

# Development of an S-band RF Window for Linear Colliders

A. Miura and H. Matsumoto\*

*The Graduate University for Advanced Studies  
1-1 Oho, Tsukuba, Ibaraki 305, Japan*

*\*KEK, National Laboratory for High Energy Physics  
1-1 Oho, Tsukuba, Ibaraki 305, Japan*

## Abstract

We report on our research and development of an S-band (2856 MHz) alumina RF window for a high power transmission which exceeds 100 MW. We have studied the mechanism of RF breakdowns of alumina disks experimentally with a test facility based on a resonant ring. At a higher power transmission (>50MW), impurities within alumina due to sintering binder materials and internal voids were shown to be mostly responsible. An experiment at a resonant ring has shown that the new RF window by using high-purity (99.9%) and low porosity (0.5%) alumina disks can successfully withstand a maximum peak transmission-power of 310 MW with a pulse width 2.5  $\mu$ s at 10 Hz repetition rate, and a maximum average transmission-power of 300 MW with pulse width 2.5  $\mu$ s at 50 Hz.

## I. 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 with accelerating gradient of 22 MV/m, an 85 MW klystron (TOSHIBA) with a SLED, and a klystron modulator. An RF window with a power capability up to 100 MW must be used between the klystron and SLED cavities 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 [1].

Until now many studies of window failure were mainly made on local heat build-up due to multipactoring [2], and a variety of surface coating materials, such as TiN, were tested as a cure [3]. More recently it was calculated that multipactor phenomena occurred when the RF power transmission is below 50 MW at the S-band frequency [4]. We have come to suspect that in the power regime of up to 50MW high power breakdowns of alumina disks may be due to phenomena taking place inside alumina rather than at its surface. We considered that the root cause of the problem could be voids within alumina or structural defects due to binder materials used during the sintering process. In order to reduce the porosity (volume fractions of voids) in alumina we have applied a Hot Isostatic Pressing (HIP) treatment [5]. This allows an unambiguous study of effects of binding materials used during the sintering process. We have studied behaviors of alumina disks with a varying amount of binders in an RF environment with the resonant ring. We

have experimentally examined time profiles of breakdown phenomena.

## II. PREPARATION OF HIGH PURITY, LOW-POROSITY ALUMINA WINDOWS

Typical disks for RF windows have been made of 99.5 % purity alumina. The sintering binders, such as MgO, account for a major part of impurities. It has recently become possible to manufacture fine alumina particles with diameters of less than 0.5  $\mu$ m. This and concerning the progress of a sintering technique allow us to make alumina disks with an ultra-high purity of 99.9%. In addition, it has been learned recently that the RF loss due to the binders depends strongly on the choice of binder materials [6]. For example, it is very sensitive to the presence of MgO. We have fabricated alumina disks with a varying purity with and without MgO, and have measured their RF loss. If the alumina disk does not contain MgO at all, a very low dielectric loss ( $\tan \delta = 2.0 \times 10^{-5}$ ,  $f = 1000$  MHz) is achieved.

By using high-purity ultra fine alumina powder as the raw material and using a sintering process without MgO as the binder, high purity and low RF loss alumina disks can be fabricated. Then by treating them with a HIP method, remaining voids are further removed to porosity of 0.5 % level. We have fabricated several of these new alumina disks for our RF power testing.

## III. HIGH POWER TESTS

We have conducted high power tests of alumina disks as RF windows with a varying fraction of sintering binders with a resonant ring. In order to study the high power behaviors and properties of high purity alumina material itself, in our test several noteworthy points are 1) we have significantly reduced the alumina porosity with the HIP treatment. 2) None of the alumina samples has TiN coating.

### A. Alumina Samples

We have tested six alumina disks. Table 3 summarizes their parameters. The samples #1 and #2 are based on 99.5 % purity grade alumina. While sample #1 had no visible imperfections, the sample #2 had a concentration of impurities which looked like a dark cloud. The sample #3, #4, #5 and #6 are made of 99.9 % alumina. Especially the sample #4 does not contain any MgO binder. The test with sample #5 is made to study the reproducibility of the result with

sample #3. The sample #6 was made intended 10 pin-holes whose diameter is 0.5mm in order to investigate behavior of multipactoring around the pin holes.

