MICROWAVE BREAKDOWN NEAR A HOT SURFACE

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Breakdown below the normal threshold can be induced in a waveguide system by the presence of a hot surface because the adjacent layer of heated gas is more readily ionized.[1] Under uniform conditions the breakdown electric field strength is inversely proportional to absolute gas temperature. However, if the layer of hot gas is sufficiently thin, the rate of electron diffusion out of the region of ionization tends to restore the breakdown threshold. Thus breakdown can be controlled because the thickness of the film of hot gas is a function of the velocity of the gas across the hot surface.[2] To take advantage of this effect cool gas may be forced across the hot surface with the added benefit of cooling the hot surface.

To show the conditions under which the film thickness controls breakdown, the theory must be extended to include a nonuniformity arising from a spatial variation in gas density. The mathematical model is sketched in Figure 1, where the hot surface is located at x = 0 and the gas temperature varies from T_w (wall temperature) to T_o (ambient gas temperature). The dashed line shows the spatial distribution of electron density in an electron attaching gas during the build-up of ionization preceeding the actual breakdown. The solutions are based upon the electron continuity equation which in the presence of a gradient in gas density takes the following form in a one dimensional case:

$$\frac{\nu_n}{D} \Phi\Psi + \Phi \frac{d^2\Psi}{dx^2} + \left(\frac{d\Phi}{dx}\right)\left(\frac{d\Psi}{dx}\right) = 0, \qquad (1)$$

where $\psi = Dn_e/\Phi$ (normalized electron density function), $\Phi = T/T_0$ (ratio of absolute temperatures), D is the electron diffusion coefficient and ν_n is the net ionization frequency. The last term appears because of the gradient in gas density. For the condition of gradients in electric field only, where this last term vanishes, a number of solutions have already been obtained[2,3].

Solutions for breakdown in air are given in Figure 2 in terms of curves of E/p_∞ as a function of $p_\infty L$ where E is electric field strength, L is film thickness and p_∞ is the value of pressure remote from the surface. For large values of $p_\infty L$ the normalized field strength is simply reduced by the temperature ratio. The range of pL of interest is that where the transition occurs - pL values of 10 to 100 (mmHg cm).

Breakdown experiments with a hot surface were carried out in air-filled resonant TM_{010} cavities in which a stream of air at atmospheric pressure could be directed across a hot surface situated in a position of maximum electric field. In one experiment cool air was forced across one wall. Although the wall temperature decreased with increasing flow rate; when the measured breakdown power was corrected for this, it was found that there remained a net increase in breakdown power which could be attributed to a reduction in film thickness. Typical results are sketched in Figure 3 for air that had been cooled in a heat exchanger containing dry ice. It is immediately apparent that the increase in breakdown threshold did not rise to the upper limit indicated by the temperature ratio although improvements of 20 to 30 percent were realized. A complete explanation involves the variation of film thickness with flow rate and the differences between laminar and turbulent flow.

The second experiment was carried out with a fine heated wire stretched across the cavity in an orientation perpendicular to the electric field. The wire, 0.005" in diameter and made of platinum rhodium, was heated to values up to 1500°C. The results for several different flow rates are shown in Figure 4. At lower temperatures the breakdown power is essentially constant indicating that a relatively thin film of heated gas has formed and that breakdown remains inhibited by rapid electron diffusion out of the heated region. As the temperature increases a value is reached where a sufficiently large region of hot gas exists at which point the breakdown power becomes reduced. At higher flow rates higher temperatures are required before breakdown is appreciably affected and generally the breakdown threshold is higher. Thermionic emission is probably not an important factor particularly since the hot wire is exposed to air at atmospheric pressure.

These results demonstrate that the reduction of the breakdown threshold by a hot surface can be partly overcome by providing a gas flow sufficient to produce a thin film of heated gas rather than providing the much greater flow required to completely cool the surface.

