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# Dynamic Behavior of Multi-Phase Structure Plasmas in a Cathode Arc Spot

## アーク陰極点近傍に形成される重相構造プラズマの動的挙動

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Dynamic behavior of multi-phase structure plasmas generated at the interface region between high current density arc plasmas and hot molten cathode has been studied experimentally. Hot molten cathode spot was observed directly by color high-speed camera and dynamic evolution of the cathode surface temperature from arc ignition was estimated from the RGB signals of color camera. In addition to the cathode temperature measurement, the dynamic and unstable behavior of the cathode molten pool was seen as the hot spot rotation and, abrupt boiling and droplet ejection from the molten cathode surface.

### 1. Introduction

Study of the dynamic response of tungsten surface to the transient and extremely high plasma heat load in type-I ELM's and disruptions (>100MW/m$^2$) requires experimental approaches different from those in steady state and low heat flux experiments(<10MW/m$^2$). In the present experiments, high current stabilized arc plasmas with ~GA/m$^2$ is used as a high heat flux pulse and steady state plasma source. The plasma heat flux onto the cathode surface is several hundreds MW/m$^2$ in the steady state and is several GW/m$^2$ in the arc ignition phase. These properties of high heat flux arc plasmas are very useful to study the transient behavior of the divertor materials during ELMs and disruptions in fusion reactor complementally with other ELM/disruption experiments.

On the other hand, arc plasmas are used in various devices, such as light sources, plasma arc cutting, electric circuit breakers and ignition plugs, etc. It is very important to understand the physical and chemical interactions of the high heat flux arc plasmas with the refractory metal cathode for improvement of these industrial devices. In the present experiments dynamic interactions of high current density arc plasmas with hot metal cathode are studied using a plasma arc cutting device, which can generate stable arc plasmas in a small fixed volume[1] .

### 2. Experimental set up

Figure 1 shows a schematic view of the plasma arc cutting torch(Komatsu Industries) employed in the experiments. Arc plasmas are generated between water-cooled cathode made of hafnium and a water-cooled copper target as an anode. The arc plasma is erupted from the nozzle outlet with the plasma gas. The plasma gas is supplied as swirl gas so as to fix the cathode spot at the center of Hf electrode at the arc ignition phase. The diameters of the Hf cathode and nozzle are 1.6 mm and 1.3 mm, respectively. In this study, a quartz window was installed at the nozzle in order to observe the cathode surface directly. The High-speed color camera can observe the cathode surface through this quartz window. Two type of high-speed color cameras(Keyence:VW-6000, VW-9000) are used. The max frame rates of VW-6000 and VW-9000 are 24,000 fps and 230,000 fps, respectively.

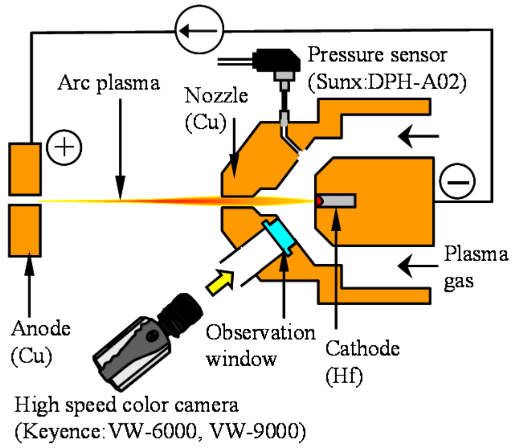


**Fig. 1** Schematic view of the hot cathode of arc discharges in the arc plasma cutting torch.

### 3. Dynamic evolution of the hot cathode spot

Figure 2 shows images of the cathode hot spot and arc current waveform after arc ignition to

