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STUDY OF SOFT X-RAY EMISSON FROM LASER PRODUCED PLASMA OF DIFFERENT MATERIAL

RINGKASAN: *Pemancaran sinar-X yang lembut dari laser plasma yang dihasilkan dari bahan-bahan yang berbeza telah dikaji. Laser Nd:YAG (1.06 µm) bertenaga 10 mJ, dan FWHM 12-ns telah digunakan untuk menghasilkan plasma daripada bahan sasaran yang berbeza. Sinar-X yang dijana daripada plum plasma adalah disebabkan interaksi antara laser. Eksperimen dilakukan di bawah vakum dalam lingkungan 1 mTorr dalam bekas keluli tahan karat yang mempunyai 8 port. Tungsten, perak, aluminium dan tembaga telah digunakan sebagai bahan sasaran untuk kajian. Sinar-X yang lembut dikesan oleh 10 mikron Al PIN fotodiod (BPX 65). Semua pancaran sinar-X disimpan pada storan osiloskop digital 200 MHz osiloskop digital. Adalah didapati bahawa tungsten adalah sumber yang tidak sesuai untuk penjanaan sinar-X lembut berbanding dengan perak, aluminium dan tembaga.*

ABSTRACT: The soft X-ray emission from laser produced plasma of different materials has been investigated. We used Nd:YAG (1.06 µm) laser, of energy 10 mJ, and FWHM 12 ns to produce plasma from different target materials where X-rays were generated from the plasma plume due to laser matter interaction. The experiments were performed under vacuum of approximately 1 mTorr in a stainless steel chamber, consisting of eight ports. Tungsten, silver, aluminum and copper were used as the target materials for the investigation. The soft X-rays were detected by 10 micron Al filtered PIN photodiode (BPX 65) where all the X-rays signals were stored in the 200 MHz digital storage oscilloscope. It was found that tungsten is a poor source of soft X-rays as compared with the silver, aluminum and copper.

Keywords: Laser Produced Plasma, soft X-Rays, plasma.

INTRODUCTION

The present project was aimed to inspect the soft X-ray emission from plasma, generated by a 12 ns Nd:YAG (1.06 μm) laser when metal targets were irradiated. Various techniques are commonly used for X-rays analysis including Charged Couple Device (CCD), semiconductor PIN photodiodes with appropriate filters and Photo Multiplier Tubes (PMT). Among all these techniques, semiconductors PIN photodiode detectors are the simplest and most economical tool for X-ray detection (Dutta *et al.*, 2012). Laser-produced plasmas have attracted strong interest for its potential use as an X-ray source with their high brightness and small source size (Kodama *et al.*, 1987). Plasma formed due to high power laser matter interaction is presented as ultra-bright source of X-ray radiation (Giulietti, 1998). A number of experiments have been conducted to characterize the emission of soft (Ditmire *et al.*, 1995) (Parra *et al.*, 2000) and hard X-rays (McPherson *et al.*, 1994) from Laser Plasma (LP) (Liu *et al.*, 2009). The specific spectral range emitted depends largely on the target material (Spencer *et al.*, 2005).

X-rays are created by radiative interaction of electrons with matter and collisional interactions of electrons with matter (Bushberg *et al.*, 2012). In radiative interaction of electrons with matter, an electron (which is negatively charged) approaches the nucleus (which is positively charged), can be deflected from its original direction by the attractive force of the nucleus. The change of direction causes deceleration in forward direction of the electron or a loss of its kinetic energy. The energy lost by the electron is given as an X-ray photon. The radiation produced by this type of interaction is called bremsstrahlung (in German, literally means 'braking radiation' or 'deceleration radiation') or continuous X-rays. X-rays are also generated when electrons interact with the firmly bound orbital electrons of a solid surface. This is referred as collisional interaction of an electron with matter. This type of interaction produces characteristic or line radiation.

X-rays can also be produced from laser matter interaction (Alaterre *et al.*, 1986). When intense laser pulse is irradiated on a target material, a small quantity of the material is vaporized. Through further absorption of photons, the vaporized material is heated up until it ionizes and expands from the surface of material as a plasma cloud (Kompitsas *et al.*, 2000). This laser-induced plasma acts like a micro-source of light. This can be analyzed by the detection of spectrally and temporally resolved characteristic emissions through a spectrometer (Carranza *et al.*, 2002). For temperatures of hundreds of electron volts (which is many million degree Kelvin, 1ev = 1.6 x 10-23 Joule = kT, where k is Boltzmann's constant and T is temperature in Kelvin), a very broad spectrum is emitted. This spectrum has a range from infrared to X-ray region.

MATERIALS AND METHODS

In this experiment, PIN Photodiodes BPX 65 was used to detect the soft X-rays emitted from the Laser Produced Plasma of the target metals whereby commercially available BPX 65 diodes are manufactured for IR detection (Johnson, 2003). For X-ray detection, the glass window of the TO-18 casing of the diode was removed (Patran, 2002). Al filter of thickness of 10 microns was used to cover the diode since Al has the ability to filter the low energy or simply long wavelength radiations (Sprawls, 1993). The biasing circuit for diode is shown in Figure 1.

