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Nitrogen doping technique with dielectric barrier discharge under high temperature

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Plasma nitriding is one of the plasma diffusion technology utilized for hardening or functionalizing metal surfaces by thermal diffusion of nitrogen (N) atoms created in plasmas. The conventional plasma nitriding for industrial use requires low-pressure plasmas such as DC glow plasmas for mass production. On the other hand, we focus on applying the atmospheric-pressure plasmas to the nitriding process in order to offer new technological seeds to manufacturing industries. We have developed original atmospheric pressure plasma nitriding techniques with the pulsed-arc plasma jet mainly. Achievements include local surface hardening of tool steels [1,2], stainless steels, and upgrading hard-tissue compatibility of titanium alloy [3,4].

The plasma-jet nitriding is, however, suitable only for high-mix low-volume production because it can treat only a limited area. To target larger-area treatment, we have studied nitriding with the dielectric barrier discharge (DBD) ignited under atmospheric pressure [5]. Note that to apply this non-thermal plasma to steel nitriding treatment, the ambient temperature has to be increased up to ca. 800 K by an external furnace. As a result of high temperature, we found that a planar DBD exhibits an extension phenomenon in which the plasma spreads beyond the existing range of the opposite electrode under high temperature. In this paper, we present the extension phenomenon of DBD and the nitriding performance in relation to the extension phenomenon.

The electrode system is illustrated in Fig. 1(a). The downside planar electrode is made of the tool steel JIS SKD61 (15×15×5 mm^3), the upper surface of which is to be treated by the DBD plasma igniting in the gap of 1.5 mm between the electrode and the barrier. The barrier is an alumina plate (75×75×2.5 mm^3). The opposite electrode, contacting the barrier, is made of a needle of 0.7 mm in diameter for making the extension phenomenon as conspicuous as possible. The operating gas is N_2 in the extension experiment and is N_2/H_2 gas mixture of the flow ratio of 9:1 in the nitriding experiment. The ambient temperature is controlled with an tubular furnace. The ac voltage (6 kV, 29 kHz) is applied to the planar electrode to ignite DBD.

Fig. 1 shows the appearance of DBD ignited under high temperatures. For relatively low temperature, the filamentary discharge appears only beneath the needle electrode as shown in Fig. 1(a), as readily expected. When the temperature is increased, however, the area of DBD ignition obviously extends beyond the area of the needle electrode. This means that under high temperature, we can generate a large-area DBD easily. The cause of the extension phenomenon is under investigation.

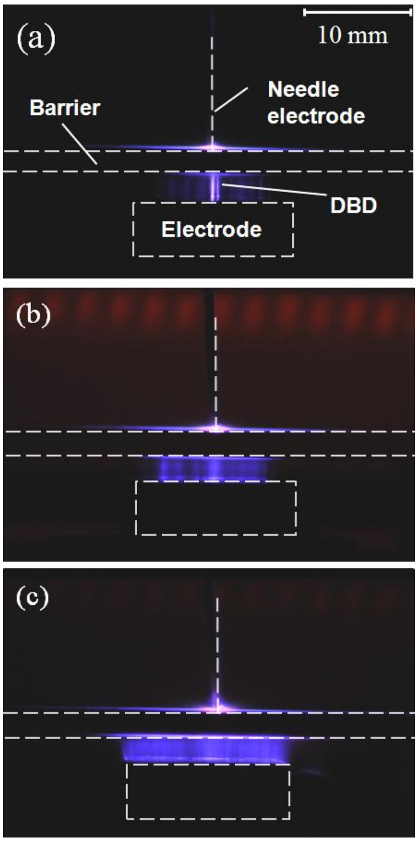

Fig. 1 Side view of electrode system and planar DBD at (a) 620 K, (b) 720 K, and (c) 820 K.

Next, we addressed to perform nitriding treatment of the planar electrode in the analogous situation. As a result of 2-h treatment at 800 K, we achieved to diffuse N atoms into the entire surface of the planar electrode even with the needle electrode. This fact implies the future feasibility of a large-area nitriding technique using the atmospheric-pressure DBD plasma.

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