DEVELOPMENT OF AN S-BAND HIGH-POWER PILLBOX-TYPE RF WINDOW

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Abstract

We report on the development of RF windows which are used to handle a high transmission power up to 100 MW for the Japan Linear Collider. A detailed simulation on multipactoring has been carried out. The results were compared with cathode-luminescence on the surface of alumina RF windows experimentally observed with power transmission up to 200 MW.

Introduction

At the KEK Accelerator Test Facility (ATF) for the Japan Linear Collider (JLC), an S-band linac with the energy of 1.54 GeV will be used as an injector for a damping ring. Each accelerating unit consists of two 3 m long accelerating structures, a high-power wave guide system, an 85 MW klystron with a SLED, and a klystron modulator. The injector linac is operated at an accelerating gradient up to ~ 35 MW / m and the maximum repetition rate of 50 pps. The entire system will comprise of eight such units. An RF window with a power capability up to 100 MW must be used between the klystron and SLED cavities [1] for an ease of klystron maintenance work. However, window failures often occur in the power range of a few tens of MW. An improved reliability of RF windows is highly desirable.

It has been known that breakdowns occur because of following reasons: (1) electron bombardment onto the surface due to the multipactoring, (2) material imperfections such as voids and impurities, and (3) poor surface conditions such as contamination and micro-cracks [2, 3]. Although the detailed mechanism has not yet been understood, it has been widely believed that the multipactoring on the surface of an alumina disk is mainly responsible for the breakdown. In the past the trajectories of multipactoring electrons on the window surface have been calculated in one or two-dimensional models where only the TE11 mode electromagnetic field is assumed to propagate through the window [3]. In those models since the electric field is parallel to the alumina surface, only the surface charge build-up could cause electron bombardment on the window. However, more recently Yamaguchi [4] calculated electromagnetic fields through the RF window by using a three-dimensional (3D) computer code MAFIA [5] and simulated multipactoring electrons in a 3D space.

We have extended the method in reference [5] and carried out further studies on multipactoring by taking into account the effect of magnetic fields and by considering a detailed mechanism of the secondary electron emission. We have compared such calculations with our breakdown experiment on alumina window using a resonant ring. In this report we report on results of those studies.

Simulation of multipactoring

In our simulation program, the equation of motion of electrons is written as;

$$\frac{d\vec{v}}{dt} = \frac{e}{m}\left(\vec{E}(x,y,z,t) + \vec{v} \times \vec{B}(x,y,z,t)\right) \qquad (1),$$

where m is the electron rest mass, e electron charge, and E and B being the electromagnetic fields through the RF window (see Figure 1), calculated by using MAFIA code. These 3D were numerically integrated by using Runge-Kutta-Gill's method. A Monte-Carlo technique is used to randomly create the initial electron position and the RF phase. The velocity and emission angle of secondary electrons are assumed to be 10 eV and 90 degrees, respectively. The delay of the secondary electron emission from the primary electron bombardment is taken to be 28 ps [6]. The tracking of each electron trajectory is continued until: (a) the number of RF cycles exceeds 20, or (b) the electron impinges on the metal part of the window, or (c) electric field is in the deceleration phase at the moment of the electron emission. We used the following equation to describe the secondary electron emission coefficient δ which was introduced by Dionne [7]:

$$\delta = \frac{B}{\varepsilon}\left(\frac{An}{\alpha}\right)^{\frac{1}{n}} (\alpha d)^{\left(\frac{1}{n}-1\right)}(1-\exp(\alpha d)) \qquad (2),$$
$$d = \frac{E_p^{\,n}}{An}$$

where B is the escape probability, ε the excitation energy of the secondary electron, A the absorption constant of the primary electron, n the power-law exponent, a the absorption constant of the secondary electron, d the maximum penetration depth and E_p the energy of the primary electron. The $(B/\varepsilon)An$ and α in Equation (2) are determined by fitting experimental data by Dawson (see Fig. 2) [9].

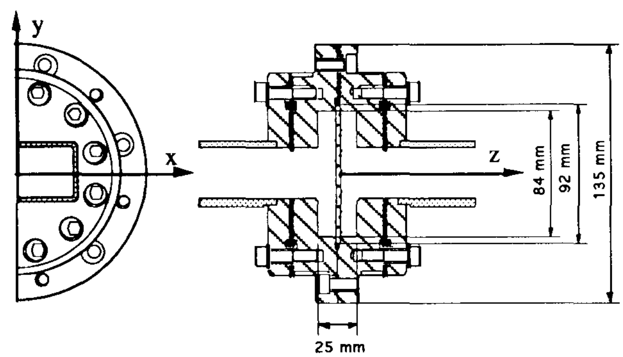


Fig. 1 The structure of the rf window

A typical electron trajectory is given in Figure 3, in which the multipactoring electrons drift only a few cm on the surface. The calculated distributions of the number of impinging electron due to the multipactoring on the alumina disk are indicated in Figure 4 for the transmission power of (a) 4 MW, (b) 10 MW and (c) 50 MW. The multipactoring is predicted to occur only in the low transmission power regime below 50 MW. As shown in Figure 5, the energy of the impinging electron is mostly between 0.8 and 3 keV.

