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Micro-arc discharge plasma in high-pressurized sea water

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We have been developing micro-arc discharge plasma generation in high-pressurized sea water for possible application to on-site elemental analysis of sea water[1-3]. The analysis will be useful for searching mineral resources such as hydrothermal deposits in the deep sea, and for detecting water pollution including heavy metal ions in industrial effluent and micro-plastics in oceans. Also, the characteristic emission spectra from the micro-arc plasma in high-pressurized sea water will be interesting as light source of intense and white light. The key technical issues were material and configuration for durable electrode and compact and reliable driving circuit, and the academic interests were characteristics of gas discharge and plasma generation in such the conductive sea water (45 mS/cm at 20.3°C) at such the high pressures until 19 MPa which was equivalent to 1,900 m water depth.
Figure 1 shows micro-electrode consisting of a pair of metal rods (Ni or SUS) supported in parallel with insulating adhesive. The diameter, the gap and the exposing length of rod electrodes were 500 μm, 100 μm and 500 μm, respectively. The developed electrodes in parallel configuration enabled reproducible micro-arc discharges repeating for many times regardless of local surface damages induced by micro-arc spots. The electrode was set in a high pressure chamber filled with artificial sea water of 10 main components (10ASW) pressurized using a high pressure pump.
The electrodes were connected to a custom-made impulse generator circuit consisting of a primary capacitor, a MOSFET switch, and an inductor. After the capacitor was charged to a certain voltage, the MOSFET switch was turned on to induce a pulse current between the electrodes. The pulse current performed rapid local heating of water between the electrodes with resulting in vaporization of water and bubble formation between electrodes. Due to the inductance in the circuit, the current was controlled to avoid excess power even after termination of electrodes by micro-arc discharge.
Figure 2 shows a typical voltage and current waveforms between the electrodes at 19 MPa water pressure. The discharge scheme consisted of 3 phase as follows; the preheating phase before ignition of arc plasma, micro-arc discharge phase, and the remaining oscillation after termination of arc plasma. During the arc discharge, the voltage was almost constant at a small value for sustaining micro-arc discharge regardless of the instantaneous current peak induced by the circuit while, before and after the arc discharge, the voltage and current followed the same waveform due to the Ohm's law at a resistance of the sea water between the electrodes. During the preheating phase, the power was used for vaporization of sea water by joule heating and bubble formation between the electrodes in which micro-arc plasma was ignited.
For ignition of micro-arc discharge in sea water, it requires preheating energy rather than the breakdown voltage. As shown in figure 2, the micro-arc discharge happens even at the voltage decaying after the peak when the accumulated power consumption reaches a necessary level. Even at 19 MPa, the micro-arc discharge plasma was ignited such the low voltage around 400 V with such a small preheating energy about 40 mJ. Because of the low source voltage below 0.75 kV and a small energy for discharge, the driving circuit can be designed compact and simple.

References

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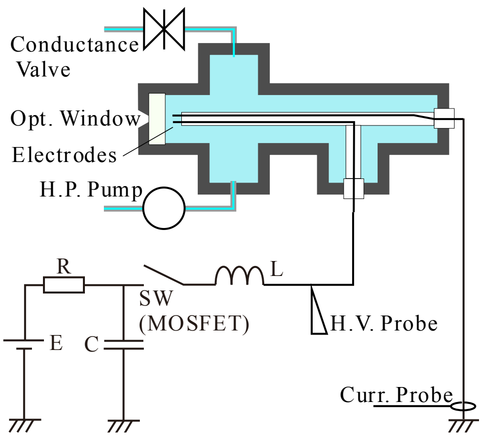

Figure 1 Experimental setup

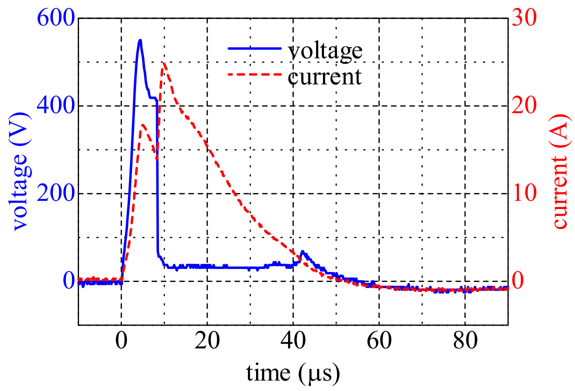

Figure 2 Typical current and voltage waveforms