Table 1 parameters of tested alumina disks

	#1	#2	#3	#4	#5	#6
Purity (%)	99.5	99.5	99.9	99.9	99.9	99.9
Impurity concentrated	no	yes	no	no	no	no
MgO (Binder)	yes	yes	yes	no	yes	yes
Intended pin hole	no	no	no	no	no	yes

All alumina disks performed HIP treatment and no coating

### B. Experimental Apparatus

The diagram of the resonant ring is shown in Figure 1. The vacuum pressure monitored with cold cathode gauges (CCGs) and B-A gauges (BAGs). Photo multiplier tubes installed on a downstream view window are used to measure the time profile of light emissions from the alumina disk. The X-rays from the RF window are measured with scintillation counters in the upstream and downstream neighborhood of the RF window. On the outer wall of the RF window Alumel-Chromel thermocouple detectors were installed to monitor the temperature rise of the alumina disk.

A schematic diagram of the window structure is shown in Figure 2. The vacuum on both sides of the alumina disk is separated by the Helicoflex. Since it allows to replace the alumina disk easily without disturbing the window frame.

The RF pulse width is always maintained at 2.5  $\mu$ s. In the first step the repetition rate of is set to 10 Hz, and the power transmission is gradually increased. When the peak transmission power reaches 200 - 310 MW and the alumina disk survives, the same procedure is repeated at the pulse repetition rate of 25 Hz and 50 Hz.

More detail of experimental apparatus was shown in reference [5].

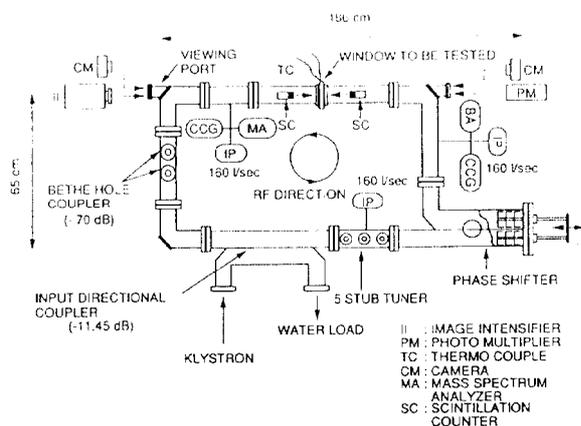


Figure 1. The diagram of the resonant ring

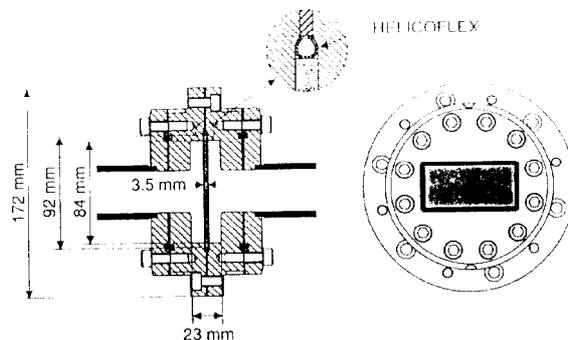


Figure 2. A schematic diagram of the rf window

### C. Experimental Results and Discussions

Figure 3 summarizes the results of the experiment, showing the observed temperature rise at the window frame as function of the average power for each sample.

Sample #1: During the first 10 Hz operation, a localized light emission from a same single spot continuously increased. With a transmission power 200 MW a large discharge took place, and the disk was destroyed. An inspection with an electron microscope indicated numerous melted pin-holes and cracks at the point where the light emission was seen. Sample #1 showed the highest temperature rise among the samples tested. Our interpretation is that a highly localized multipactor started on a defective spot on the surface, and resultant electron collisions on the surface has become the heat source to cause the disk failure.

Sample #2: No localized discharge was seen during the test. It did not experience a steep temperature rise as the sample #1. After running with 204 MW at 10 Hz, the repetition rate was raised to 25 Hz. At 25 Hz, when the power reached 113 MW, the alumina disk was cracked and destroyed. No traces of melting were seen on the surface. We interpret this failure as caused by a heating due to the localized sintering binder.

Sample #3: After running up to 200 MW at 10 Hz, the test was continued up to 280 MW at 25 Hz, then up to 200 MW at 50 Hz. The test was terminated at that moment. The alumina disk has seen no damage. Figure 4 shows the time profile of the light emission from sample #3. The signal trace is superimposed with the RF power profile. At the rising and falling edge of the RF pulse, when the power transmission reaches near 10 MW, light emissions for a few hundred nano-seconds are clearly seen. We understand that although the canonical operation power was well above the multipactor regime, during the pulse transient time the disk momentarily experiences the power level where multipactor is prominent. Therefore, for real-life RF window disks, TiN coating is still required.

Sample #4: After running at 203 MW at 10 Hz, the power was raised to 230 MW at 25 Hz, then 280MW at 50 Hz. No failure occurred. Sample #4 showed a very stable performance after aging with the lowest temperature rise even at the maximum

power of 280 MW at 50 Hz. No traces of melting or cracks were found on alumina surface.