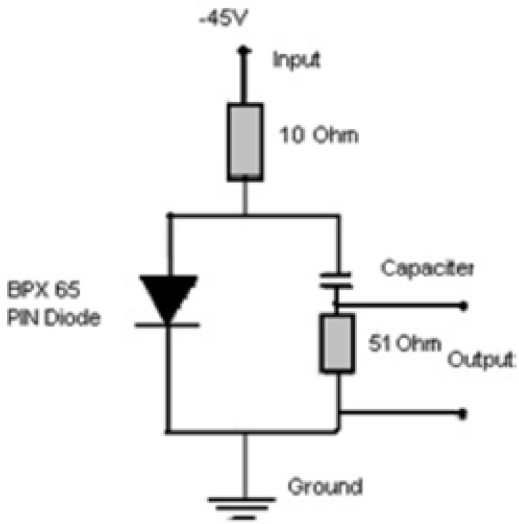

Figure 1. *Biasing Circuit for Diode.*

The schematic diagram of experimental setup is shown in the Figure 2. The laser was focused on the target materials one by one, hence produced plasma cloud on target surface. X-rays were then generated from this cloud due to laser plasma interaction. A properly biased PIN photodiode (BPX 65) was used to detect soft X-rays where these signals were stored on 200 MHz oscilloscope. The equipment was arranged in the 8 ports of a stainless steel chamber. The experiment was performed under vacuum of approximately 1 mTorr where this vacuum level was achieved using a diffusion pump, which was supported by a rotary pump in the initial stage of evacuation process.

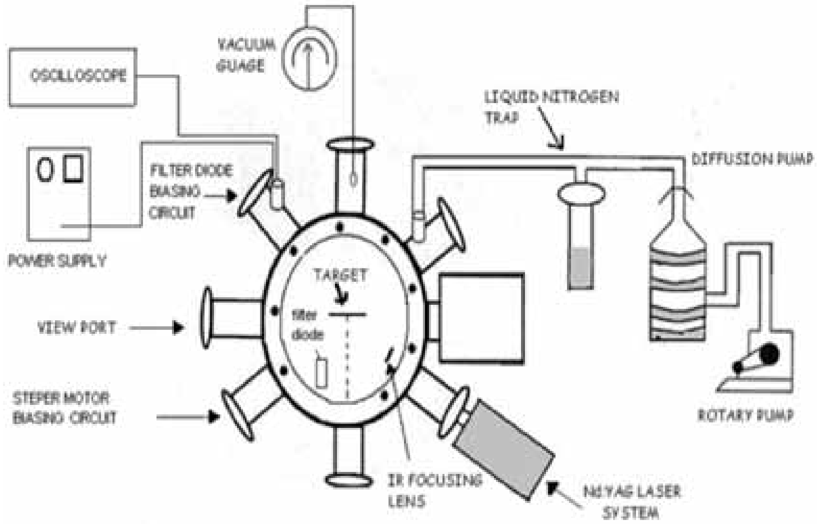

__Figure 2.__ Schematic Illustration for Experimental Set-Up.

RESULT AND DISCUSSION

The graph between transmission factor and photon energy for Al filter with a thickness of 10 micron is shown in Figure 3. From the graph we can see that the transmission factor was 5 % at the photon energy of 1000 eV, and increased sharply up to 38 % at 1500 eV of photon energy. It then dropped sharply to zero transmission from 1500-2000 eV. The transmission increased again after that where it reached 50 % and 90 % of transmission at 4,500 and 9,000 eV respectively. Details of the transmission factor of photons with, respect to the photon energy are given in Table 1.

Table 1. Transmission coefficient of Aluminum filter.

Photon Energy (eV)	Transmission (percentage)	Wavelength (nm)
1000	5%	0 – 1.242
1500	38%	0.828
1500 – 2000	No	0.828 -0.621
4000	40%	0.3105
4500	50%	0.27
9000	90%	0.138

