HIGH-GRADIENT EXPERIMENTS WITH NARROW WAVEGUIDES

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Abstract

High-gradient RF breakdown studies have been in progress at Nextef (New X-band Test Facility at KEK) since 2006 [1]. To study the characteristics of different materials on high-field RF breakdown, we have performed high-gradient experiments by using a narrow waveguide that has a field of around 140 MV/m [2]. The first high-gradient test was conducted using a waveguide made of copper at XTF: the old X-band Test Facility at KEK. The second high-gradient test has been conducted using a stainless-steel waveguide at Nextef. The result of stainless-steel type showed a good performance for higher electric field and less RF breakdowns than copper type. A description of the high-gradient test of copper and stainless-steel waveguides is described in this paper.

INTRODUCTION

XTF was relocated to Nextef in 2007 to conduct high power tests of X-band accelerator structures and fundamental researches on the RF breakdown [3]. For conducting the breakdown study, reliable RF sources and measurement systems are required and great efforts are fulfilled to establish the reliable system. Interlock for RF processing and breakdown measurement systems were replaced with new scheme which has been improved as well. It took about half a year for RF processing for RF components such as a guard window, a directional coupler and a dummy load. The copper and stainless-steal waveguides were tested to launch high-gradient experiments at Nextef.

NARROW WAVEGUIDE

The narrow waveguide is a size-reduced waveguide from usual X-band rectangular waveguide (WR90); width from 22.86 mm (λ_g ~ 32.15 mm) to 14 mm (λ_g ~ 76.59 mm) to obtain a group velocity of 0.3 c and height from 10.16 mm to 1 mm to yield a field gradient of 200 MV/m at an RF power of 100 MW at the centre [2]. In order to investigate the difference of high-field capability, stainless-steal (AISI-316L) waveguide is manufactured and tested to compare with the copper waveguide tested in XTF. Table 1 shows the parameters of copper and stainless-steel narrow waveguide by measurements and calculations (HFSS). Figure 1 shows a photo of a narrow waveguide of stainless-steel (#SUS003).

Table1: RF parameters of waveguides.

product name	#CU002	#SUS003
material	Copper (OFC)	stainless-steel (AISI-SUS316L)
vswr	1.44	1.12
loss [dB]	-0.42	-1.56
vswr (HFSS)	1.0405	1.0765
loss [dB] (HFSS)	-0.258	-1.830
E-filed at 100 MW (HFSS) [MV/m]	212.34	189.25

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Figure 1: Narrow waveguide of stainless-steel (#SUS003).

HIGH-GRADIENT EXPERIMENTS

Setup for BD Observation

An RF power is supplied to a narrow waveguide from a PPM focused klystron, which is operated at 11.424 GHz with pulse width of 400 ns, a pulse repetition rate of 50 Hz and a peak output power of approximately 50 MW. Acoustic sensors and photomultipliers (PMT) along the waveguide are located to observe breakdown events as shown in Fig.2. Figure 3 shows a measurement system of a RF pulse which is detected with a crystal diode and an oscilloscope that calculates the power, VSWR and power loss. Every RF pulse is calculated and digital data of 10 successive 10 pulses are saved to make use of them to analyze the waveform when some interlocks such as HV, Trig. and RF trip. In order to distinguish the breakdown in the narrow waveguide from the breakdown occurred in