Sample #5: After running at 310 MW at 10 Hz, the transmission power was raised to 280 MW at 25 Hz, then 300 MW at 50 Hz. No failure occurred. Figure 3 shows that the temperature rise with sample #5 is very similar to that of sample #3. No melting spots or cracks were found on the disk after 500 hours of operation.

Sample #6: after running at 200 MW at 10 Hz. No failure such as a crack occurred. During rf operation local discharge was continuously occurred around pin-holes. Temperature rise of this sample was very high compare with that of sample #3 and #5 which were made from a same alumina quality as sample #6. It clearly this heat source was electron bombardment due to local discharge at the pin-holes. At this moment this test has continued.

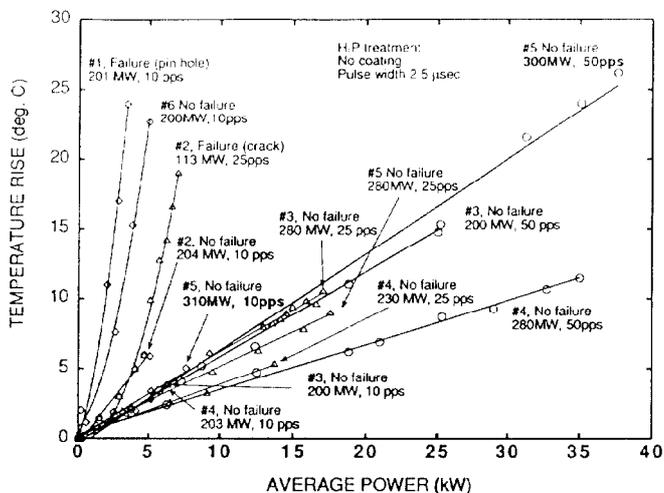


Figure 3. Temperature rise at the window frame as function of the average power for each sample

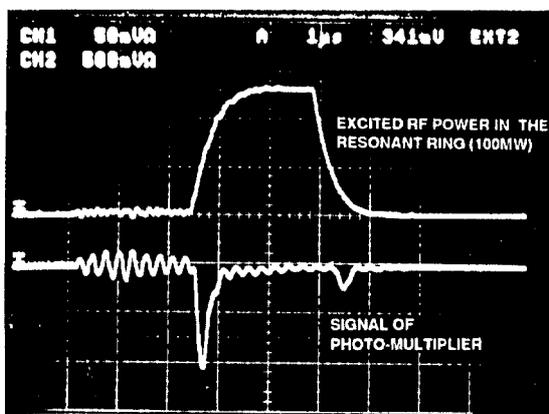


Figure 4. The time profile of the light emission from sample #3

#### IV. CONCLUSION

For the power level higher than the multipactor region, imperfections inside the alumina disk are the dominant

source of breakdowns. As a cure, we have developed a technique based on a combination of i) high-purity alumina disk, ii) avoidance of MgO sintering binder, and iii) the HIP treatment. This significantly improves reduces the dielectric RF losses and the porosity. The high power performance of alumina disks fabricated this way is significantly superior to that of disks made in a traditional way. It was found that multipactor occurs during the RF pulse transient time at the high power region. Therefore, coating with TiN is still necessary to maintain the best possible overall characteristics of alumina disks for RF windows.

#### V. ACKNOWLEDGMENTS

The authors wish to thank Professors Y. Kimura and K. Takata at KEK for their continuous encouragement. The discussions with Drs. T. Shintake and S. Yamaguchi at KEK inspired us to initiate the present study on the breakdown mechanism of alumina disks. The present work has been carried out as part of a research and development program for the JLC-I with the following participants: Drs. S. Takeda, J. Urakawa, H. Hayano, Messrs. Y. Otake, T. Naito, S. Araki and many other people at KEK. The authors are grateful for their help. The authors thank Messrs. R. S. Callin and W. R. Fowkes at SLAC, Drs. Y. Saito and S. Michizono at KEK and Dr. H. Baba at Nihon Koshuha Co. Ltd. They generously contributed advise and information on the breakdown phenomena of RF windows and on high power experiments. The authors wish to thank the NKK Corporation for the HIP work, Nihon Ceramic Co. Ltd. for fabrication of high-purity fine alumina disks and Kobe Steel Co. Ltd. for production of high-purity low rf-loss alumina disks. The help by Messrs. S. Morita and T. Matsui of ATC Co. for resonant ring tests are also appreciated. A part of the resonant ring experiment was carried out under a collaboration with Drs. M. Nagl, B. Dweresteg and M. Summerfeld from DESY. Finally, thanks are due to Drs. N. Toge and M. Yoshioka at KEK for fruitful discussions and critical reading of the manuscript.

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