Plasma Propagation Through Porous Dielectric Sheets

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***Abstract*—The propagation of plasmas through porous materials is one extreme example of a packed-bed reactor. Mechanisms for atmospheric-pressure plasmas flowing through porous dielectric films are computationally investigated. Images of this plasma flow are discussed.**

***Index Terms*—Photoionization, plasma functionalization.**

ATMOSPHERIC-PRESSURE plasmas (APPs) in dielectric barrier discharge (DBD) configurations are widely used for remediation of toxic gases. One such configuration is a packed-bed reactor where the plasma flows along the surface of high-dielectric-constant (ε) beads where electric fields are intensified by the gradient in ε [1]. Typical DBD plasmas operate in air at atmospheric pressure at a few to tens of kilohertz, having electrode separations of a few millimeters to a centimeter. One extreme example of a packed-bed DBD reactor would have the plasma flow through a porous dielectric sheet. The pores would be interconnected to provide a path for the plasma through the sheet. In this paper, we present computed images of an air plasma penetrating a porous dielectric sheet.

The propagation of plasmas through porous dielectric sheets is ultimately governed by a surface-modified Paschen law *(PL)* [2]. The usual *PL* states that the breakdown voltage of a gap is a function of the product of gas pressure and gap length, $V = f(pd)$. The breakdown voltage is usually a minimum for a pd of about 1 Torr · cm. With pore sizes being tens to hundreds of micrometers, the usual *PL* implies that the internal electric fields in the pores would be hundreds of kilovolts per centimeter. Such high electric fields might approach the dielectric strength of materials to be treated. The large surface-to-volume ratio of these porous materials adds additional wall losses that might increase the breakdown voltage above that given by the *PL*. The porous structure also provides the possibility of electric field enhancement at the interface between the dielectric and gas where there is a gradient in the dielectric constant, thereby possibly reducing the breakdown voltage.

Plasma propagation in atmospheric-pressure humid air through a 600-μm-thick porous dielectric ($\varepsilon = 4$) with a pore diameter of 100 μm was simulated to investigate breakdown conditions (see Fig. 1). Although the test geometry is typical of materials of interest, the results are sensitive to the details of the geometry. The 2-D modeling platform, described in detail in [3], is a multifluid hydrodynamics simulation in which transport equations for all charged and neutral species and Poisson's equation are integrated as functions of time on an unstructured numerical mesh. Radiation transport and photoionization of O_2 by VUV radiation are addressed using a propagator-based Green's function. The interconnectivity of pores is 100% with the narrowest neck between pores being about 50 μm. An electrode wire at the top is biased at -60 kV with a planar grounded electrode at the bottom. The four openings of the interconnected pores at the top of the dielectric are seeded with small spots of plasma (5 μm in diameter, 10^{12} cm^{-3}). The subsequent propagation through each interconnected set of pores depends on local conditions.

Ionization by UV light produced by the plasma [S_{photo} (in $\mathrm{cm}^{-3} \cdot \mathrm{s}^{-1}$)] and electron densities are shown in Fig. 1. Results are shown for two photoionization cross sections (σ_{ph}) of 10^{-19} and 10^{-16} cm^2 to demonstrate the role that ionizing radiation may have in propagation through constricted spaces. Less than 1 ns is required for the plasma to penetrate through the porous network. Charging of the internal surfaces of the pores produces retarding electric fields which would otherwise halt the propagation of the plasma. Photoionization occurs a bit ahead of the electron avalanche front, which leads to further avalanche and enables the plasma to turn corners and therefore subvert the surface charging. With the smaller value of σ_{ph}, there is only a single path that is able to support the formation of a plasma channel completely through the material. The plasma in the other paths dies out due to the retarding forces from surface charging. The larger σ_{ph} is able to provide sufficient ionization ahead of the avalanche front and ahead of the retarding surface charging that the plasma fills all of the paths. This is augmented by a plasma produced around the wire that enters into outlying openings into the dielectric.

In conclusion, images of APPs propagating through interconnected pores in a dielectric sheet were discussed. For these conditions, the propagation is controlled by a balance between retarding charging of the internal surfaces of the pores and photoionization that extends the plasma around corners.