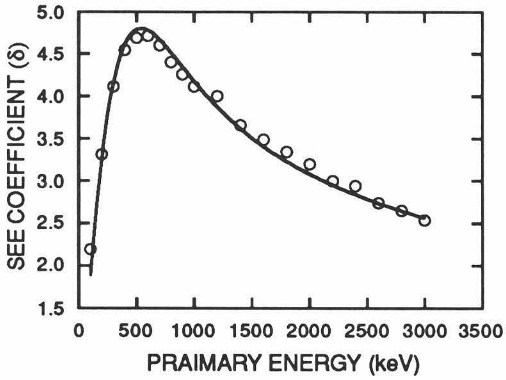


Fig. 2 Secondary electron emission (SEE) coefficient of an alumina as a function of primary energy. The open circle is the measured data by Dawson[10], and solid line is fitted with eq. (2)

Experimental apparatus and procedure

The purpose of this experiment is to observe fluorescence light on the RF window surface when a high RF power is transmitted through it. Their pattern is compared with the distribution of multipactoring electron as predicted by the simulation outlined in the previous section.

Figure 6 shows a schematic drawing of the resonant ring used as the experimental setup. The S-band RF power is fed to the ring through a -11.54 dB two-hole-type coupler. Details of the apparatus have been described elsewhere [8]. Tests were carried out with an alumina disk window whose diameter was 92 mm, thickness 3.5 mm, with purity 99.5 %. No TiN coating has been applied to the window. During the test fluorescent light on the window surface was observed through the viewing port.

Results and discussions

During the test two types of cathode luminescence were observed. The first is the one observed when the transmitted power is relatively low, below 10 MW. Features of the luminescence depend on the transmitted power. The second is the one observed under a high transmission power condition. It was a small bight spot (1.5 mm in diameter) which appeared at 90 MW. Once it appeared, from then on the bright spot continuously grew to 20 mm in size, irrespective of the transmitted power. The alumina window eventually broke at a peak power of 201 MW at 10 pps. The broken window was later examined with a microscope. A cluster of small melted spots of 50 μm in diameter

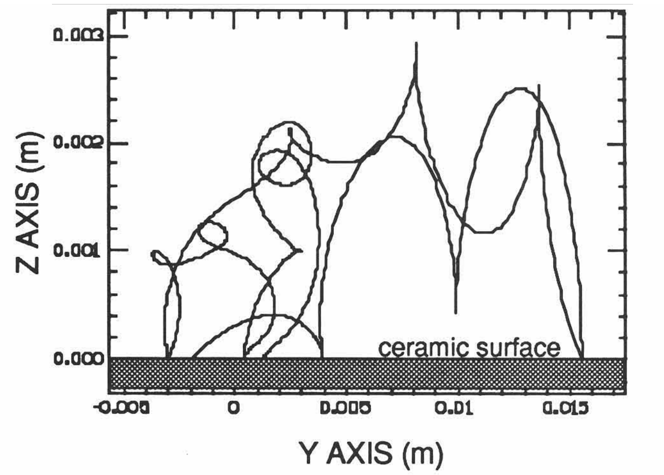


Fig. 3 The typical trajectory of the simulated multipactoring electron at the power of 4 MW.

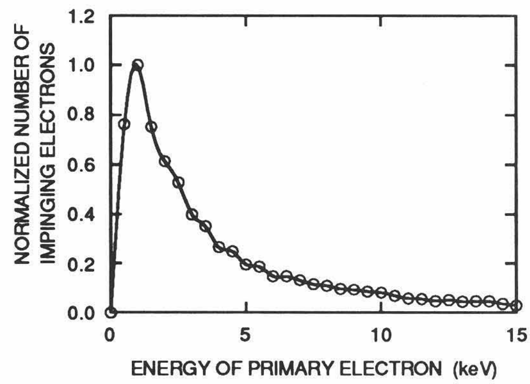


Fig. 5 The distributions of energy of multipactoring electrons at the transmission power of 4 MW

