HIGH-POWER TESTS OF PILL-BOX AND TW-IN-CERAMIC TYPE S-BAND RF WINDOWS

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Abstract

The structures of S-band rf windows are discussed in this paper. A window with traveling wave in ceramic (TWC) having lower electric fields in the dielectric and the conventional pill-box-type window were examined using a resonant ring. Comparisons between these structures are reported from the viewpoints of the power dissipation and the durability under high-power operation.

Introduction

The breakdown of alumina ceramic rf-windows is one of the most serious problems in the high-power klystrons. Such phenomena have been studied at SLAC and KEK [1-4]. The results are summarized bellow.

(1) Optical emission is observed during rf operation. This is caused by electron bombardment during the multipactor process (electron multiplication by an rf field on an alumina surface having a high secondary electron emission (SEE) coefficient). The optical emission is the luminescence of alumina.

(2) A thin-film coating, such as TiN on an alumina surface, is effective for reducing the SEE coefficient and to suppress the multipactor effect. The thickness must be optimized not only to suppress multipactoring, but also to avoid excess ohmic heating of the thin film. The optimized thickness for a pill-box-type window under 30 MW operation is 0.5-1.5 nm.

(3) When bright spots of luminescence with a band at 410 nm (F-center defects of oxygen vacancies) take place due to the multipactor effect, surface melting or puncturing is found to occur. The F-center defects enhance localized heating.

Based on these results, a choice of the dielectric materials not liable to F-center, as well as a TiN coating is necessary for an rf window having high durability [2,3].

Further reduction of electric field strength by the window structure is expected to be effective for preventing window breakdown. In this report, a new window structure called the TWC (traveling-wave in ceramic)-type [5] was examined. High-power tests using a resonant ring were carried out.

TWC-type window

Two types of pill-box windows have been used at the KEK-linac [6]. One is the shrunk-type, in which a ceramic disk is fixed by an aluminum helicoflex. Another is brazing-type, in which the periphery is brazed, as shown in Figure 1. The latter (pill-box type) was first designed at SLAC [4], and has been used as windows for klystron output.

Recently a window structure having reduced strength of the electric fields (TWC-type) was proposed by S. Yu. Kazakov [5]. The main property of this window is a pure traveling wave in the ceramic, since an impedance is matched by one side of a ceramic disk and an iris: an impedance matching of the conventional window (such as a half-wavelength dielectric window and a pill-box window) is usually made by both sides of a ceramic disk and thus standing wave is existing in the ceramic. The strength of the electric fields at the surface of the ceramic is approximately $\{\varepsilon^{(1/4)}\}$-times less at the TWC-type window, based on a comparison with a conventional half-wavelength window having the same size of dielectric disk; $\{\varepsilon\}$ is the dielectric constant. For Al_2O_3 ceramic ($\varepsilon \sim 9.8$), the field-reduction factor is about 1.7. The concept of the TWC-type window is clarified in Figure 2.

Another advantage of the TWC-type window is that the VSWR at the operating frequency is independent of the thickness of the ceramic. One can thus choose the ceramic thickness sufficiently for mechanical firmness, and can easily

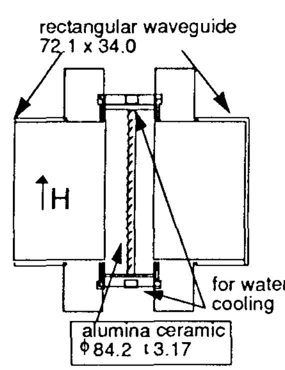

Fig.1 Structure of a pill-box-type window.

