discharge this capillary. Further increment of length to obtain higher output energy will need higher discharge voltage. Therefore, there will be a limitation in the scaling of output energy for this capillary discharge to obtain higher output energy.

Since the capillary discharge is classified as arc discharge, amplification in an arc array discharge will be investigated in this project. Instead of scaling the capillary discharge by increasing the discharge length, a new method of scaling will be employed in this project. In this project, an array of transverse arcs will be employed. This will enable amplification to occur transversely.

The arc array in this experiment consists of 64 separated electrodes, which are discharged transversely and separately. By this transverse discharge, the voltage needed for discharge will not be too high. This is because the separation gap between the cathode and the anode is kept within a few centimeters. The scaling of the gain of laser action is obtained by increasing the number of arcs instead of the length of the discharge. Therefore, the separation gap of the electrodes can be kept to a short distance.

1.3: Applications of short wavelength lasers

Short wavelength lasers such as x-ray or VUV lasers have abundant applications in many fields such as microscopy, material science and plasma physics.

Precise control of optical energy over narrow frequency bands in the UV region will enable a detailed examination of electronic structure of atoms and molecules.

Moreover, these short wavelength sources will be useful in a vast array of photochemical processes, which implies the development of efficient methods for isotope separation and other wavelength selective chemical syntheses.

Application of short wavelength laser in lithography is very important. Shorter wavelength used in the lithography process means smaller integrated circuits can be manufactured. In other words, smaller size and higher density IC's can be made with shorter wavelength lasers employed in the lithography process.

The short wavelength, high brightness and good spatial coherence of soft x-ray lasers make them ideal sources for the diagnostics of dense plasma. Interferometry with visible and ultraviolet lasers has been used to map the evolution of a large variety of plasmas [14]. However, free-free absorption and refraction of the probe beam limit the maximum electron density, plasma size and plasma density gradient that can be probed with optical lasers. The developments of powerful soft x-ray lasers will allow detailed mapping of the electron density evolution in a great variety of dense plasma.

Moreover, the application of x-ray lasers and short wavelength lasers in biology is tremendous. X-ray holographic tomography with simultaneous exposures of coherent x-ray from several directions may be a suitable method for the three dimensional observation of cellular structure. X-ray lasers in particular can provide a suitable light source for this type of application.

1.4 : Objective of this project

The objective of this project is to investigate the laser action in an array of transversely excited arc discharge. In conventional transverse excited laser, there is a pair of electrodes, which are discharged uniformly along the laser channel. Only glow discharge may provide uniform discharge along the laser channel and the discharge circuit is either a charge-transfer-circuit or a Blumlein circuit.

However, in this project, an array of arcs is generated using 64 separated electrodes. This arc array will give amplification transversely with the discharge. One arc is approximately equivalent to one capillary discharge although the arc is not constrained inside a capillary. By putting these separated arcs side by side, amplification may be obtained. Investigations will be carried out on laser action in nitrogen gas using this arc array amplifier.

The setup that provides the lowest inductance and fast discharge will be investigated. The voltage and current characteristics of the discharge will also be studied. Other parameters such as pressure and output power will be studied too.

1.5: Outline of the thesis

A brief introduction of laser and the objective of the project have been given in this chapter. More detailed literature review will be given in chapter two

The experimental setup and the experiments carried out will be presented in chapter three. In chapter four, results of the experiment will be reported and discussions of the results will be presented in chapter five. Conclusion of this study will then be presented in chapter six. Some suggestions for future studies will also be included in this last chapter.