Al density = 2.7 g/cm^3 Thickness = 10 microns

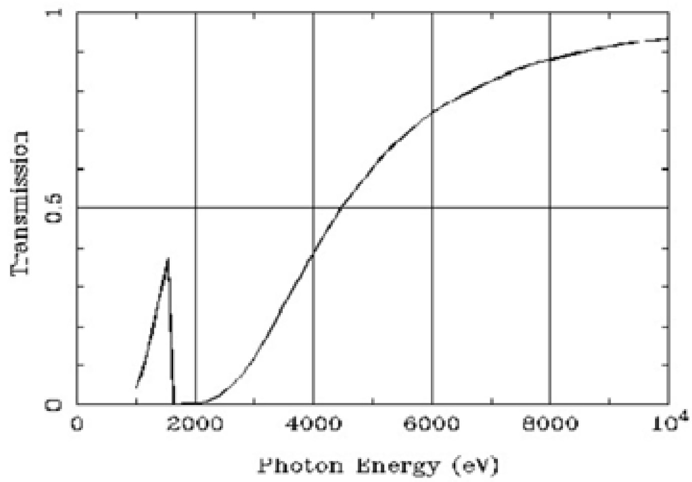

Figure 3. *Filter Transmission Factor.*

Four different metals, namely, tungsten (W) (Table 2), silver (Ag) (Table 3), aluminium (Al) (Table 4) and copper (Co) (Table 5) were irradiated by intense laser pulses to study the time-resolved emission of X-rays from the plasma produced by these metals. These metal targets were attached to a mount and connected to a stepper motor which was capable of completing a round trip in four steps so that one metal target was irradiated at a time. This whole system was placed in a vacuum of approximately 1 mTorr, evacuated using a diffusion pump which was supported by a rotary pump. An Nd:YAG laser of wavelength 1064 µm, energy of 10 mJ and 12 ns pulse duration was used. The soft X-rays emitted from the Laser Produced Plasma in the metal targets were detected by PIN diode.

Table 2. Parameters for PIN Signals for Tungsten Target.

Signals	Peak under observation	Peak start time t_1(ns)	Peak end time t_2(ns)	$\Delta t = t_2 - t_1$ (ns)	Peak Voltage (mV)	FWHM (ns)
1^{st} Signal	1^{st}	8	16	8	120	6
	2^{nd}	24	39	15	324	7
2^{nd} Signal	1^{st}	0	11	11	120	6
	2^{nd}	17	35	18	320	9
3^{rd} Signal	1^{st}	5	15	10	140	6
	2^{nd}	21	35	14	340	9

Table 3. Parameters for PIN Signals for Silver Target.

Signals	Peak under observation	Peak start time t_1 (ns)	Peak end time t_2 (ns)	$\Delta t = t_2 - t_1$ (ns)	Peak Voltage (mV)	FWHM (ns)
1st Signal	1st	11	19	8	78	4
	2nd	19	23	4	62	3
	3rd	27	30	3	50	2
	4th	33	44	11	316	7
2nd Signal	1st	16	____	__	60	4
	2nd	____	26	____	80	3
	3rd	30	34	4	40	1
	4th	37	47	10	29	9
3rd Signal	1st	16	____	____	4	80
	2nd	____	30	____	2	78
	3rd	32	36	4	2	40
	4th	40	49	9	7	338

Table 4. Parameters for PIN Signals for Aluminium Target.

Signals	Peak under observation	Peak start time t_1 (ns)	Peak end time t_2 (ns)	$\Delta t = t_2 - t_1$ (ns)	Peak Voltage (mV)	FWHM (ns)
1st Signal	1st	21	____	____	80	4
	2nd	____	34	____	80	3
	3rd	36	41	5	60	2
	4th	43	53	10	310	8
2nd Signal	1st	6	____	____	80	3
	2nd	____	20	____	100	2
	3rd	25	28	3	38	1
	4th	32	43	11	322	6
3rd Signal	1st	4	____	____	98	4
	2nd	____	16	____	78	4
	3rd	17	22	5	77	2
	4th	25	38	13	340	7

Table 5. Parameters for PIN Signal 1 for Copper Target.

Signals	Peak under observation	Peak start time t_1 (ns)	Peak end time t_2 (ns)	$\Delta t = t_2 - t_1$ (ns)	Peak Voltage (mV)	FWHM (ns)
1st Signal	1st	7	12	5	80	3
	2nd	13	19	6	75	3
	3rd	22	24	2	50	2
	4th	29	39	10	320	7
2nd Signal	1st	4	____	____	65	4
	2nd	____	16	____	70	3
	3rd	18	22	4	60	2
	4th	26	38	12	360	7
3rd Signal	1st	4	____	____	70	5
	2nd	____	17	____	99	3
	3rd	18	22	4	50	2
	4th	27	38	11	342	7

TIME-RESOLVED SOFT X-RAYS EMISSION

In order to find which material is a good source of soft X-ray we studied the time-resolved soft X-rays emission. These emissions were observed from properly biased Al masked PIN diode through a 250 MHz digital oscilloscope.

TUNGSTEN

The starting time of Peak 1 in all 3 signals (Figures 4, 5 and 6) varied in obvious manner. However, the ending time of Peak 2 was almost the same, showing that the soft X-rays emission finished at the same moment in tungsten. The FWHM values were the same for Peak 1 in all three signals but a slight decrease was observed for FWHM for Peak 2 in Signal 1, compared to the other two signals. The voltage height was the same for the first two signals and there was an increase of 20 mV in the third signal. In summary, the time resolved variation in three signals from tungsten was observed to be small. Therefore, tungsten is not believed to be a good source of soft X-rays.

