EMISSION OF NICKEL Kα LINE RADIATION BY USING A LOW ENERGY PLASMA FOCUS DEVICE

G. RASULE[a], M. SHARIF[b], M. I. ARSHAD[b], M. ZAKAULLAH[c], M. SHAFIQ[d], M. AJAZ-UN-NABI[b,*]
[a]*Government College Jaranwala, Pakistan*
[b]*Department of Physics, Govt. College University, Faisalabad, Pakistan*
[c]*Government College University, Lahore, Pakistan*
[d]*Department of Physics, Quaid i Azam University, Islamabad, Pakistan*

Nickel Kα line radiation of energy 7.47 Kev and wavelength 1.6606 Å is studied in the present work by using a low energy plasma focus device which can be used for microscopy, micro lithography and radiography etc. Three Quantrad Si PIN- diodes are used for the detection of x-rays emitted from the plasma. The range of the pressure for which the x-rays are emitted from plasma lies in the range 0.5 – 2.0 mbar. It is found that when the filling pressure is 1.75 mbar, the nickel Kα - line radiation emission exhibits the maximum value of about 0.26 J/sr having 0.01% efficiency. The main cause of the emission of Ni Kα – line may be assumed to be result of interaction between electron beam and nickel insert in the focus region.

(Received November 12, 2018; Accepted March 5, 2019)

Keywords: Plasma focus, X-ray emission, Ni Kα-line

1. Introduction

The plasma focus has been remained under investigation for the generation of x-rays for last five decades. This device has the advantage of being operated at comparatively lower voltage and easy installation in comparison with other pulsed x-ray sources. In recent studies, plasma focus devices have been proved as vital source to generate helium ions beam profile, angular and iso-ion beam distributions [1]. As this device is also known to be a generator of an intense pulsed neutron and x-ray source, so it may be employed for x-ray microscopy, X-ray lithography, x-ray micro - machine, x-ray backlighting, and x-ray radiography etc. [2-6].

Kalaiselvi et al [7] reported the possibility of enhancement of soft x-ray emission by using a fast miniature plasma focus device (0.235KJ). They doped krypton (Kr) with neon (operating gaseous medium). The 1% doping in Kr enhanced the average optimum soft x-ray emission efficiency from 0.47% to 0.6%.

Morteza Habibi [8], studied angular distribution of argon ion beam by using plasma focus device having energy 3.5 KJ with the help different anode shapes i.e., two cylindrical anodes with hollow and flat tops and two cone shaped with flat top and hollow tops at different working pressures. He concluded that the ion flux increases from 5.57 x 10^{12} ion /sr to 9.82 x 10^{12} ions/sr when cone flat anode tip was used instead of cylindrical flat anode tip. Kalaiselvi et al [9], first time demonstrated the potential of very small sized plasma focus devices in the field of x-ray production which may be useful for lithography. The main objective of this study is to obtain smaller X-ray spot size to get higher resolution micro components. Zakaulah et al [10] used three different shaped anodes by using low energy Mather type plasma focus device to produce x-ray and ion beam emissions. They used argon as a filling gas and found that the anode shape had a great importance because both the x-ray yield and and the filling gas pressure highly depend upon the shape of the anode. The results revealed that the best x-ray emitter is tapered anode. Zakaullah et al [11] inquired production of x-rays from a low energy plasma focus and used argon as a filling

[*] Corresponding author: majazunnabi@gcuf.edu.pk

gas. Their focus was to determine the highest argon K – series line emission which they successfully found at filling pressure of 1.5 mbar. The average amount of energy they found in 4π geometry was approximately 30mJ and corresponding efficiency was 0.0015% at that pressure. The interaction between energetic electrons and anode were reported to be the main cause of this emission. Yasuo Kato et al [12] made a splendid and steady x-ray source for x-ray lithography. A good ceramic insulator made up of alumina was used to improve the system reliability. The system was used for more than 105 capacitor bank discharges without maintenance. The stability of the location of X-ray spot on the axis was achieved by using new spherical electrode. The size of X-ray source achieved in the neon filling was 1 mm in diameter and 10 mm in length. It resulted a fine pattern of 0.4 µm with x-ray intensity of 5 MJ/cm^2 /shot, 25 cm from the source with an irradiance of 10 MW/cm^2 at the 2 Hz repetition rate. Shafiq et al [13] calculated K - series line radiation emission from molybdenum (Mo) and copper (Cu) by using a low energy plasma focus. Silicon pin diodes and pinhole camera were used as time resolved x-ray detectors and time integrated analysis. They used hydrogen as a filling gas and observed that the pressure range for which the x-ray flux was measureable lies in between 0.5 - 3.5 mbar. The x-ray yield was maximum when the filling pressure was at its peak i.e. 2.0 mbar and that was approximately 0.05 J/sr and 0.17 J/sr for Mo and Cu respectively. Hence the related efficiencies were 0.03% and 0.09% respectively. Sharif et al [14] reported a detailed study of x-ray emission by using the Mather type plasma focus device with different anode tip inserts (Cu, Mo, W) by changing charging voltage and the operating conditions were correlated with the emission parameters in order to increase x-ray production for devising x-ray emission scaling laws.