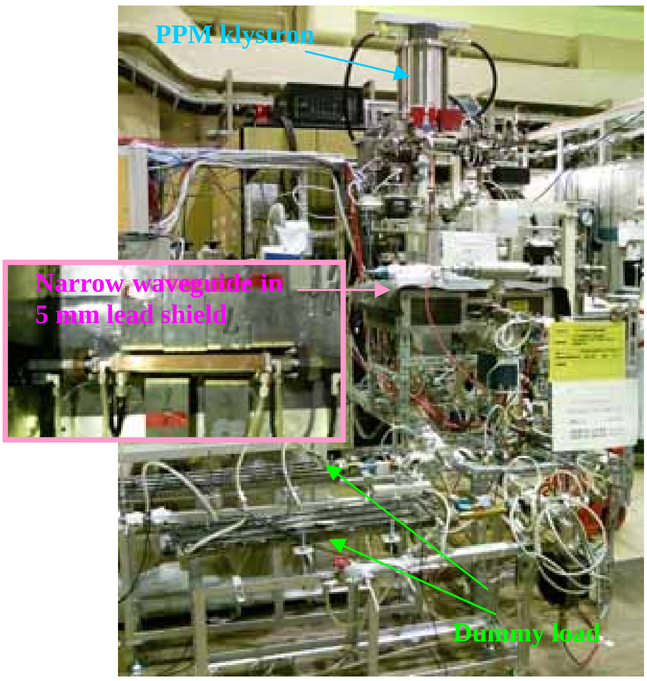

Figure 2: Experimental setup at Nextef.

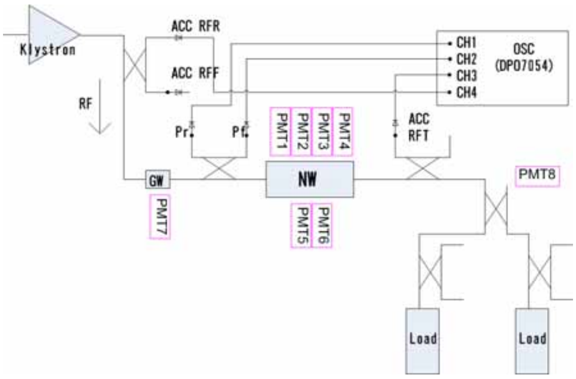

Figure 3: Measurement system of RF pulses.

the other location, waveform analysis system are under preparing. Forward and reflected RF wave observed in the directional coupler located upstream and downstream of the narrow waveguide are saved in digital oscilloscope. By comparing with the pulse shortening or reflected power due to the breakdown, it is possible to distinguish the breakdown occurred at the guard window for example. It is possible to add other information such as the photomultiplier signal or X-ray detector. This enables us to measure the true breakdown at the narrow waveguide more precisely.

Scheme of RF Processing

During the processing, the RF pulse width is varied from 50 ns to 400 ns and the output power is varied by changing the input drive power of the klystron under the fixed applied voltage to the klystron at a fixed repetition rate of 50 pps. The time interval and the output power increments are controlled in accordance with the past processing history depend on the experienced power and condition of the vacuum by a computer. When the pressure in the waveguide goes high, the power is kept constant until the pressure goes to normal level. When the pressure increases dramatically, the processing power is decreased and the processing is repeated from lower power again. We haven't established yet the efficient and optimal processing scheme, but we're investigating the proper pattern of processing in order to avoid serious breakdown damages to the structure.

Since the #CU002 and the #SUS003 were tested at the different location as well as different system condition, it is difficult to compare the processing difference directly. The processing time for #CU002 was for a month depending on the XTF operation scheduling. #SUS003 has been operated for about one year due to the establishment of the high-gradient experiments at Nextef.

Figure 4 (a) and (b) show processing history of #CU002 and #SUS003, respectively. The number of breakdown (BD) events depend on an RF power during the processing of #CU002 and #SUS003 and are shown in Fig.5 (a) and (b), respectively. They have the different distribution. #SUS003 had less breakdown events and attained higher power than #CU002. We interpret this difference partly due to the system difference, i.e. different protection scheme, though there is a different material dependence. Figure 5 and 6 shows the electric field and the temperature-related parameter $PT^{1/2}$ (the product of RF power and the square root of the pulse width) with the function of the pulse width. #SUS003 attained higher electric field and $PT^{1/2}$ than #CU002. However, from this result a 50 MW of an RF power isn't enough to obtain the gradient limit of a stainless-steel at the short pulse width.

