Thermal stability of a plasma in a homogeneous microwave field in Air

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The mechanisms of microwave breakdown in gas-filled rf systems are well understood and have been the subject of many studies during the past 50 years. The electrical breakdown of the gas is recognized as a dangerous failure mechanism and the bulk of the investigation effort has been concentrated on finding the specific breakdown threshold for the electric field strength in a given system, when ionizing mechanisms are balanced by electron loss mechanisms. A slight increase in field strength beyond this value implies an exponential growth of the density of free electrons, which leads to the formation of a plasma and the risk of serious damage to the system.

However, comparatively little attention has been spent on the dynamics of the breakdown plasma following the breakdown event. In systems with mainly homogeneous electric fields, this problem is of little importance since a breakdown of the gas anywhere in the system rapidly leads to the formation of plasma in the entire system - global breakdown. On the other hand, in the presence of local field enhancement, the result could be a plasma formation that remains small enough to be harmless to the rf equipment. The expansion of a small volume of plasma, formed in a high field region, into the ambient larger volume of low field is achieved through heating of the surrounding gas, through Joule heating of the plasma. When the surrounding gas is heated, its breakdown threshold will be lowered due to the decrease of the effective gas pressure.

A complete analysis of a small breakdown plasma volume forming in a high field region and its subsequent evolution is not analytically tractable. In the present analysis, we have therefore chosen to study a reduced, but relevant, form of the problem by investigating the stability of a spherical plasma region in Air at atmospheric pressure and located in a homogeneous rf field. It is found that there is a stationary equilibrium solution to this problem corresponding to a certain radius of the plasma. However, this solution is unstable and a plasma sphere that is smaller will collapse, whereas plasmas of larger radii will expand indefinitely. Thus, this radius provides a maximum safe size for heated regions and regions of intense field in otherwise homogeneous rf systems. If critical regions larger than this size are present, the entire system is prone to breakdown.