2. Experimental set up

A low energy plasma focus device is used in this experiment. To energize this device a single 12.5 µF capacitor which is charged up to 19 kV and having discharge energy 2.25 kJ is used. In this research work, nickel inserts at the anode tip and argon as a filling gas are used to study x-ray emission. To transfer electrical energy of capacitor to the electrodes a pressurized spark gap is used. The experimental set up of plasma focus used is shown in the figure1. A 160 mm long copper rod with 18 mm diameter is used as anode. Ni disc is inserted in the anode tip with depth and diameter 0.8 mm and 7 mm respectively. A symmetrical arrangement of six 10 mm thick copper rods of equal length and located at the same distance from the anode is used to make a cathode of 50 mm diameter.

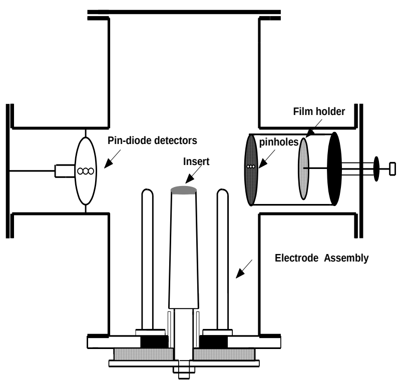

Fig. 1. The schematic diagram of plasma focus device.

By using a rotary vane pump the chamber of plasma focus is cleaned up to 10-2 mbar pressure. The existing gas is removed to reduce the effects of impurities after every five to six shots and fresh gas is filled again. By varying filling pressures five to seven shots have been taken. The Quantrad Si pin diodes of thickness of the order of 125 µm are employed for time resolved x-ray measurements. The diode is covered with a lead disc of thickness 1.5 mm which has a hole at the center of diameter 2 mm so that the x-ray flux may reach the diode at a safe level. The detectors are located at a distance of 15 ± 0.2 cm from the anode axis and height of anode tip is kept 1.5 ± 0.1 cm. A four channel 200 MHz Gould 4074A digital storage oscilloscope has been used to register the electrical signals from x-ray detectors and high voltage (HV) probe and the whole data is conveyed to a computer by using a GPIB 488.2 interface.

3. Evaluation of system efficiency

The selected Ross filter pair comprising of Ti (37.5 μm) and Co (20 μm) are employed to detect the Ni-Kα line radiation. Fig. 2 depicts the transmission curves of the filters. The data used are taken from the Handbook of Spectroscopy J. W. Robinson [15] to elaborate these particular curves. The absorption edge of Co lies at 7.70 keV, and it permits the transmission of x-rays through 4 - 7.70 Kev window. The Ti filter has the absorption edge at 4.97 Kev, and provides 2.0 - 5.0 Kev window for radiations. The Ni-Kα line of 7.47 keV is blocked by Ti filter. The presence of Ni Kα – line is determined bu taking the difference of transmissions with Ti and Co filters.

The x-ray emission is determined by using the following relation

$$Y = \frac{4\pi Q_{\exp}}{d\Omega\, S(E)T(E)}$$

where $Q_{\exp} = \int \frac{Vdt}{R}(coulombs)$; dΩ is the solid angle; S (E) is the average sensitivity of the detector. T(E) is the FWHM transmission of the filter in the said interval and R = 50Ω in this experiment.

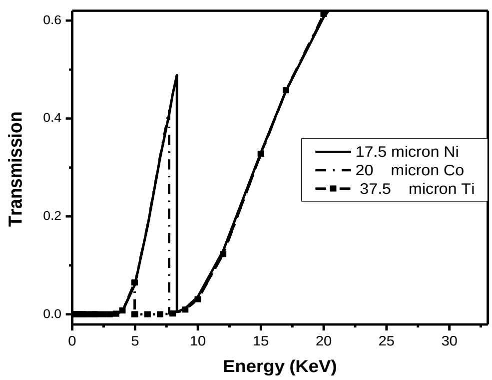

Fig. 2. The transmission curves of the filters.

4. Results and discussion

Fig. 3 indicates the variation of Ni - Kα versus pressure. The range of the pressure for a significant yield is from 0.25 mbar to 2.0 mbar, above or below which yield is negligible because very weak or even no focusing is observed. A peak of high intensity is observed at about 1.75 mbar. Then it happens that with further increase in pressure, the x – ray emission drops. It is quite possible that at low filling pressure, the electron beam emission Choi et al [16] is dominant and probably the beam strikes the anode tip and generates x-rays. With gradual increase in filling pressure, the intensity of electron beam and hence the x-ray emission increases. Further increase in the filling pressure, the device will be in the high pressure mode generating high temperature and high density plasma filament, enhancing the x-ray emission.