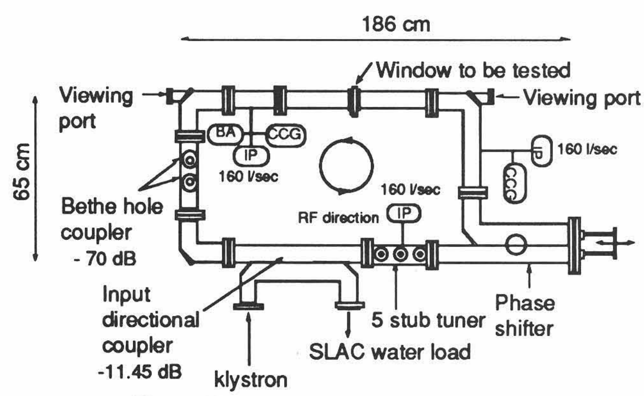


Figure 6 Schematic drawing of the resonant ring

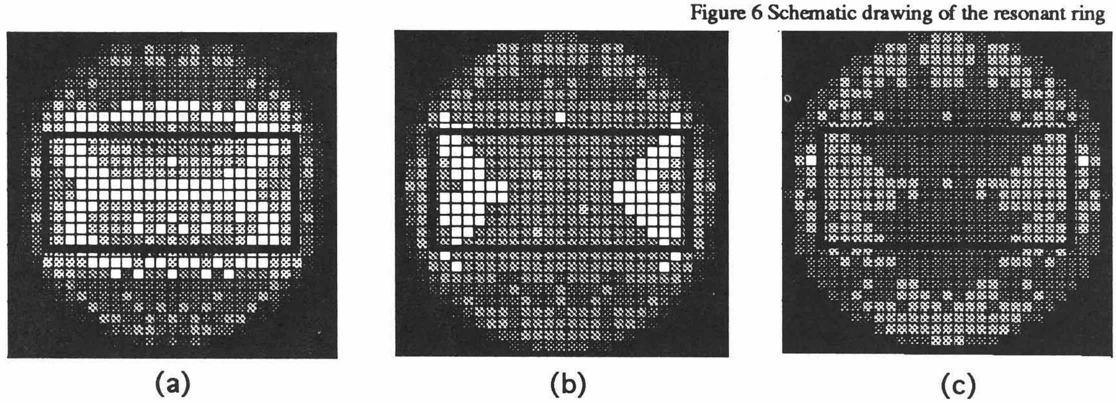
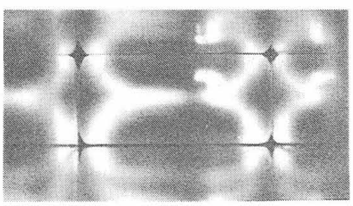


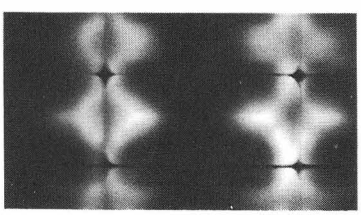
Fig. 4 The density distributions of number of impinging electrons at the power level of (a) 4 MW, (b) 10 MW and (c) 50 MW. The rectangles in figure are corresponding to rectangular wave guide.

were found (see Figure 8). They were localized in the area that corresponded to the bright spot seen during the experiment. Some cracks, a few cm long, were formed around this area due to a local heat stress. The wide patterns of cathode-luminescent seen in the low power range (< 10 MW) is shown in Figure 5. They agree well with the calculated distributions of impinging electrons as shown in Figure 4. The energy of impinging electron due to multipactoring is below a few keV (see Figure 5). It is known that to initiate an imperfection such as F-center [10] in an alumina an energy deposit up to 300 keV is required. Therefore, we speculate that the breakdown of an alumina disk in the multipactoring regime is caused by a cumulative effect of many low energy electrons, rather than by a few numbers of high energy electrons.

When the peak RF power is larger than the multipactoring region (~ 50 MW), the multipactoring can still occur during the rise and fall time of the pulsed RF power. This phenomenon was observed with photo-multiplier tubes as shown in Figure 9. Multipactoring can occur between edges of voids or micro cracks. This may account for the bright spot on the window which was seen near 90 MW in our experiment. This multipactoring is a serious problem, because it will grow by itself with increasing tan δ and the secondary emission coefficient due to the temperature rise. A further study of this localized multipactoring must be carried out.



(a)



(b)

Fig. 7 Experimental observation of the cathode luminescence at the transmission power of (a) 4MW and (b) 10MW from viewing port

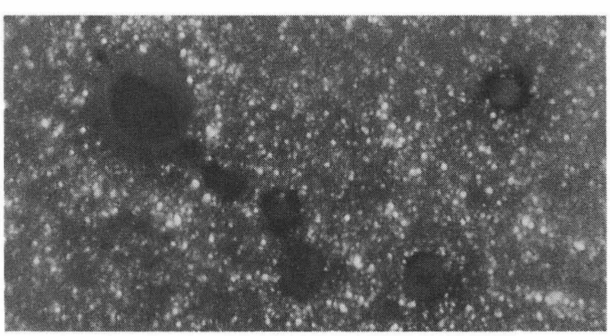
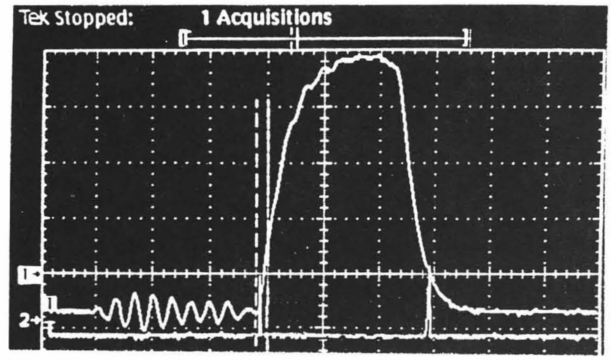


Fig. 8 The melting spots of the broken alumina disk observed by a microscope



1.0 µsec / div

Fig. 9 The cathode luminescence for the few tens nsec was observed. The upper line is the excited power of the resonant ring and the under a signal of photo-multiplier. The rf peak power of 100 MW, cathode luminescence occured at the point of about 10 MW

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