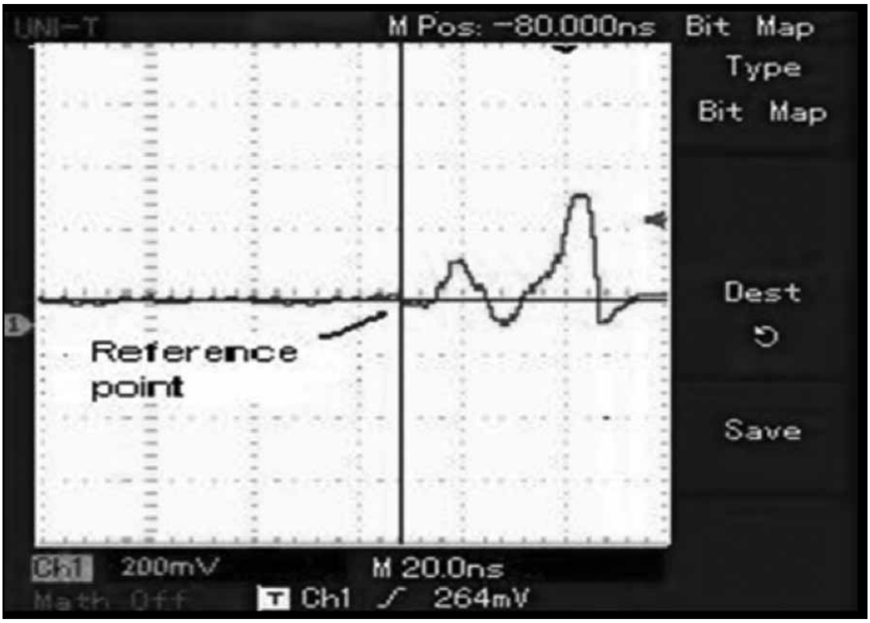

Figure 4. *PIN Signal 1 observed for Tungsten Target.*

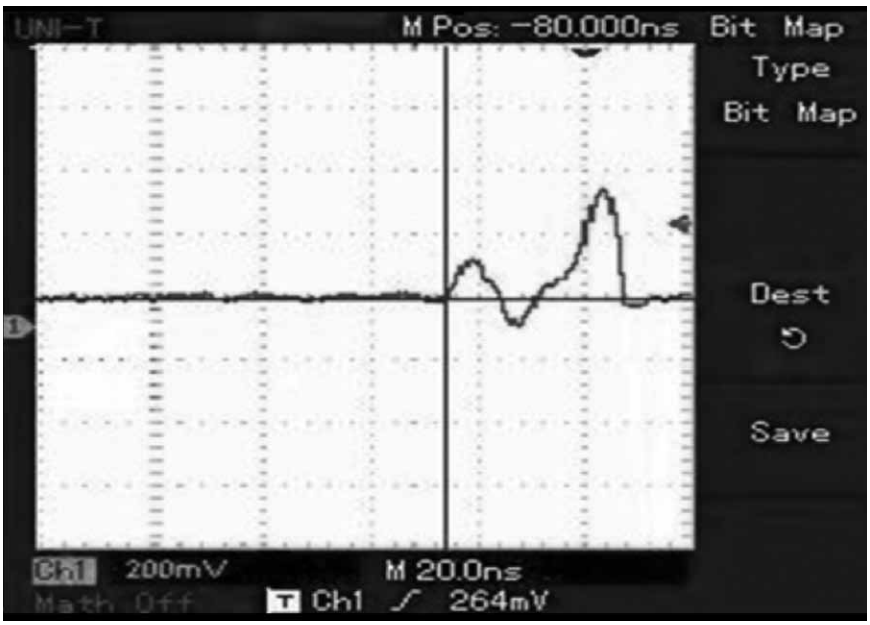

Figure 5. *PIN Signal 2 observed for Tungsten Target.*

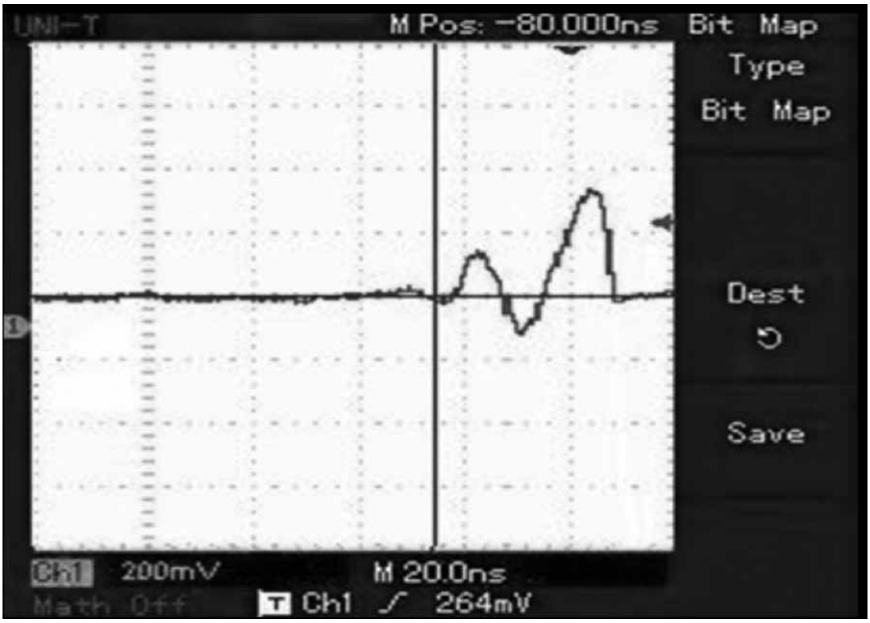

Figure 6. *PIN Signal 3 observed for Tungsten Target.*

SILVER

The starting time of Peak 1 in all three signals was almost the same but Peak 4 ended at the same moment in the three signals. In signal 1, the first two peaks were distinct in nature, whereas the same peaks overlapped in Signal 2 and Signal 3 yet the combined time duration of these two peaks remained the same. After every shot, the behavior of voltage for all peaks was not the same. The FWHM was the same only for Peak 1 in all three signals. Time resolved variation for soft X-rays from silver is quite significant showing that it is a good source of soft X-rays.