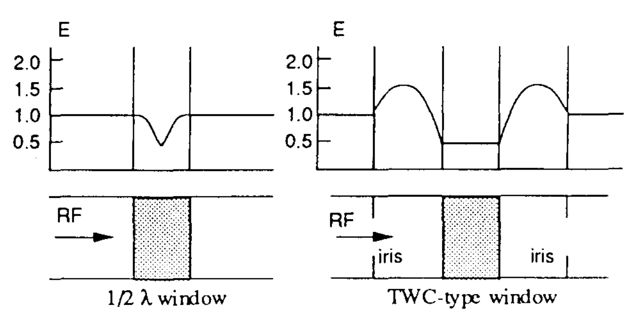

Fig.2 Concept of a TWC-type window.

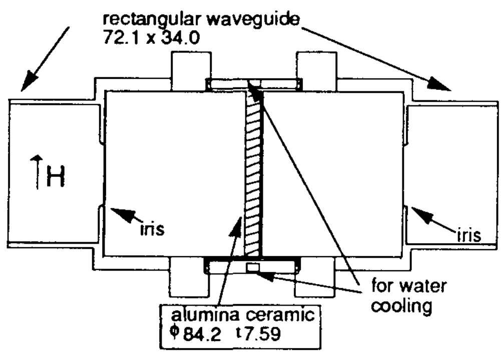

Fig.3 Structure of a TWC-type window.

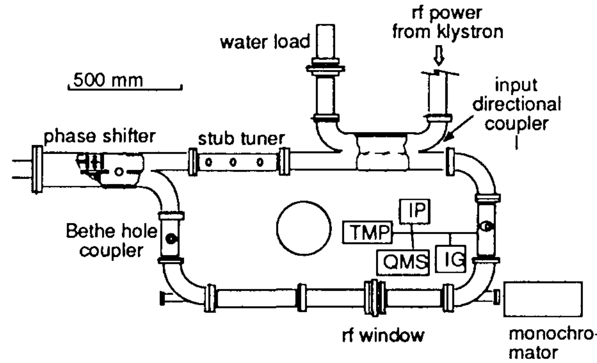

Fig.4 Resonant ring.

avoid ghost modes. Calculations have shown that the TWC-type window has a maximal pass band when the thickness of the ceramic is close to (2n-1)/4 of wavelength, (n=1,2,3,...). Furthermore the TWC-type window should have low rf losses per thickness and a low temperature rise compared with other types of windows, since only a pure traveling wave carrying power exists in a ceramic.

In order to confirm the advantages mentioned above, S-band (2856 MHz) TWC-type windows were made by BINP. Figure 3 shows the schematic of a TWC-type window. The diameter of the ceramics was chosen to be equal to that of the pill-box type. Table 1 shows the features of both types of window structures as well as the typical pass-band. The TWC-type window has a lower electric field at the surface by the factor 2 than that of the pill-box type window with a dielectric disk of the same diameter. No normal-direction electric field appears at the surface of the ceramic. Although the TWC-type window has a narrower band than that of the pill-box type window, it will be sufficient for linac use where the operation frequency is constant.

TABLE 1
Comparisons of Window Parameters.

	pill-box type	TWC-type
diameter of ceramic	84.2 mm	84.2 mm
thickness of ceramic	3.17 mm	7.59 mm
surface Emax @ 50 MW		
(tangential to ceramic)	4.1 kV/mm [7]	2.2 kV/mm
(normal to ceramic)	5.6 kV/mm [7]	0.0 kV/mm
pass-band (<1.2 VSWR)	600 MHz	80 MHz

High-power tests using resonant ring

The windows were tested at the resonant ring, to which the rf output power from a pulsed-klystron (30 MW, 2856 MHz, 50 pps, maximum 2 μs) is fed through an input directional-coupler and resonated [1-3]. The configuration of the resonant ring is shown in Figure 4. An rf window could be examined at a maximum power of 400 MW by cooling the stub tuner. The base pressure was about 10^{-7} Pa, and was maintained to be lower than 10^{-6} Pa during rf operation. The HA997 alumina ceramics (made by NTK, Japan), which had shown good feasibility for high-power use [2], and the "Russian" alumina ceramics (made by "Istok", Russia), were used for window materials as shown in Table 2. The ceramic surfaces were coated with 1.5 nm TiN films (No.1, 2, 3). Uncoated window (No.4) was also examined.