Measurement of Breakdown Rate

After processing, breakdown rates (BDR) of #SUS003 were measured with the function of an RF power and a pulse width. Figure 8 shows the power history during the measurement of BDR. Constant power was fed for about 24 hours and the events of breakdown were counted. Many RF breakdowns in a short time were observed after serious breakdown which associated the pressure jump under the long pulse width condition. Unstable condition of 06-11-08 after the stable period in Figure 8 is such a case. We regard this phenomenon as a kind of processing. To take the BDR data with a function of a power, we need to finish these processing processes. Figure 9 shows BDR of #SUS003 with a function of an RF power. Though events of BD fluctuate, there is a trend that BDR increases if the power increases, and relation between the BDR and the input power has an exponential nature as shown in Figure 8.

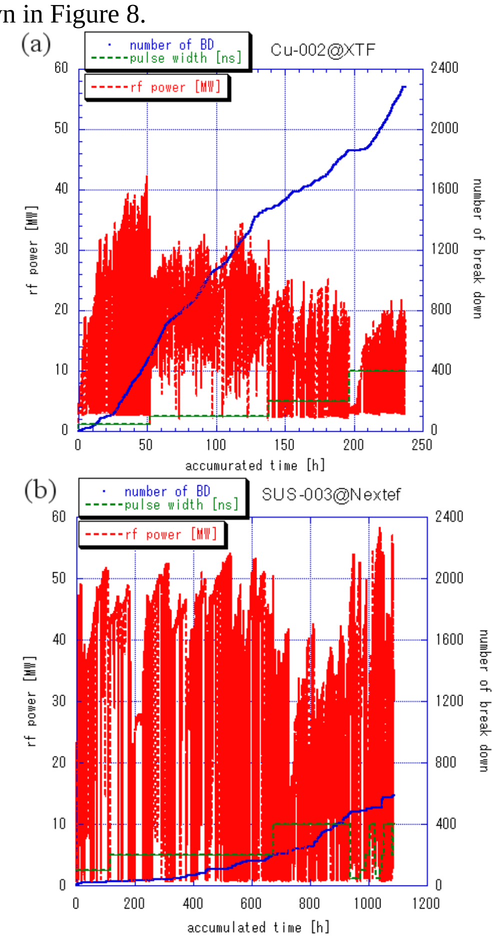

Figure 4: Power history of (a) #CU002 and (b) #SUS003 during processing.

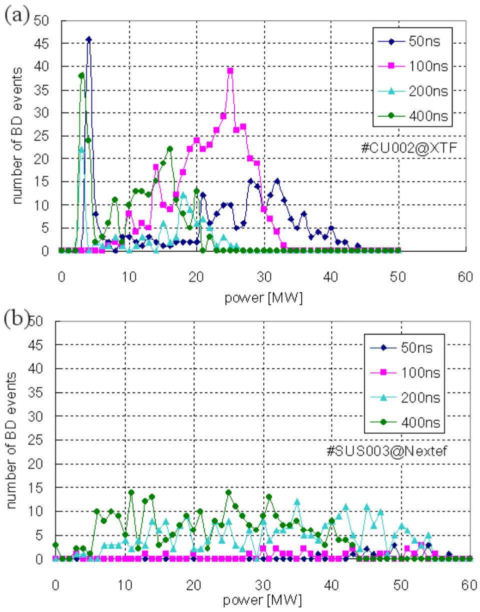

Figure 5: Power distribution of breakdown events of (a) #CU002 and (b) #SUS003 during processing.

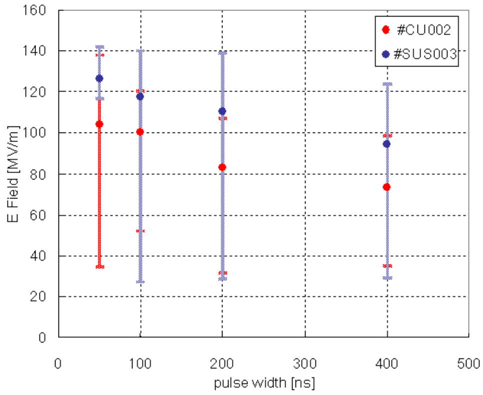

Figure 6: E-field of #CU002 and #SUS003.