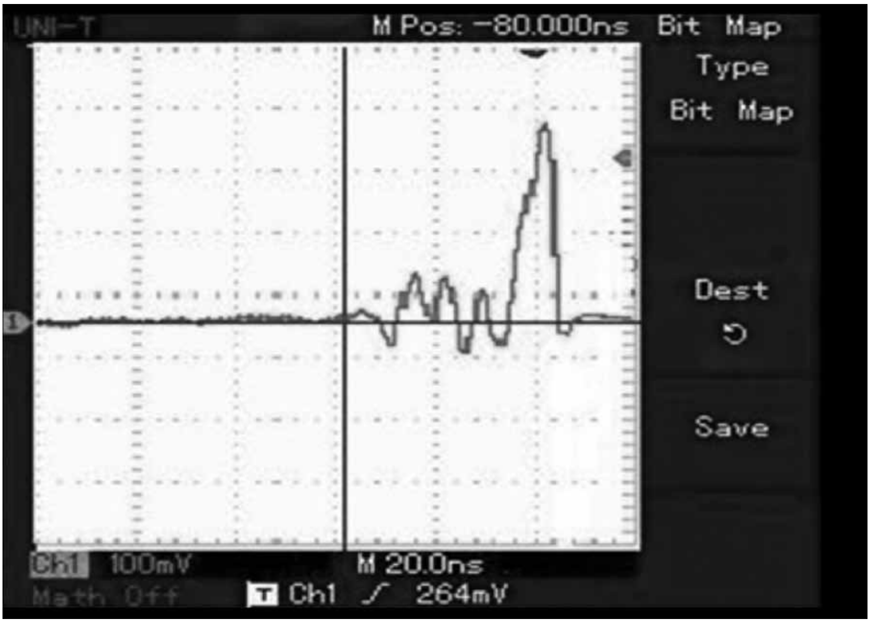

Figure 7. *PIN Signal 1 observed for Silver Target.*

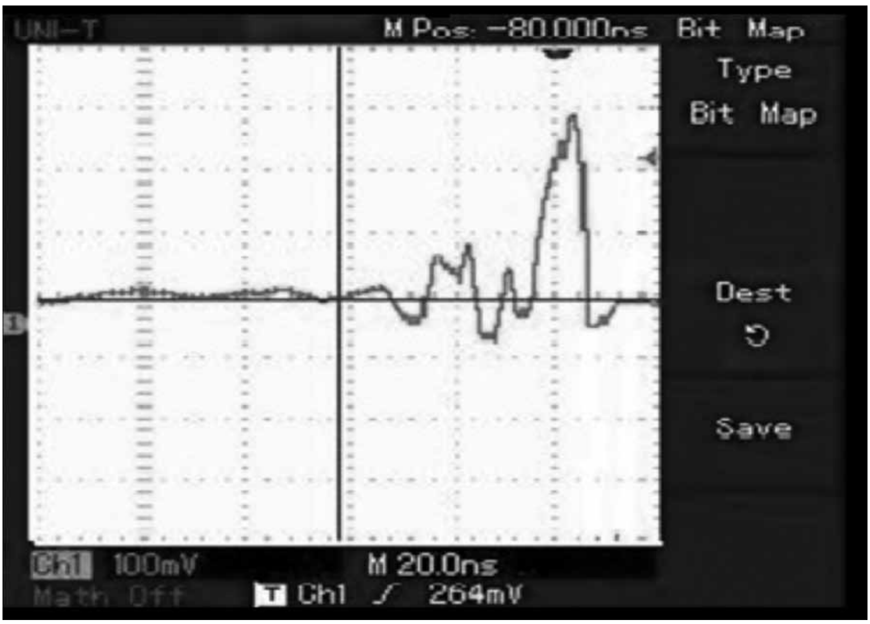

Figure 8. *PIN Signal 2 observed for Silver Target.*

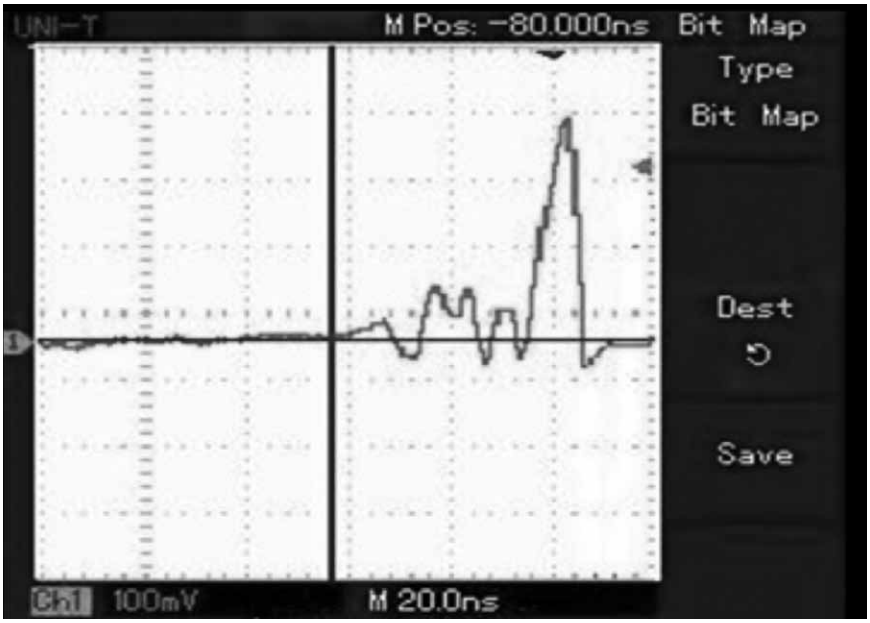

Figure 9. *PIN Signal 3 observed for Silver Target.*

ALUMINIUM

There was a significant variation in the starting time of Peak 1 and finishing time of Peak 4 in all three signals. However, the combined time duration remained almost the same in all signals. The overlapping of the first two peaks was observed in all signals. The maximum voltage of the first two peaks in Signal 1 was the same while it varied in other signals. The FWHM for all peaks in these signals had shown no significant correlation. The significant time-resolved variation showed that aluminium is also a good source of soft X-rays.

