§7. Development of Brewster Windows for High-power, CW Millimeter Waves

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A Brewster window is advantageous for a reduction of mode competitions and tunable gyrotrons, because the incident angle at which the wave reflection completely disappears for a linearly polarized wave in the incident plane does not depend on the frequency, but only on the permittivity. From a viewpoint of high power windows, the Brewster window has a lot of merits. In addition to its frequency independence, it has an effectively large area and the power density of an injected RF beam can be reduced by several times. Being different from normally-injected resonant windows, the thickness of the Brewster window can be selected freely from the RF wavelength and determined from the aspect of mechanical designs. Most important point is re-adjustability by changing the inclination of the disk, because permittivities of sintering materials have a little difference between samples even at the same temperature, furthermore they have various temperature dependence. If a disk is heated up during a high power RF injection, the reflection from the window can be minimized by changing the disk inclination.

Its elliptical shape also has less internal stresses and smaller deformation than a circular shape with the same surface area. For instance, an elliptical disk with the elliptivity of 3 has about 60% maximum tensile stress and 30% deformation of a circular one with the same area and thickness.

For the silicon nitride composite with a permittivity of 7.92, the Brewster angle θ_B is 70.44°. When an elliptical disk is installed in a circular waveguide, the disk has an elliptivity of approximately three. Let's estimate the size of a 0.5MW CW window with this material and with the forced gas-cooling. Since a 130kW CW transmission is possible from the experimental results[1)], 3.84 times of the disk area is required for 0.5MW, if the peaking factor of the incident wave is kept constant (about 3.7 for HE_{11} mode). This means that the size of 100 × 300 mm^2 will be necessary. The thickness of the disk will be about 2.5 mm, if the maximum tensile stress is suppressed below 100MPa, when the maximum deformation is expected to be 0.2mm.

We performed the thermal analysis of the Brewster window with forced air-cooling on the basis of the finite element method (ANSYS code). Figure 1 shows the calculated results of peak temperature time evolution during 500kW, HE_{11} mode input to the 100 × 300 mm^2 silicon nitride disk with 3mm thickness, witch is fixed at the Brewster angle to the incident RF beam. In this calculation we took into account the temperature dependence of the permittivity of the disk material which was low loss silicon nitride composite. The heat transfer coefficient of 0 - 1.0 W/cm^2K was assumed on the one surface of the disk. For the case of 0.1 W/cm^2K which is the experimentally obtained heat transfer coefficient for forced air-cooling, the peak temperature is completely saturated over 20sec. This means that the Brewster window of this size has a capability of 500kW CW transmission with the assistance of forced air-cooling.

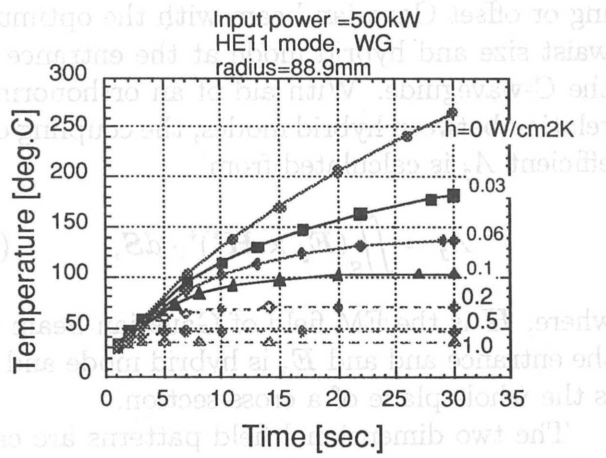

Figure 1 Calculated results of time evolution of the peak temperature during 84GHz, 500kW, HE11 mode injection to the Brewster window with forced air cooling. Disk material is a low-loss silicon nitride composite.

Reference

1) Shimozuma, T., Morimoto, S., et al.: Int. J. Infrared and Millimeter Waves 18(1997)1479-1493.