別紙様式８(Attached Form 8)

研究主論文抄録 Abstract of Thesis

論文題目
和文：　ナノ秒パルスパワー駆動Ｚピンチプラズマによる高輝度紫外線光源
（英文）：Z-pinch Plasmas Driven by Nanosecond Pulsed Power for Intense Ultraviolet Light Source

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主論文要旨 Summary of Thesis

This dissertation presented a study of a pulsed power-driven Z-pinch plasma intense ultraviolet (UV) radiation source which focused on two purposes: The use of such a source as plasma extreme ultraviolet (EUV) source, especially for its application in EUV lithography; and the application of nanosecond pulsed power-driven Z-pinch plasma UV radiation to biological stimulation research to exploit its rich UV spectral lines, whose broad wavelength ranges from vacuum UV to UVA regions. Moreover, the nanosecond pulsed power driven UV source can emit instantaneous intense UV photon pulse allowing accurate control of irradiation dose to target the biological activation and inactivation zones.

Chapter 2 described a laser-assisted tin plasma EUV source. Both the main discharge and post discharge stages were investigated and dynamics of the laser-assisted tin plasma were reported. Comparison of time-resolved pinhole EUV imaging and high speed visible photography revealed that intensive EUV is emitted only from the neck of the hot plasma, which initially appears near the laser spot on the cathode before moving away. This movement of the neck plasma results in the enlargement of the EUV emissive region acting as its source.

Highly repetitive discharge up to tens of kHz is required for the discharge produced plasma (DPP) EUV source, to achieve sufficient average radiation power at IF. The electrical recovery of electrode gap prior to each discharge influences EUV emission and determines discharge repetition rate. Electrical recovery after laser-assisted discharge was studied through the measurement of electrical breakdown. The electrical recovery process lasts for a few ten to several hundred μs, and recovery time is proportional to the discharge shot energy. Measured time-varying hold-off and breakdown voltage can provide a basis discharge voltage selection and corresponding maximum repetition rate. Electrical recovery was explained on the basis of dynamic variation of tin discharge products, suggesting that electrical recovery depends

mainly on the diffusion of the tin vapor and its density decay while tin droplets do not significantly affect the electrical recovery. Larger discharge energy generates denser tin vapor, slowing the electrical recovery process, and thus limiting the maximum repetition rate of the EUV source. As a result, relative small shot energy is most suitable for a laser-assisted discharge EUV source under high repetition rate operation.

Previous research regarding both tin plasma and xenon plasma EUV sources have shown that Z-pinch plasma movement along the axial direction enlarges the size of the EUV-emitting area which is not good for its application as a EUVL source due to the limit of EUV scanner. The amplitude, rising time and duration of current pulse all of which affect the plasma dynamics and EUV-emitting size are the most important parameters.

Chapter 3 introduced a study on the effect of current pulse width on xenon Z-pinch plasma. The shortest current pulse width was reduced to 85 ns by decreasing the inductance of the discharge circuit. Four current pulse conditions were designed with current pulse widths of 85 ns, 110 ns, 230 ns and 460 ns. Comparison of 85 ns and 110 ns current driven xenon Z-pinch plasma was studied in aspects of EUV emission, plasma dynamics, and EUV-emitting plasma size. Results showed that the use of a shorter current pulse can inhibit axial plasma outflow as well as reduce both axial and radial size of EUV-emitting plasma, all beneficial for use as an EUV lithography source.

Chapter 4 introduced as study on stimulation of HeLa cells through intense pulsed UV (PUV) irradiation and presented results of cell viability and proliferation response. The PUV source was driven by a pulse current capillary discharge with 15J discharge energy and 10 pulses per second (pps) repetition rate; the measured UV spectral region was from 150 nm to 380 nm. After cell irradiation, dead cells were identified using a fluorescent molecular probe (PI) propidium iodide, and the cell death ratio was statistically analyzed using a flow cytometer. A cell viability curve against UV pulse number was created which shows that the threshold of significant increase in cell mortality is 600 pulses. The effective action spectral region was less than 300 nm. PUV irradiation lethality may be due to severe intracellular damage to DNA or membranes which induced the cell apoptosis. Caspase-3 activation of HeLa cells was detected as a marker of apoptosis. HeLa cells exposed to 600 UV pulses begin to show an increasing level of Caspase-3 activation compared with the sham sample. A real- time cell imaging system was employed to monitor cell proliferation over 96 hours. Quantitative cell growth was examined by measuring monolayer cell confluence, and the proliferative effect was found to be in the sub-lethal region, which demonstrates a hormetic response of HeLa cells to PUV irradiation: Irradiation with UV pulse number between 10 and 100 promotes cell growth. The average growth rate rose to about 1.4 times that of the sham control after exposure to 50 UV pulses. When the UV pulses number exceeds 100, the toxicity of PUV tends to be severe, inhibiting cell growth and raising the cell death rate. This UV pulse number dependence suggests an accumulating effect on the cells. Application of a small number of UV pulses may activate some protein kinases and signal pathways related to cell proliferation, such as JNK and ERK. Further study will examine the level of specific protein expression and actual DNA damage.