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A High Efficiency Soft X-ray Source for Scientific and Industrial Applications

A. Patran[1, 2], R. S. Rawat[1], D. Wong[1], S. V. Springham[1], T. L. Tan[1], P. Lee[1], and S. Lee[3]

1. Natural Sciences, National Institute of Education, Nanyang Tech. Univ., Singapore
2. on leave, National Inst. for Laser, Plasma and Radiation Physics, Magurele, Romania
3. International Center for Dense Magnetised Plasmas, Warsaw, Poland

Abstract

A new electrode system is designed and implemented for the NX2 device, a low energy plasma focus, at the Nanyang Technological University, Singapore. Different electrode shapes, lengths, as well as different insulator lengths were investigated in order to determine the optimum conditions for generation of soft X-rays in a narrow spectral range, 0.9 – 1.55 keV. The maximum average X-ray yield of 140 J/shot has been observed; this is an increase by a factor of almost 5-6 as compared to the one reported by previous works on the same device. For repetitive studies (2 Hz), the operating parameters were adjusted for lower average production, around 80 J/shot, in order to extend the life of the sensitive insulator sleeve. The soft X-rays emitted by the NX2 device were used for contact microlithography, using SU-8 resist.

Introduction

The study of the soft X-ray emission from dense, magnetised plasmas represents one aspect of particular importance, both for academic studies and for practical applications. In recent years an increasing number project were dedicated to develop plasma focus devices as a powerful point X-ray source for microlithography, microscopy and other applications. These applications require specific characteristics for the emitted X-rays, in terms of energy, fluence, geometrical characteristics of the beam, etc. For microlithography purposes, neon X-rays seems to be the best choice for a plasma focus device. The photon energy from highly-stripped neon ions (line radiation) is of the order of 1 keV [1], where certain commercially-available chemically-amplified resists show reasonable sensitivity [2].

Experimental Set-up

The experiments were carried out on the NX2 device. The details of the original device are described by Zhang [3]. Several upgrading works were performed on the machine in recent years, but the main parameters of the device remained unchanged: capacitance 27.6 μF, quarter period time 1.3 μs, charging voltages between 6 and 15 kV, typical current of 350 kA and stored energy up to 3.2 kJ. Different electrode shapes, lengths, as well as different insulator lengths were investigated in order to determine the optimum conditions for generation of neon soft X-rays.

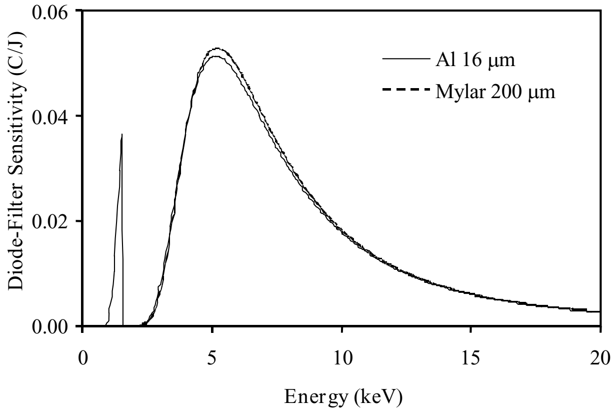

Fig. 1: Sensitivity curves for the diode-filter system.

The total X-ray yield in this spectral range was measured using filtered BPX-65 PIN diodes. They were placed 250 mm radially from the anode axis. The history mode of the Yokogawa DL1540 oscilloscope was used for taking up to one hundred single shot characteristics and the 64-shot averaging mode was used when operating in repetitive mode. Diodes were used in a saturated regime, based on Liu's experiments [1].

The filters used for the experiments were mylar (200 μm) and aluminium (16 μm). Using Henke's data for the X-ray attentuation length in solids [4], the overall transmission curves of the diode-filter detectors for argon SXR were obtained, and are presented in Fig. 1. The spectrum obtained by Liu [1] on the same device was employed to compute the neon soft X-ray. The schematic diagram of the experimental set-up, along with types of anode tips used, is shown in Fig. 2

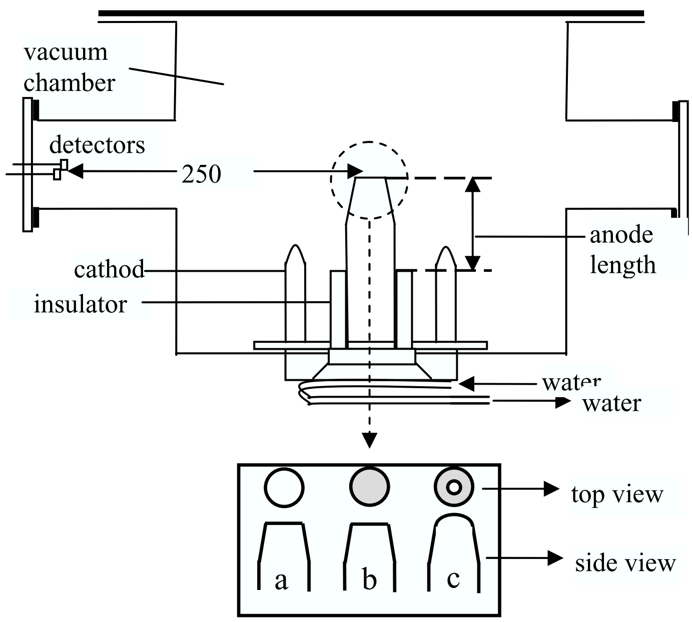

Fig. 2: Experimental set-up.