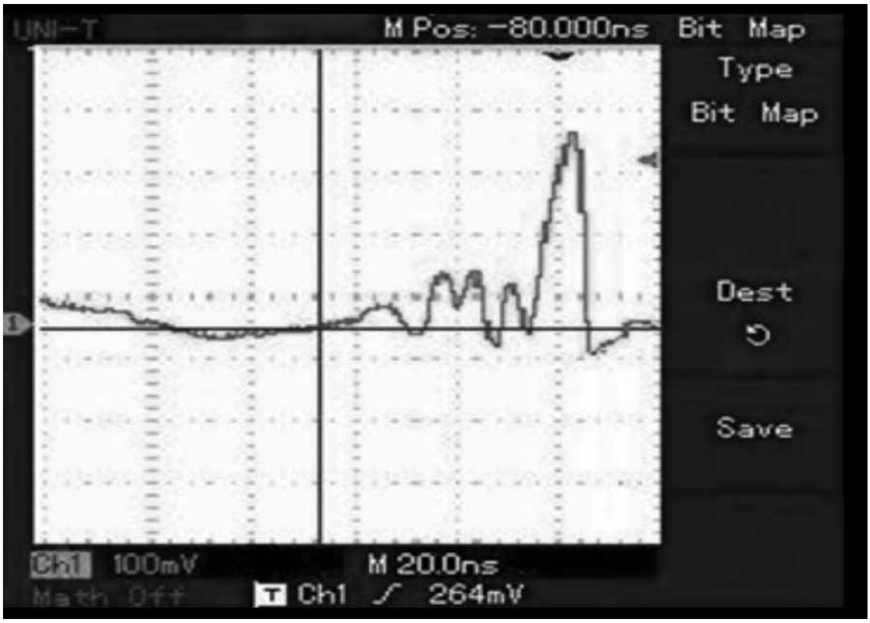

Figure 10. *PIN Signal 1 observed for Aluminium Target.*

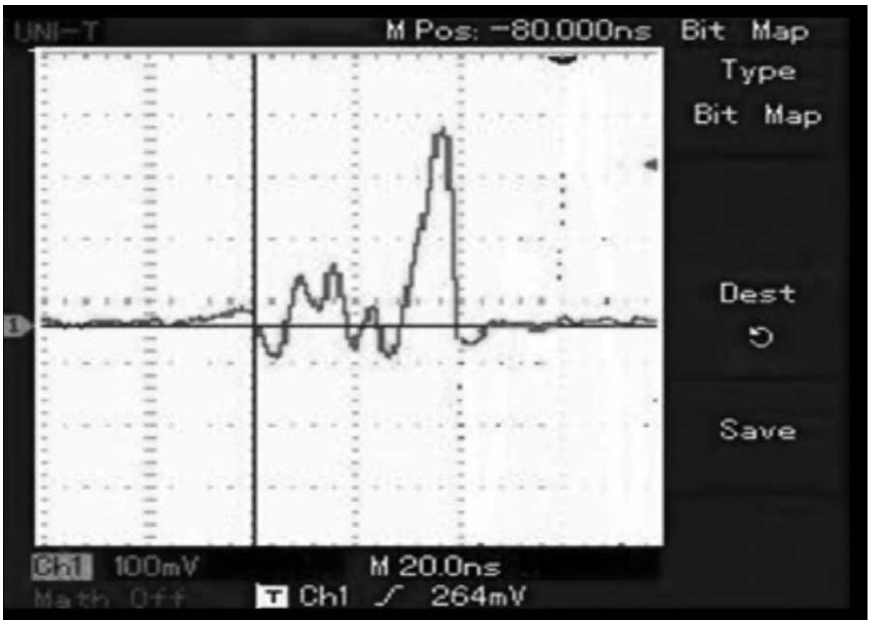

Figure 11. *PIN Signal 2 observed for Aluminium Target.*

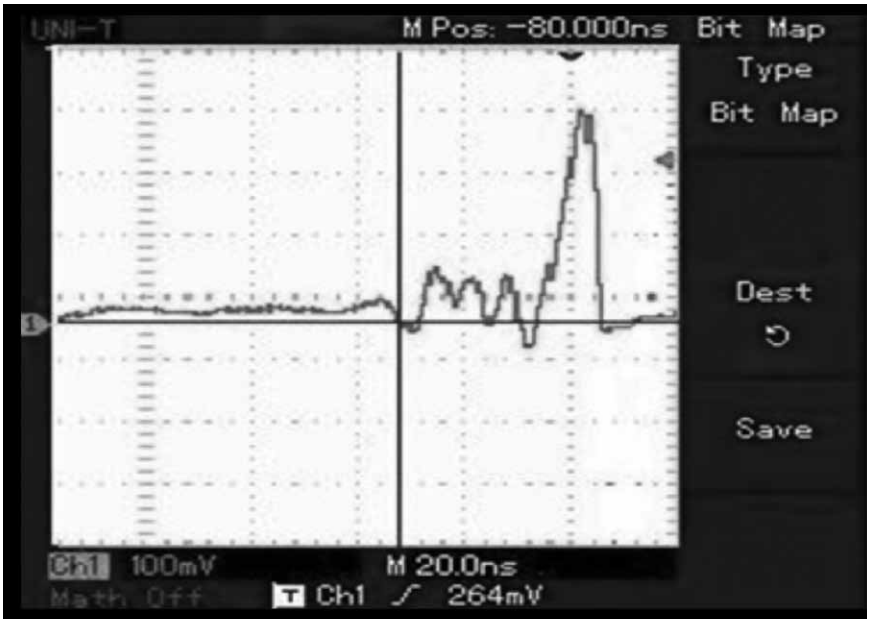

Figure 12. *PIN Signal 3 observed for Aluminium Target.*

COPPER

The starting time of Peak 1 and ending time of Peak 4 in Signal 1 was significantly different from those for other signals. In signal 1, first two peaks were distinct in nature, whereas the same peaks overlapped in Signal 2 and Signal 3 yet the combined time duration of these two peaks remained the same. The FWHM of all peaks was the same except for Peak 1. After every shot, the behavior of voltage for all peaks was not the same. Time resolved variation for soft X-rays from silver was quite significant, showing that it is a good source of soft X-rays.

