Mechanism of droplet ejection from liquid metals interacting with hydrogen plasmas

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Plasma-liquid interaction is a hot topic in the field of low-temperature plasma. It is widely investigated by using atmospheric-pressure plasmas and water, but atmospheric-pressure plasmas have difficulty in diagnostics. Our strategy in this work [1,2] was to use low-pressure plasma and liquid metals. The merit in this approach is easier control and diagnostics of plasma. In addition, the interaction between hydrogen plasma and liquid metal has an important application in nuclear fusion research. The design of divertor devices is the most challenging task in the development of nuclear fusion reactors. The energy flux irradiating the divertor material is so great that even tungsten is subjected to severe erosion. An unconventional idea to address the issue is the concept of liquid metal divertors. However, a serious problem that must be considered in the concept of the liquid metal divertor is the production of metal droplets via the interaction with plasma. In this work, we examined the mechanism of droplet ejection from liquid metals interacting with hydrogen plasma. Note that the droplet ejection is also observed in the interaction between an atmospheric-pressure plasma and water [3], and its mechanism has not been understood yet.

Liquid gallium was stored in a quartz container which was installed in an inductively coupled hydrogen plasma. We also used liquid tin and a brass container for comparison. The temperature of the liquid metal was controlled using a heater. The liquid metal was connected to a negatively biased dc power supply, by which we controlled the irradiation energy of positive ions to the surface of the liquid metal. The flux of positive ions was controlled by the rf power to produce the plasma. The ranges of the ion flux, the ion energy, and the sample temperature were 10^{14}-10^{15} $cm^{-2}s^{-1}$, 15-300 eV, and 300-550 K, respectively. The space above the sample was illuminated by a continuous-wave laser beam at a wavelength of 457 nm. The shape of the laser beam was arranged to be planar using two cylindrical lenses. We observed Mie scattering of the laser light when a droplet passed through the planar laser beam. The scattered laser light was captured using a video camera with an image intensifier. We counted the number of frames with the scattered laser light in the movie and obtained the frequency of the droplet ejection.

The frequency of the droplet ejection increased with the ion flux and the liquid metal temperature, whereas it decreased with the energy of irradiating positive ions. The incubation period, which was defined by the delay time between the initiation of the plasma irradiation and the first ejection of a droplet, was shorter if the ion flux was higher. We observed the formation of bubbles inside the liquid metal, and the ejection of droplets was synchronized with the burst of the bubble. Figure 1 shows the trajectories of droplets ejected from liquid gallium. This picture was captured by arranging the planar laser beam to be perpendicular to the liquid gallium surface. As shown in Fig. 1, droplets were ejected in directions nearly perpendicular to the liquid gallium surface. The nearly perpendicular ejection of droplets suggests that it is a phenomenon known as “jet drops” at the burst of a bubble [4].

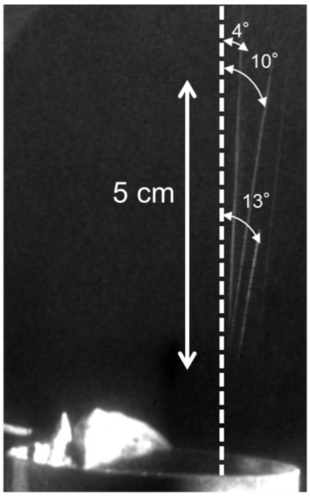

Figure 1 Trajectories of droplets ejected from liquid gallium.

Considering various experimental results, we have proposed the following mechanism for the ejection of droplets from liquid metals interacting with hydrogen plasma. The first step is the ion irradiation. It results in the forced transport of atomic hydrogen into the liquid metal. The density of atomic hydrogen exceeds the dissolution limit, since the Henry’s law does not work against the ion irradiation. A hydrogen bubble is formed in liquid gallium due to the supersaturation. The bubble collapses if the inside pressure of the bubble exceeds the limit determined by the surface tension, and droplets are ejected at the burst of the bubble.

References

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