<u>Optimisation of Soft X-ray Emission</u>

In order to find the optimised conditions for generating soft X-rays in the desired spectral range, several parameters had to be investigated: charging voltage (6–15 kV), filling pressure (4–14 mbar), anode length (25–55 mm), insulator length (51–60 mm), shape of the tip of the anode (flat or hemispheric) and the configuration of the central part of the anode (solid or hollowed, with various diameter for the hole). After systematic studies of different combinations of all these parameters, the 45 mm with the biggest possible hole and a 54 mm insulator was found to be the optimum anode configuration. The soft X-ray yield for this anode operated at the various pressures and charging voltages in single shot regime is shown in Fig. 3. It can be seen that the soft X-ray yield increased with increased charging voltage reaching close to 140 J/shot at 13.5 kV; this represents a plug efficiency of 5.6%, an excellent result for any X-ray source.

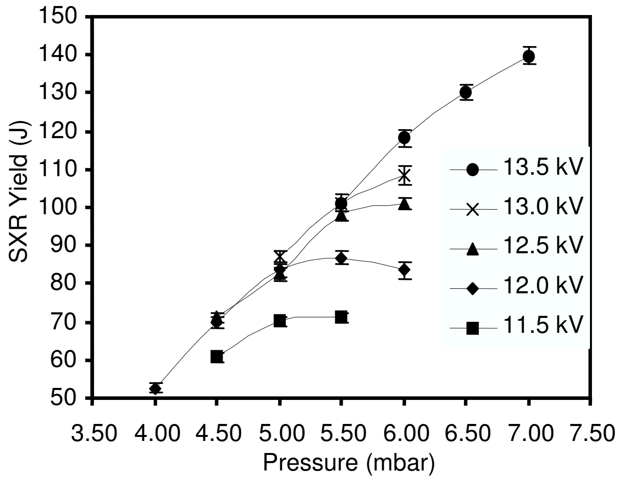

Fig. 3: Soft X-ray production for the optimised anode geometry for various operating conditions.

<u>Repetitive Operation Mode</u>

The optimised anode was operated at 6 mbar neon pressure and 12.5 kV charging voltage, at 1 Hz repetition rate; these conditions were chosen in order to be less stressing for the insulator sleeve. The soft X-ray yield for 800 shots in the same gas filling, is given in Fig. 4. It can be seen that the linear regression line of the 800 shots is fairly horizontal and the average soft X-ray output for a big number of shots can therefore be considered constant at 82 J/shot; the general shot-to-shot standard deviation was at a narrow ±18%; the maximum single-shot yield was close to 140 J. The best average wall plug efficiency obtained under repetitive mode was 4%.

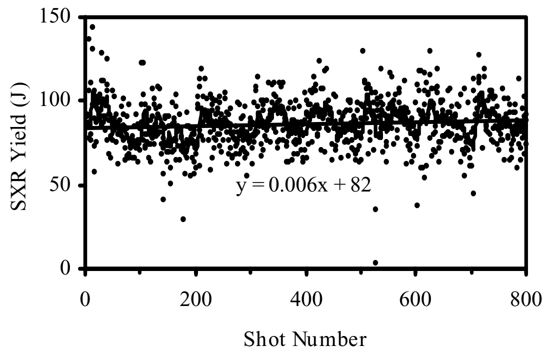

Fig. 4: Soft X-ray yield in repetitive mode.

Although the anode itself was water-cooled, the chamber gets hot, with the top flange reaching to temperatures close to 80°C during repetitive firing. For lithography purposes the SU8 resist has to be kept at temperature below 90°C. We are able to fire at least 800 shots while maintaining constant average soft X-ray emission, without the need for gas flow or change. The typical maintenance cycle (limited by the insulator sleeve life span) was longer than 10,000 shots.

Microlithography Test Exposure

Two exposures were made on an SU-8 resist film. The SEM micrograph in Fig. 5 shows the first (300 shot) exposure and second exposure with 30% and 200% of the optimum dose respectively. The first shows incomplete cross-linking at the bottom surface leading to smaller structures in the resist. The second exposure shows the test structures having clear, sharp edges and high aspect ratios implying complete cross-linking. These results confirm our yield measurements.

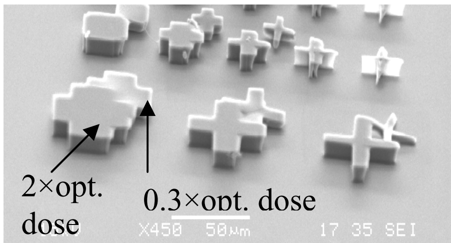

Fig. 5: Microlithography test structures on SU-8 resist.

Conclusions

The newly-designed, optimised electrode system for the NX2 device lead to an excellent 5.6% plug efficiency for the plasma focus device as an X-ray source in the 0.9 – 1.55 keV. In single shot operation mode the best average X-ray yield in the desired energy range is 140 J/shot. In repetitive mode, optimized for long maintenance cycle, the yield is 82 J/shot (about 4% efficiency). We demonstrate that the device can be used to provide optimum dose for SU-8 resist without gas change in 800 shots.

Acknowledgment

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References

1. M. Liu, *Soft X-Ray from Plasma Focus*, Ph.D. thesis, Nanyang Technological University, Singapore (1997).
2. MicroChem, *NANO^{TM} SU-8 2000 Negative Tone Photoresists Formulations 2 - 15 Report*, (2001).
3. G. Zhang, Plasma Soft X-Ray Source for Microelectronic Lithography, Ph.D. thesis, Nanyang Technological University, Singapore (1999).
4. B. L. Henke, E. M. Gullikson, and J. C. Davis, Atomic Data and Nuclear Data Tables Vol. 54, 181 (1993).