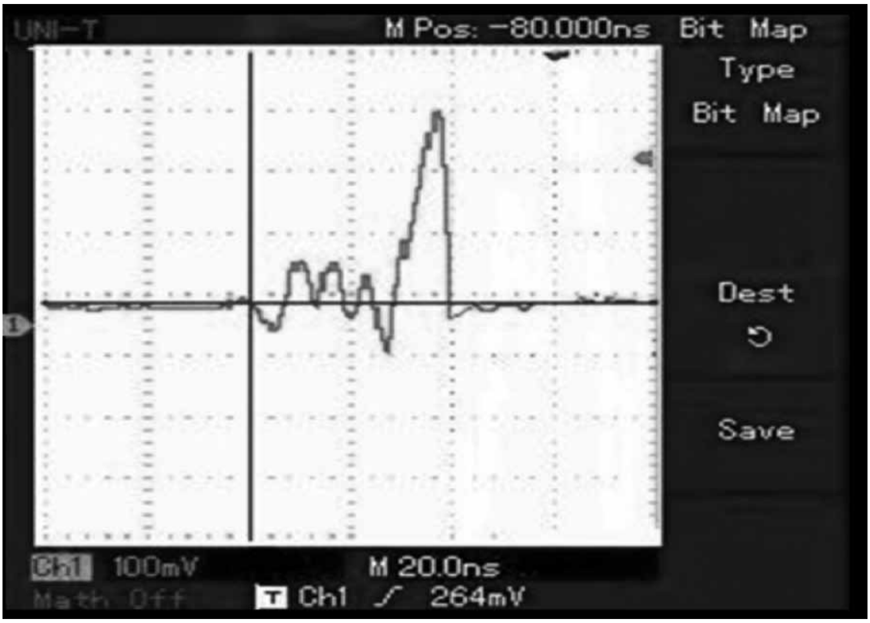

Figure 13. *PIN Signal 1 observed for Copper Target.*

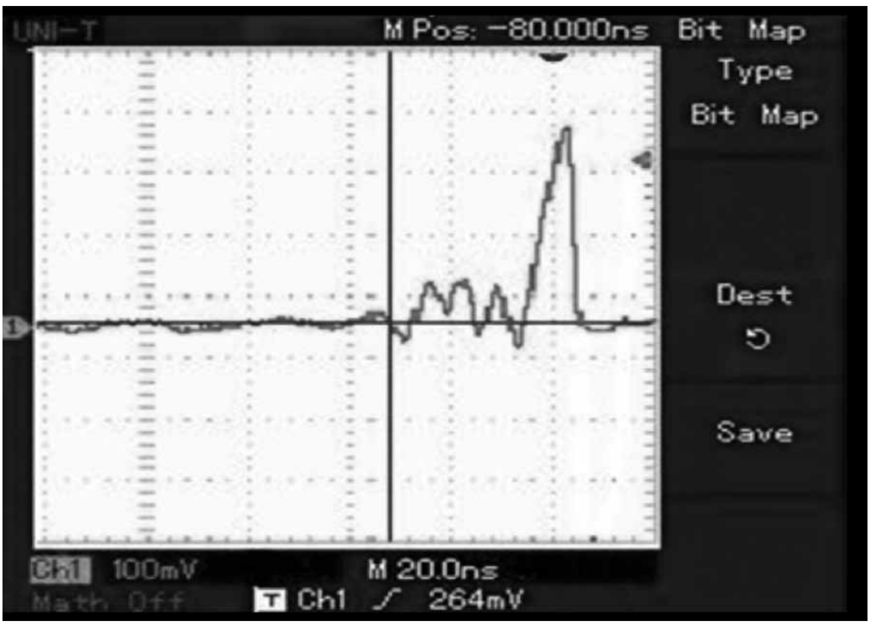

Figure 14. *PIN Signal 2 observed for Copper Target.*

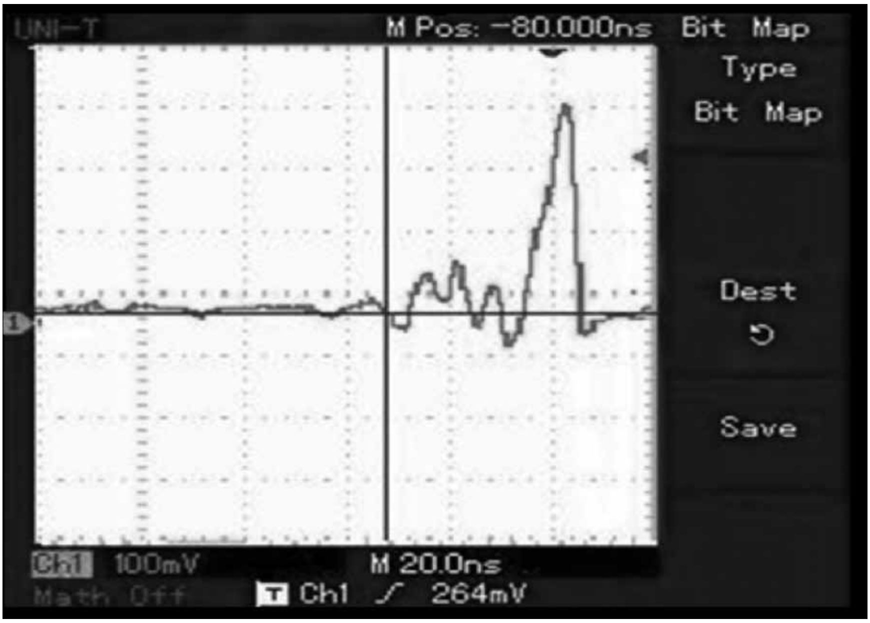

Figure 15. *PIN Signal 3 observed for Copper Target.*

CONCLUSION

The time resolved soft X-ray emission from Laser Produced Plasma of different materials had been studied successfully. The materials used were tungsten, silver, aluminium and copper. The Al masked PIN diode was used to detect soft X-rays emitted from the laser produced plasma of the target materials. The three soft X-ray signals for each metal had been observed. We observed that there was good time resolution for silver, aluminium and copper targets and poor time resolution for tungsten target. From the result obtained, it could be conclude that silver, aluminium and copper are the good sources of soft X-rays emission from Laser Produced Plasma, compared with tungsten. The results revealed that X-rays emission from the plasma depends strongly on the nature of atom. It also confirmed that tungsten is not suitable for producing soft X-rays from Laser Produced Plasma.

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