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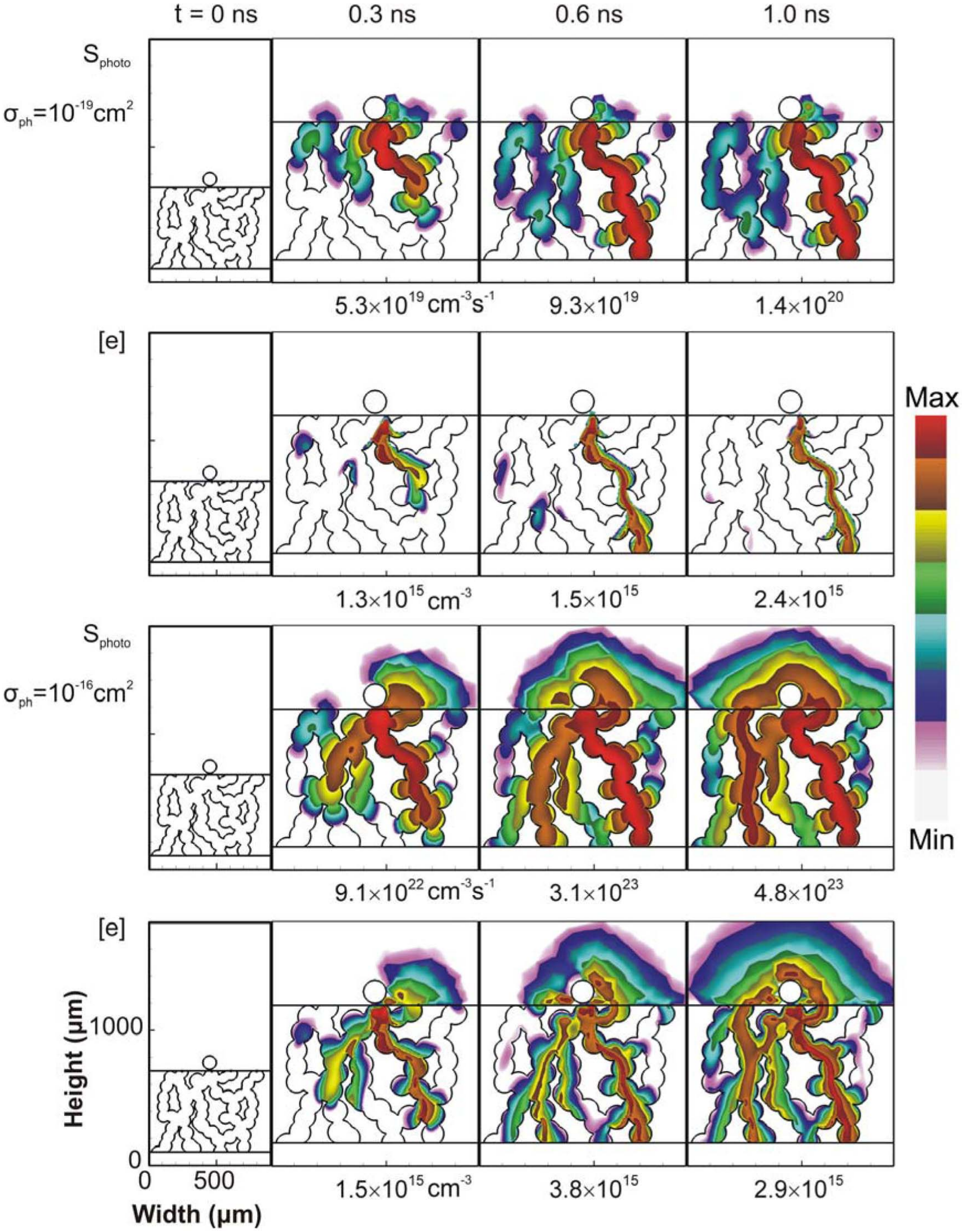

Fig. 1. Plasma propagating through a porous dielectric sheet. Photoionization source S_{photo} and electron density for (top) $\sigma_{\text{ph}} = 10^{-19}$ cm^2 and (bottom) $\sigma_{\text{ph}} = 10^{-16}$ cm^2. The maximum values are noted for each frame. Contours are plotted over a five-decade log scale.

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