Abstract

Experimental investigations on spatially- resolved- laser-generated Zirconium (Zr), Tin (Sn) and Iron (Fe) plasma parameters and their relationship with the Self-Generated Electric and Magnetic Fields (SGEMFs) have been performed under vacuum condition as well as Ar environment. Nd : YAG laser (532 nm, 6 ns) is employed as an irradiance source. The Faraday Cup (FC) is employed to measure plasma species' kinetic energy (K.E) and fluence, while electric and magnetic probes are used to measure SGEMFs of plasma. Under vacuum condition, to explore the spatially resolved measurements of plasma, the probe to target distances were varied from 1, 2, 3, and 4 cm and all the measurement were performed at different irradiances ranging from 10 $GW\ cm^{-2}$ to 26 $GW\ cm^{-2}$. The measurements have also been performed under Argon (Ar) environment at various pressures ranging from 1 Torr to 200 Torr at a fixed irradiance of 17 $GWcm^{-2}$ for probe to target distance of 1 cm. The decreasing trends for evaluated values of plasma parameters and SGEMFs have been found with increasing FC/ probe axial distance from the target, whereas, increasing trends with increasing laser irradiance are observed. Under various Ar pressures ranging from 1 Torr to 200 Torr, an increasing trend for evaluated values of K.E and decreasing trends for the fluence of Zr, Sn and Fe plasma ions have been observed.

In case of vacuum condition with increasing laser irradiance, the kinetic energy of plasma ions increases from 1.8 keV to 11.8 keV for Zr, from 0.3 keV to 4.2 keV for Sn and from 2.2 keV to 4.2 keV for Fe. Whereas, fluence increases from $10.7 \times 10^{12} cm^{-2}$ to $16.6 \times 10^{12} cm^{-2}$ for Zr, from $14.8 \times 10^{12} cm^{-2}$ to $19.4 \times 10^{12} cm^{-2}$ for Sn and from $13.6 \times 10^{12} cm^{-2}$ to $18.6 \times 10^{12} cm^{-2}$ for Fe. Similarly, the electric field of plasma increases from 107 Vm^{-1} to 237 Vm^{-1} for Zr, from 92.6 Vm^{-1} to 217 Vm^{-1} for Sn and from 132 Vm^{-1} to 281 Vm^{-1} for Fe, whereas, magnetic field increases from 235 G to 590 G for Zr, from 150 G to 425 G for Sn and from 290 G to 630 G for Fe.

In case of Ar as a background gas at a fixed irradiance of 17 $GWcm^{-2}$ for a probe to target distance of 1 cm, the K.E of plasma ions increases from 15.6 keV to 140.8 keV for Zr, from 19.2 keV to 113 keV for Sn and from 10 keV to 128.7 keV for Fe. Whereas, fluence decreases from 1.2×10^{12} cm^{-2} to 0.68×10^{12} cm^{-2} for Zr, from 1.06×10^{12} cm^{-2} to 0.63×10^{12} cm^{-2} for Sn and from 1.43×10^{12} cm^{-2} to 0.72×10^{12} cm^{-2} for Fe by increasing the Ar pressures. Similarly, the Self-Generated Electric Field (SGEF) of plasma decreases from 95 Vm^{-1} to 0 for Zr, from 85.3 Vm^{-1} to 0 for Sn and from 145 Vm^{-1} to 0 for Fe. The self-

generated magnetic field (SGMF) of Zr plasma initially increases from 100 G to 340 G and then decreases to 145 G under the increasing Ar gas pressure. A similar trend has been observed for the SGMF of Sn and Fe plasma under increasing Ar gas pressure due to shielding effect.

The generation of SGEF is attributed to charge-separation and double-layer-structure, whereas, SGMF is attributed to anisotropic temperature (∇T_e) and density (∇n_e) gradients of plasma. The monotonic decrease in electric field with increasing the Ar gas pressure is attributed to the monotonic decrease of ion fluence due to ambipolar diffusion and decrease in charge separation by recombination losses. Similarly, the initial increase and then a decrease of magnetic field along with reversal is related to initial increase and then the decrease of electron fluence and non-parallel density and temperature gradients ($\nabla n_e \times \nabla T_e \neq 0$) of plasma. These metallic plasmas can be used as electron or ion sources as well as a source of electric and magnetic fields for various applications.

In order to correlate the evaluated plasma parameters with the surface modification, Scanning Electron Microscopy (SEM) analysis of laser-ablated Zr, Sn, and Fe targets has been performed. For Zr, Sn, and Fe, small-sized cones, ripples, and ridges are the dominant structures at the lower irradiances, whereas higher values of irradiances along with enhanced fluence and K.E of plasma ions result in the formation of more diffusive structures such as periodic ridges, diffusive cones, micro-sized cavities, and nano-scale ripples due to more energy deposition and plasma recoil pressure. At low Ar gas pressure, distinct cracks, ripples, periodic ridges, and cones have been observed to be the most prominent laser-induced surface structures. At higher pressures, the structures of ridges, cones, and ripples become diffusive or suppressed, resulting into droplets, diffusive cones and ripples. These structured materials are potential candidates for various scientific and industrial applications. It is observed that the combinations of laser irradiance, axial distances, environmental conditions and materials particular physical properties play a significant role for plasma generation and controlling its parameters along with SGEMFs and surface structuring.