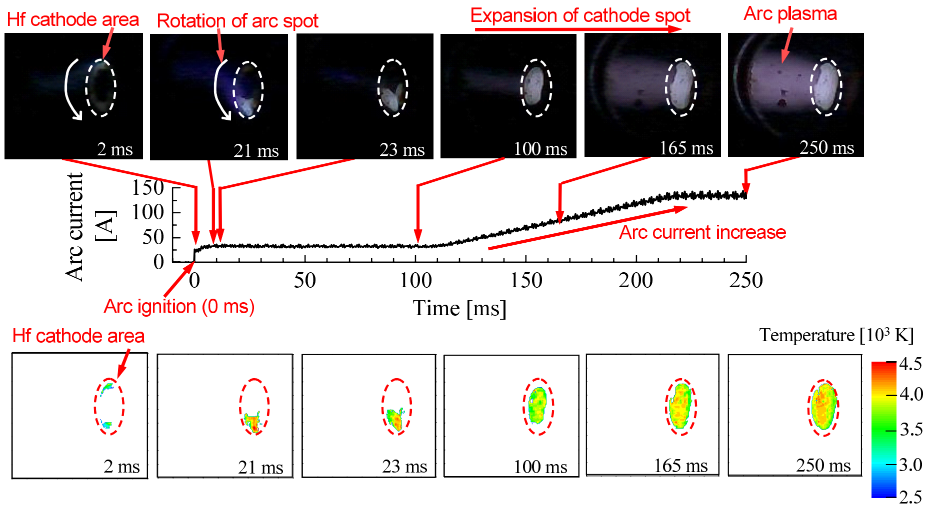


**Fig. 2** Temporal evolution of the hot cathode spot(top) and cathode surface temperature estimated from the RGB pictures shown in the figure. The preprogrammed arc current is also shown.

steady state arc. These images are observed using VW-6000. Rotation of local hot cathode spot heats the Hf cathode surface gradually and forms the larger cathode spot on the center of $H_f$ electrode at $t$ ~100 ms after ignition. The cathode spot area spreads over gradually from the fixed local cathode spot to the whole cathode area. And the cathode emission area becomes larger with increasing the arc current. Time evolution of cathode surface temperature distribution estimated from RGB signals of the pictures is also shown in Fig.2. The temperature distribution shows that the cathode surface temperature is between 3,700 K and 4,300 K. This temperature is higher than Hf melting temperature(2,503 K) and lower than Hf boiling temperature(4,547 K)[2]. Therefore, it is clear that the cathode hot surface is melted during arc discharges. Thermionic electron emission current density $J$ is calculated from the estimated cathode temperature, supposing that whole cathode surface is solid $H_f$ or solid $HfO_2$. Thermionic electron emission current $I_{Hf}$ and $I_{HfO2}$ are estimated to be ~160 A and 40 A, respectively when the preset arc current is $I_{arc}$=135 A, where $I_{Hf}/\ I_{arc}$=1.2 and $I_{HfO2}/I_{arc}$=0.3. To estimate the themionic current $J$ in detail, physical properties of Hf and $HfO_2$ as hot liquid materials are needed[2], but unfortunately not available at the moment.

## 4. Unstable droplet ejection from the molten cathode

Unstable phenomena of the molten cathode pool, such as small droplet ejection acompanying wavy motion of the molten cathode and large dropelet ejection from the cathode, are

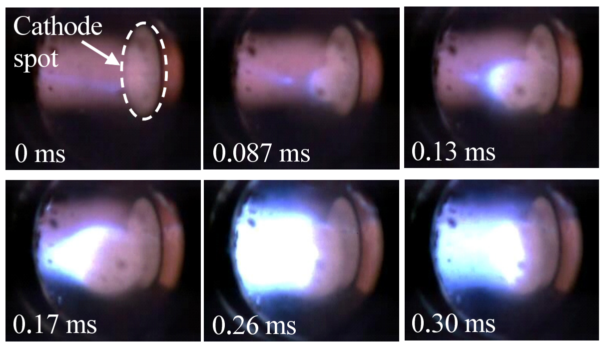


**Fig. 3** Abrupt ejection of the cathode materials from the molten cathode pool after bubble formation and growth.

often observed when a new cathode with a flat cathode surface is used at the first time. Unstable and dynamic behavior of the molten cathode like bubble formation and explosion is shown in Fig. 3. The bubble appears from the molten pool and grows within ~0.2 ms, then evaporates intensively due to the arc plasma heat flux, leading the bubble explosion. After the bubble explosion, cathode spot goes back to the quiet phase. These intensive and dynamic cathode phenomena can not seen in the arc voltage and current measurement. So far we have used the Hf cathode, which is normally used in arc plasma cutting device. Now we have modifyed it to use tungsten as a cathode in spite of Hf. In near future the interactions of tungsten cathode with the high curret arc plasma of hydrogen or helium will be shown elsewhere.

## References


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