Anti-Reflection Treatments for JET Millimeter Wave Diagnostic Windows

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This paper discusses low-power windows for millimetre-wave diagnostics on the JET torus. When tritium is used as a fusion fuel in JET repairs will be difficult on the radioactive machine and additional precautions must be taken to avoid vacuum leaks. Double, interpumped vacuum windows will be necessary. Window design is further restricted by the requirement that the bond between the window itself and its supporting ferrule must withstand repeated cycling to a working temperature of about 250° C. The most satisfactory arrangement for low power millimetre waves uses z-cut crystal quartz windows, gold diffusion bonded to stainless steel ferrules, as manufactured by the Special Techniques Group of A E A Technology. Where possible wedged windows are avoided for ease of alignment.

Even with a single window multiple reflections cause the transmission to be significantly frequency dependent. Figure 1(a) shows the calculated intensity transmission spectrum for a 6 mm quartz window, assuming $n = 2.1$ over the frequency range. With double windows the additional reflections in the multiple etalons cause the transmission to be strongly frequency dependent and create severe problems for the diagnostic systems. Temperature effects are also important. Figure 1(b) shows the intensity transmission spectrum for two 6 mm windows separated by 5 mm.

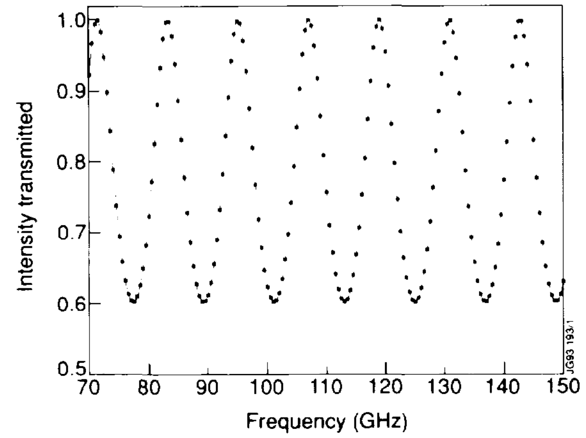

Figure 1(a)

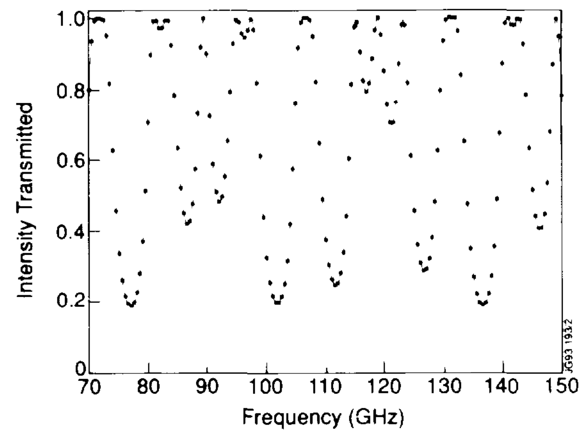

Figure 1(b)

In principle there are several ways to improve the transmission spectrum, but the various millimetre wave diagnostics on JET operate over different frequency ranges, with different resolutions, and must be considered separately. The most generally useful approach would be to treat each of the window surfaces to create a refractive index gradient, such as the "moth eye" structure described by Ma and Robinson [1]. This would, however, weaken a crystalline window substantially and would be unlikely to be acceptable on JET. A possible variant would be to create such a structure on an independent plate of similar refractive index to the crystal quartz and attach it with a thin layer of adhesive.

For the receiver of the alpha particle and fast ion collective scattering diagnostic (J A Hoekzema et al., this conference) the use of quarter wave layers of suitable refractive index would give good results over the 134 to 146 GHz frequency range of interest. The surface facing the torus vacuum will probably have to be left uncoated. Figures 2(a) and (b) show the transmission spectrum for two windows of optical thickness 6 λ at 140 GHz, with $\lambda/4$ layers on all but the first surface, separated by a gap of 2½ λ. The transmission varies by less than ±1% over the frequency range 134 to 146 GHz (Figure 2a), but over the wider range used for ECE diagnostics this solution is unsatisfactory (Figure 2b).

A suitable material for the $\lambda/4$ layer must withstand temperatures up to 250°C and will have the following properties:

1. refractive index near the square root of that of crystal quartz at the working temperature
2. thermal linear expansion coefficient similar to that of crystal quartz
3. low absorption near 140 GHz.

Measurements on possibly suitable plastics are now in progress at NPL (J.R.Birch et al., this conference).