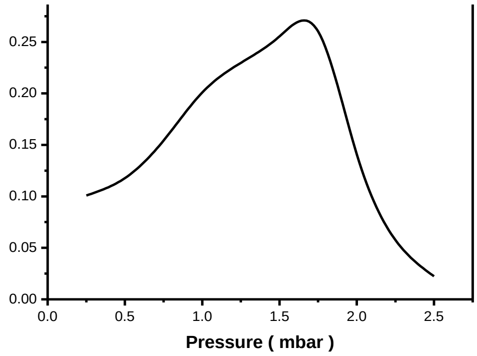

Fig. 3. The variation of Ni-Kα yield versus argon filling pressure.

It is also estimated that the x-ray yield strongly depends upon filling gas pressure. The variation of the x-ray emission with filling gas pressure could be explained in a very simple way. For good focus, the optimum x-ray yield can be obtained with the simultaneous occurrence of the peak current and the pinch. It has been observed that the number density of reacting particles increases with increase in filling gas pressure in pinch radiating plasma and hence increasing the x-ray yield. But as much as we increase the pressure, the x-ray yield does not increase anymore because the time to pinch increases further and hence the emitted x-ray emission decreases because of this fact that the pinch time does not synchronizes with peak current. It is fact that the hard x-rays are generated due to the interaction of energetic electron beam with the anode tip in the focus region in plasma focus device.

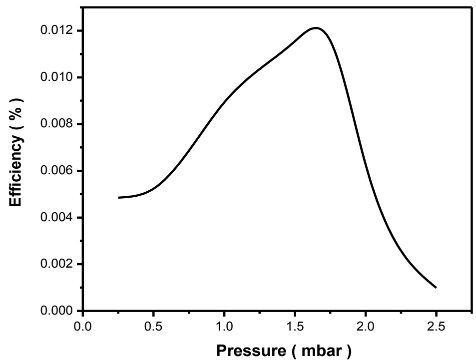

Fig. 4. The variation of efficiency of Ni-Kα versus argon filling pressure.

The variation of Ni-Kα efficiency at different filling gas pressures has been shown in Fig. 4. It is obvious that the maximum efficiency is 0.01% at about 1.75 mbar and the reason for this high efficiency is good focusing when most of the energy stored behind the current sheath must be converted to plasma energy. This is obtained by synchronizing the time of flight of current sheath from breach to the tip of the anode.

5. Conclusion

The x-ray emission from a low energy plasma focus of Cu anode with Ni insert and 19 kV charging voltage is investigated. The maximum yield is at 1.75 mbar and it has a value of 0.26J.

As expected, the yield varies with working gas pressure. We determined the pressure range for which the good focus is formed. It is 0.5 – 2.0 mbar. The maximum efficiency is 0.01% at about 1.75 mbar.

References

[1] M. Sohrabi, M. Hab.ibi, V. Ramezani, Physics Letter A **378**, 2014.
[2] R. Lebert, W. Neff, D. Rothweiler, J. X-ray Sci. Technol. **6**, 195 (1996).
[3] S. M. P. Kalaiselvi, T. L. Tan, A. Tslebitaher, P. Lee, R. S. Rawat, Physics Letter A **377**, 2013.
[4] V. A. Gribkov, S. Lee, A. Srivastava, P. L. C. Keat, V. Kudryashov, IEEE Trans. Plasma Sci. **30**, 1331 (2002).
[5] M. Zakaullah, K. Alamgi, M. Shafiq, M. Sharif, A. Waheed, IEEE Trans Plasma Sci. **30**, 2089 (2002).
[6] S. Hussain, S. Ahmad, Z. M. Khan, M. Zakaullah, A. Waheed, J. Fusion energy **22**, 195 (2003).
[7] S. M. P. Kalaiselvi, T. L. Tan, A. Tslebitaher, P. Lee, R. S. Rawat, Phys. Letter. A **378**, 2014.
[8] Morteza Habibi, Physics Letter A **380**, 2016.
[9] S. M. P. Kalaiselvi, T. L. Tan, A. Tslebitaher, P. Lee, R. S. Rawat, Physics letter A **377**, 2013.
[10] M. Zakkaullah, M. Ahmed, I. Omer, R. A. Murtaza, M. M. Beg, Plasma sources Sci. Technol. **5**, 544 (1996).
[11] M. Zakaullah, K, Alamgir, G. Murtaza, A. Waheed, Plasma sources Sci. Technol. **9**, 592 (2000).
[12] M. Shafiq, S. Hussain, M. Sharif, M. Zakaullah, A. Waheed, Phys. Lett. A **302**, 23 (2002).
[13] M. Shafiq, Sartaj, S. Hussain, M. Sharif, S. Ahmad, M. Zakaullah, A. Waheed, G. Murtaza, R. Ahmad, Mod Phys. Lett. B **16**, 309 (2002).
[14] M. Sharif, S. Ahmad, H. Hussain, A. Waheed, M. Zakaullah, Journal of Applied Physics **100**, 073301 (2006).
[15] J. W. Robinson, Handbook of Spectroscopy **1**, Cleveland, OH: CRC, 1974.
[16] P. Choi, C. Deny, S. C. Wong, Phys. Lett. A **128**, 80 (1988).