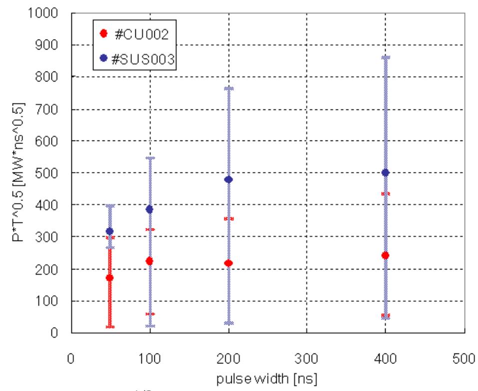

Figure 7: $PT^{1/2}$ plot of #CU002 and #SUS003.

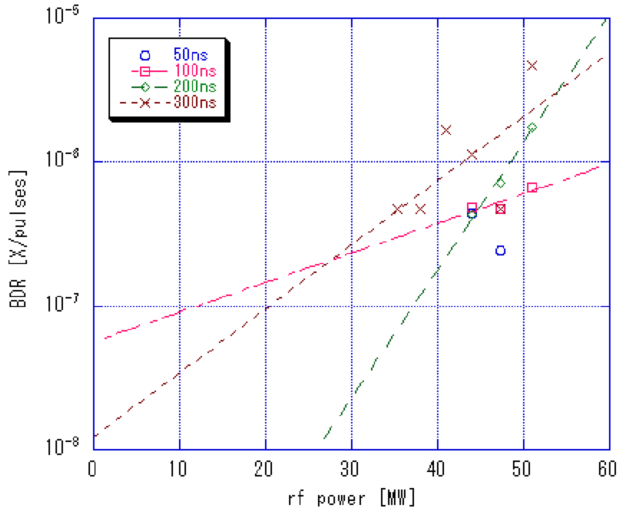

Figure 9: Breakdown rate with a function of a pulse width of #SUS003.

SUMMARY

The experimental setup for RF breakdown studies is almost established at newly developed Nextef station. Breakdown diagnoses including the waveform analysis are being developed and will be useful for the more reliable measurement. Breakdown test on different materials are being performed. Prototype #CU002 and #SUS003 had been tested under the different systems and the results are compared. After obtaining the tentative test result, stainless-steel likely has a higher capability for the breakdown threshold than copper. We plan to test the narrow waveguide made of #CU004, another stainless-steel material and other materials with different surface treatment and fabrication. Further detailed analysis will be possible using this Nextef station.

REFERENCES

[1] T. Higo, et al., "Normal Conducting High-Gradient Studies at KEK", LINAC2006, 21 - 25 August, 2006, Knoxville, TN, USA, pp. 661-663.

[2] K. Yokoyama, et al., "High Field Performance in Reduced Cross-Sectional X-band Waveguides made of Different Materials", Proc. of PAC07, Albuquerque, NM, USA, pp. 2119-2121.

[3] S. Matsumoto, et al., "Nextef: The 100 MW X-band Test Facility in KEK", Proc. of EPAC08, Genoa, Italy.

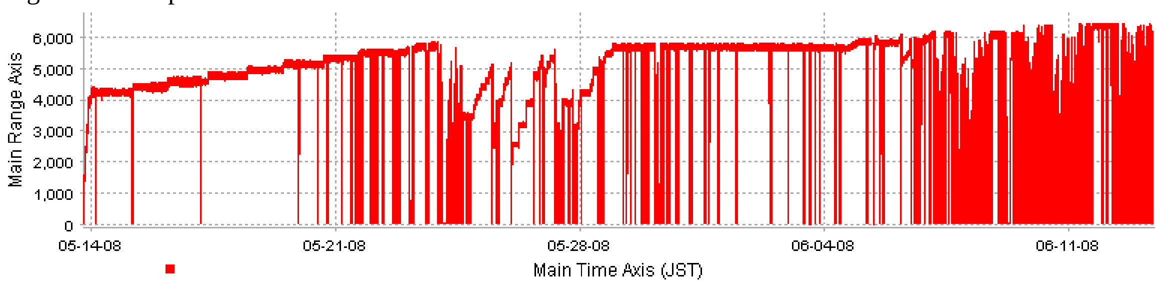

Figure 8: Power history during measuring BDR at 300 ns. The vertical axis corresponds to RF power.