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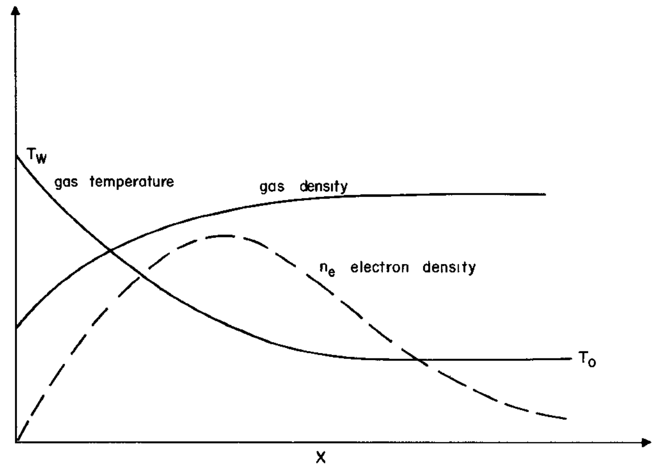

Figure 1 Model for analyzing breakdown at a hot surface and a typical solution for the electron density distribution.

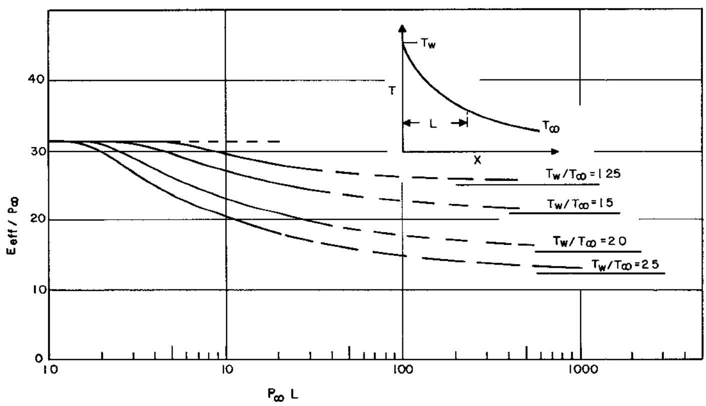

Figure 2 Theoretically determined breakdown condition at a hot surface for air in terms of E/p and pL.

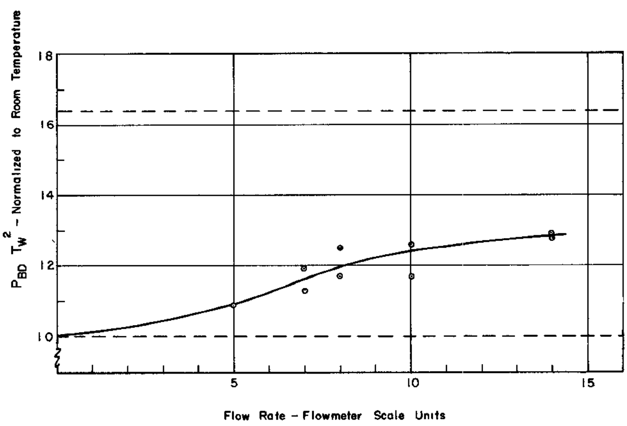

Figure 3 Normalized breakdown measurements showing the effect of film thickness at a hot surface in terms of gas flow.

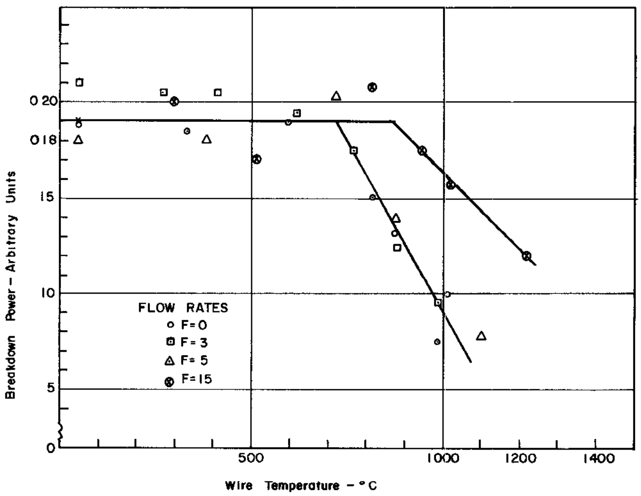

Figure 4 Breakdown measurements showing the effect of film thickness at a hot wire in terms of gas flow.

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