The results are summarized in Table 2. A power of more than 400 MW for 2 μs pulses was reached without any breakdowns for "HA997" with TiN coatings (No.1). This level of power is close to the limit of the resonant ring, though an F-center was generated, which would indicate a pre-breakdown [2].

For the TWC-type window with "Russian" ceramic (No.2), cracks were generated after 400 MW for 2 μs pulses operation, though 300 MW/ 1 μs, 250 MW/ 2 μs powers were transmittable.

On the contrary the pill-box type window with "HA997" (No.3) showed detrimental cracks after 400 MW for 1 μs pulses.

Although the luminescence was observed at all the windows during 1-10 MW operation, the intensity of the

TABLE 2
Results of High Power Tests.

No.	Structure	Material	coatings	multipactor	max. power /rf width/ rf repetition	F-center	comment
1	TWC	HA997	1.5 nm	from 10 MW	>400 MW/2 μs/50 pps	generated	surface melting
2	TWC	Russian	1.5 nm	from 10 MW	400 MW/2 μs/50 pps	generated	crack
3	Pill-box	HA997	1.5 nm	from 1 MW	400 MW/1 μs/50 pps	generated	crack
4	TWC	HA997	0 nm	from 2 MW	400 MW/1 μs/50 pps	generated	surface melting

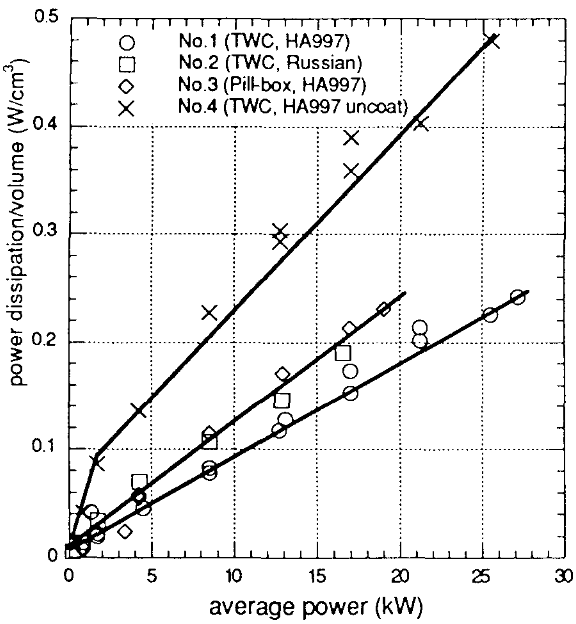

Fig.5 Power dissipation during rf operation.

luminescence from the uncoated "HA-997" window of TWC-type (No.4) was more than 10-times larger than that from others. The transmittable power was lower than that of No.1. This means that electron multipactoring takes place even when a normal-electric field component to the ceramic is absent. It has been confirmed that the coatings are also important for the TWC-type window.

Power dissipation was measured by temperature rise of cooling water. Figure 5 shows the power dissipation of a window for a unit ceramic volume. The TWC-type (No.1) demonstrated lower dissipation than the pill-box type window (No.3). This is because of the lower electric fields in the ceramic of the TWC-type than that of the pill-box type. It is thus concluded that a reduction of electric field strength is effective to suppress the dissipation power. The large dissipation of No.4 was probably due to multipactor effects on the surface of the ceramic, since dissipation power contains both rf losses and surface heating due to multipactor.

Conclusion

The TWC-type window (HA997 with TiN coatings) could transmit an rf power of 400 MW/2 µs/50pps. The TWC-type window is more promising for high-power operation than the pill-box type window. Multipactor phenomena were observed at the TWC-type window; coatings and the choice of the materials are also important for the TWC-type window. It will be necessary to examine statistically sufficient number of TWC-type windows.

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