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Arc spot grouping: an entanglement of arc spots

アークスポットのグルーピング：アークスポットの絡み合い

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In recent experiments, clear transitions in velocity and trail width of an arc spot initiated on nanostructured tungsten were observed on the boundary of the thick and thin nanostructured layer regions. The velocity of arc spot was significantly decreased on the thick nanostructured region. It was suggested that the grouping decreased the velocity of arc spot. In this study, we try to explain the phenomena using a simple random walk model that has properties of directionality and self-avoidance. And grouping feature was added by installing an attraction force between spots with dealing with multi-spots. It was revealed that an entanglement of arc spots decreased the spot velocity and increased the number of stamping times at a place.

1. Introduction

Arcing phenomena are deeply related with various fields of research [1] including high-power circuit interrupter, material deposition of protective coatings and thin films, switching devices to control electric current flow, breakdown phenomena in high-energy accelerators, and plasma wall interaction in nuclear fusion devices [2].

Recently, with an usage of nanostructured metal (tungsten), several new features of arcing has been revealed. For ex., an unipolar arcing was initiated in a controlled way in a laboratory plasma device [3], magnetic field dependence of self-affine fractality has been clearly identified [4], and grouping feature of arcing was observed on the arc trail.

In recent experiments, clear transitions in velocity and trail width were observed on the boundary of the thick and thin nanostructure layer [5]. The velocity of arc spot was significantly decreased on the thick nanostructured region, suggesting that the formation of grouping decreased the velocity of arc spot.

Earlier, we attempted to interpret the experimental results by considering the processes occurring during the operation of an individual cell of the cathode spot of a vacuum arc [5,6] in the context of the ecton model of a cathode spot.

In this study, we try to explain the phenomena using a simple random walk model. Previously, the motion of arc spots on the nanostructured tungsten was modeled with a random walk model that has properties of directionality, self-avoidance, and bifurcation features [4]. In this study, by expanding the model, grouping feature is installed.

2. Experimental observation

Arcing experiments were conducted in the linear plasma device NAGDIS-II. The stationary plasma was produced using a discharge gas of helium at the pressure of several mTorr by dc arc discharge. The plasma production region was approximately 2 m away from the position where the arcing electrode was installed.

The electrode was biased negatively using a power supply, and the current loop is formed through the plasma. To trigger the arcing, a pulsed laser was irradiated to the sample. It is likely that thermofield electron emissions are significantly enhanced from the locally heated area and helped to trigger arcing. The magnetic field strength was 0.05 T. Figure 1 (a) shows the SEM micrograph of the arc trail around the boundary between thick and thin nanostructured layer parts. The thickness of the nanostructured layer was approximately 4 μm at the thick nanostructure layer region and 1 μm at the thin nanostructure layer region. Hereafter, the two regions are called thick region and thin region, respectively.

It is seen that the width of the trail on the thick region was significantly wider than that on the thin region. Figure 1 (b) shows the distributions of the trail width in the thick and thin regions. On the thin region, the width is typically several tens of micrometer, while it has a broad distribution from 200-600 μm in the thick region. Trail width was deduced from the widest part of the trail, i.e., maximum consecutive black pixels in vertical direction in Fig. 1 (a). Figure 1 (c) and (d) shows the average trail width and velocity, respectively, on the thin and thick regions. The velocity was deduced from the fast framing camera observation of the arc spots. The trail width became wider on the thick region by a factor of eight, and the spot velocity decreased by a factor of seven.

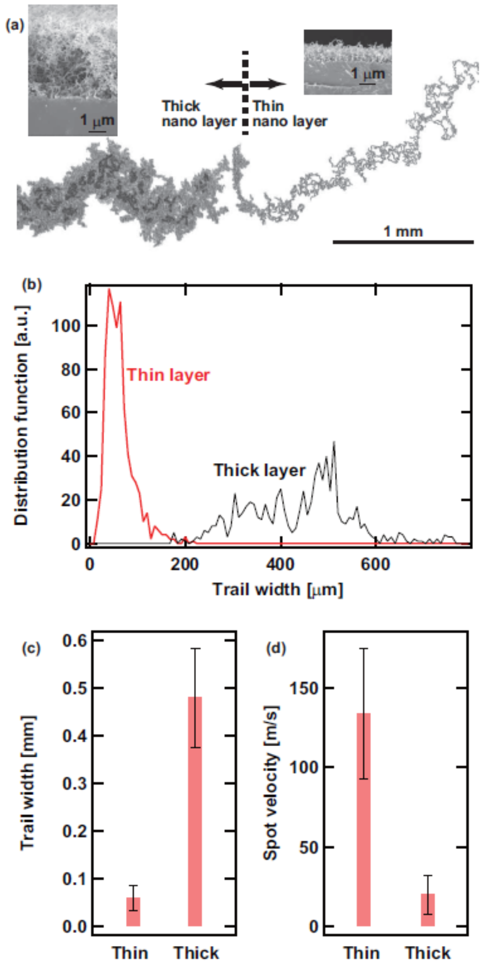

Fig. 1: (a) Arc trail recorded on the nanostructured W, (b) distributions of the trail width, (c) the averaged trail width, and (d) the averaged spot velocity on the thick and thin nanostructured layer.

3. Results

In the random walk model, an attraction force was introduced assuming that the density profile, i.e. ignition probability, has a profile with $1/r^2$ dependence, where r is the distance between two spots. Figure 2 shows some typical calculated trails for the spot number, N_{sp}, of five with the number of step of 200 000. The attractive force coefficient G in Fig. 2 (a)-(c) was 30, 100, and 200, respectively. When $G=30$, spot moves almost randomly without any strong interaction between spots. When $G=100$, the trail length decreased to less than half that at $G=30$ with high number of stamp times, N_{st}, was seen as a line in Fig. 2 (b), though the spots seem to move randomly. When G=200, all the five spots were entangled together, and a darker line with N_{st}, was formed. Enlarged trail for G=200 is shown in Fig. 2 (d). On the trail, N_{st} is basically less than ten; it is greater than 100 in some places. When the force is sufficiently strong, an entanglement of spots occurs and spots moves together with forming a group. When the entanglement takes place, the spot velocity significantly decreased and the number of stamping times significantly increased.

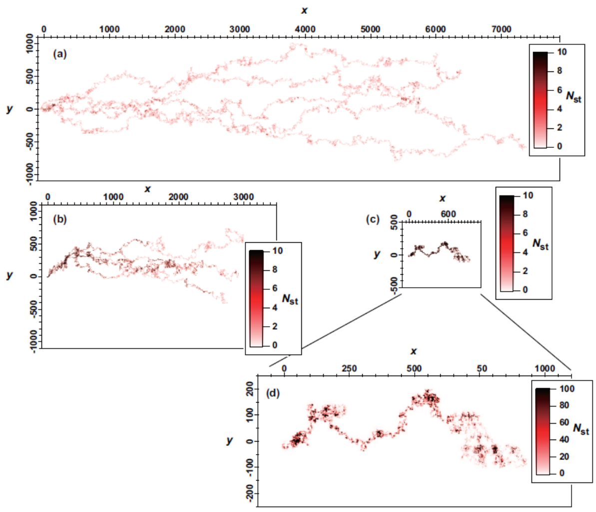

Fig. 2: Calculated trails of random spots. The attractive force coefficient was (a) $G=30$, (b) $G=100$, and (c) $G=200$. The spot number is five and the number of steps was 200 000 for each spot.

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