4.2 THE DESIGN AND TEST OF HIGH-POWER WAVEGUIDE WINDOWS

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The trend toward increased power has brought the waveguide window problem into sharp focus. Window failures have impeded the development of high-power microwave tubes. Punctures and fractures of the dielectric materials are frequently preceded by excessive heating which cannot be ascribed to dissipative losses within the body of the dielectric element. There is evidence that the temperature rise in part is due to electronic discharge on the low-pressure side of the window.

Another cause of window failure is arc-over at the output side with moderately low powers. Customarily, windows are tested at high power levels in fully pressurized waveguides. When used on tubes, the windows sometimes are found to exhibit arc-over in the pressurized load waveguide at a fraction of the test power. In some cases, the low breakdown threshold is confined to one or two narrow frequency ranges, and in others it occurs throughout the operating band. High-pressure side arc-over does not always produce puncture, but it is likely to do so if the dielectric surface is not perpendicular to the waveguide axis. In certain applications the load waveguide is evacuated, and puncture occurs without evidence of a high-current arc. This type of puncture has been correlated with the presence of contaminants, particularly vacuum pump oil.

The theoretical phase of the window investigation has led to a better understanding of the conditions that promote arc-over, and of the phenomena that are singly or jointly responsible for punctures and fractures. Calculations have shown that at typical high peak power levels, an evacuated waveguide contains a mass of charge moving under the influence of the electromagnetic field. The trajectories of field-emitted electrons and secondaries originating at the walls have been computed for practical waveguide geometries and significant power levels. The bombardment energies are sufficiently high to produce molecular changes at the surface of a dielectric window. An oscillating mass of space charge adjacent to a surface of high secondary yield is capable of producing intense local heating which, in turn, can cause evaporation of material and the formation of metallic ions. Diffusion-controlled gaseous discharge then occurs in combination with multipactor discharge, adding energetic ions as charge carriers. A mechanism of importance in the formation of puncture channels is presumed to be the migration of metal ions along lattice boundaries and dislocations in polycrystaline dielectrics. This phenomenon, which has been studied intensively by Gibbs, points to the possibility of selecting and pre-conditioning dielectric materials to increase their resistance to puncture.

Discharge on the vacuum side of a window is a stimulus for arc-over on the high-pressure side. The moving space-charge mass perturbs the normal electric field and distorts the propagating mode. In certain structures, particularly those with dielectric surfaces not perpendicular to the waveguide axis, the electric field intensity is increased at the surface on the high-pressure side. Ionizing radiation in the forms of x-rays and ultra-violet light results from electronic bombardment of the window and lowers the threshold of attachment-controlled discharge, thereby initiating arc-over.

The design of broadband windows presents many problems. Most of the practical window materials have relatively high dielectric constants which result in large power reflections at the surfaces. To withstand high-temperature bakeout and subsequent pressurization, a relatively thick dielectric element is required. Also, for a number of reasons, it is preferable to braze the element into circular, rather than rectangular, waveguide. The change in the waveguide cross section can introduce improper waveguide modes for which the dielectric element itself, or the window structure as a whole, serves as a resonant cavity. The number of mode resonances in the band increases with the dielectric thickness. Because the breakdown threshold is lowered by a large factor, each spurious mode resonance represents a potential cause of window failure. The design of broadband windows involves compromises of the electrical performance in the interest of reliability. Analytical methods have been developed for exploring the electrical capabilities of several promising window designs. The agreement between the measured and the predicted performance of selected structures has been satisfactory.

The high-power ring resonator has proved to be a useful tool for studying the operational characteristics of windows. Traveling-wave peak power densities of more than seven megawatts per square inch, averaged over the waveguide cross section, have been generated for tests of cone windows and disc windows. The test structures consist of short sections of waveguide sealed by windows and evacuated. These "windowtrons" are baked out like tubes and exhausted to pressures of 10^{-9} mm Hg for the study of electronic bombardment and multipactor. The combined effects of multipactor and diffusion-controlled discharge are studied in the pressure range of 10^{-6} to 10^{-3} mm Hg. The results serve to emphasize the importance of maintaining extremely low pressures in high-power tubes.

The flurorescent glow of the windows on a windowtron gives some indication of the areas of bombardment and the energy levels involved. Cone windows glow more brightly than disc windows, and also develop much more heat. When windows of the same type are used, the output window of a windowtron glows brighter than the input window. The intensity of the glow varies with the peak power but is essentially independent of the duty cycle.

A double-section windowtron containing three windows and exhausted by two pumping systems has been developed for the study of vacuum-to-vacuum window operation. This windowtron contains an emission source in the form of thin tungsten wire filament stretched across the waveguide in the median plane normal to the mode electric field. Copious emission from the hot filament in the r-f field serves to flood the incident surface of the central window with charge. The observations include the temperature rise of the window, the r-f loading effect, and the rate of production of physical damage to the dielectric element.

In conclusion, it can be stated that most operational window failures are directly or indirectly caused by electronic discharge on the vacuum-side of the window. Arc-over on the high-pressure side can be minimized by proper structural design. The properties of the waveguide and dielectric materials that are required to depress the electronic discharge and reduce the probability of puncture are better understood, and a significantly lower failure rate of new high-power tube windows will result. However, a "barrier" due to multipactor is anticipated at power densities only moderately higher than those presently under development, and this will stimulate the search for radically different approaches to the waveguide window problem.

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