An alternative solution for the collective scattering diagnostic is to tilt one (or both) windows and separate them so that there is no reflection from the second to the first. The two window etalons are now independent and the overall power transmission is the product of the individual transmissions. If one window has a maximum and the other a minimum in transmission at 140 GHz, the result is a smooth transmission spectrum over the range of interest, but at the cost of some polarization dependence and the loss of about half the power. Figure 2(c) shows the calculated result for two quartz windows, thicknesses 6.074 and 6.339 mm inclined at 20° to the beam axis.

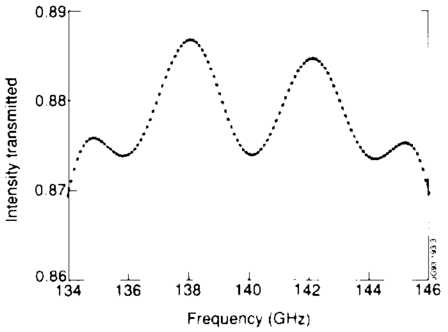

Figure 2(a)

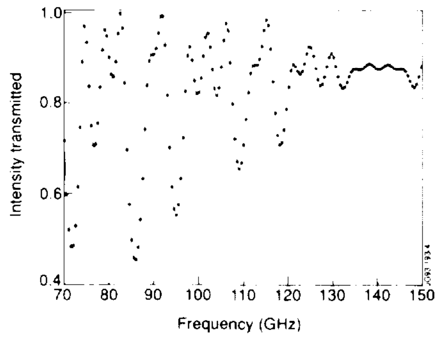

Figure 2(b)

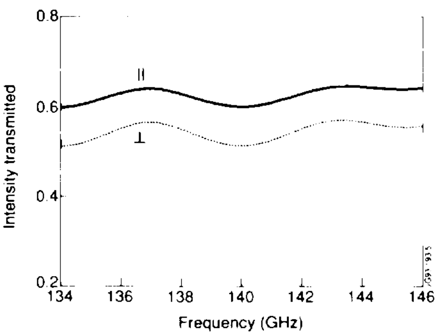

Figure 2(c)

Provided the frequency resolution required is no better than 5 or 10 GHz, it is possible to obtain a flat transmission spectrum over a wide bandwidth, as required for the ECE Michelson interferometer diagnostic, by using very thick windows with a large spacing instead of the usual wedged windows. Figure 3(a) shows the transmission spectrum of two quartz windows 100 mm thick separated by a space of 210 mm (such an assembly might be constructed within a waveguide). Averaging over 5 GHz channel bandwidths removes the fine structure and gives the almost flat spectrum shown in Figure 3(b). There is however a power loss of about 30%.

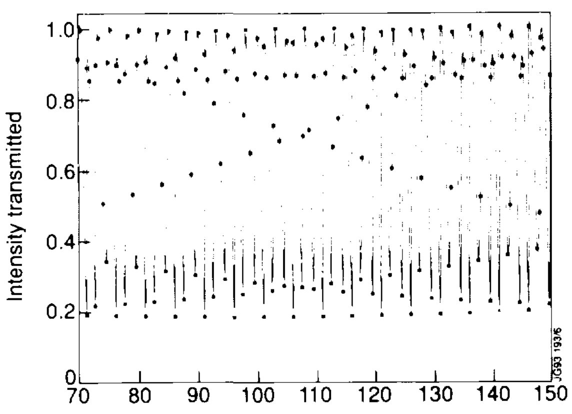

Figure 3(a)

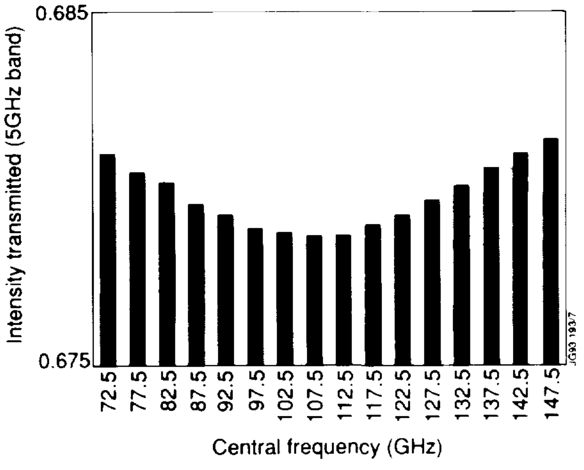

Figure 3(b)

The most difficult problem arises with the ECE heterodyne radiometer, which has high resolution (250 to 500 MHz) over a wide bandwidth (70 to 140 GHz). The development of a moth eye structure seems to be the most promising solution.

Acknowledgements. We are grateful to Dr J R Birch, Dr A E Costley and Dr J A Hoekzema for helpful discussions.

Reference Ma, J Y L and Robinson, L C, Optica Acta 30, 1685 (1983)