INITIAL HIGH POWER TEST RESULTS OF AN X-BAND DUAL-MODED COAXIAL CAVITY*

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Abstract

To better understand rf breakdown phenomena, an X-band coaxial pillbox cavity was designed in which two modes can be independently excited. One mode generates a peak magnetic field on the inner conductor surface, but no electric field, while the other has its highest surface electric field near the middle of the inner conductor, at a magnetic field null. By observing the breakdown rate for different electric to magnetic field ratios, we hope to reproduce the limiting rf field effects seen in various accelerator structures, waveguides and klystrons. The results from the initial high power tests of this cavity are presented in this paper.

INTRODUCTION

Two factors that influence the rf breakdown rate in an accelerator structure are the size of the surface electric fields [1, 2] and the pulsed rf heating [3, 4], particularly when it is over 50 ^{o}C where stress related damage is expected to occur. Studies using single-cell [4-6] and multi-cell cavities [7] show damage to the high electric field regions on the irises, while the peak heating occurs at the cell equator region. How the combination of the electric and magnetic fields, and the associated magnetic field heating, triggers breakdown is not clear.

An X-band (11.424 GHz), coaxial-type, dual-moded cavity was designed to study the relative effect of electric and magnetic surface fields on breakdown. With two rf sources, its two degenerate modes (TE_{011} and TEM_3) can be independently excited. The details of the cavity design can be found in [8]. Fig. 1 shows the cavity cross section and the mode field patterns.

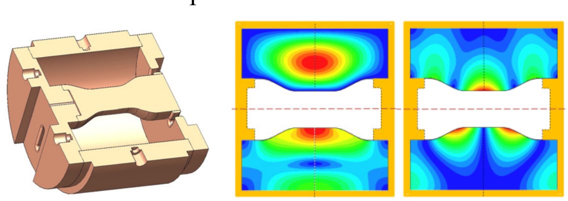

Figure 1: Cross-section of the dual-moded cavity (left) and the electric (top half) and magnetic (bottom half) fields of the TE_{011} (middle) and TEM_3 (right) modes that couple in from the left and right side, respectively.

With the two modes simultaneously excited, the center of the inner conductor will experience the peak electric field (but minimal pulsed heating) from the TEM_3 mode, and peak pulsed heating (but no electric field) from the TE_{011} mode. Past observations suggest that the presence of the latter mode could significantly enhance the breakdown rate (BDR), particularly as the peak heating and peak electric field location coincide.

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DUAL-MODED CAVITY COLD TEST

The two modes were both tuned to be resonate at 11.426 GHz at room temperature in dry N_2. This corresponds to 11.424 GHz at 45 ^{o}C in vacuum, our nominal operating condition. The minimum reflections are -12.2 dB and -25.3 dB for the TE_{011} and TEM_3, respectively, as can be seen from the S-parameter curve measurements shown in Fig. 2. The crosstalk between the two modes on resonance is -22.75 dB. The finite crosstalk turned out to be useful for adjusting the relative timing of the two X-band power sources. The cavity parameters are listed in Table 1 – they are based on both simulated field and cold test results. For the TE_{011} mode, the coupling turned out to be somewhat lower than intended. Also, it has a finite surface electric field in the coupling iris region (which is not shown in the Fig. 1 field plots).

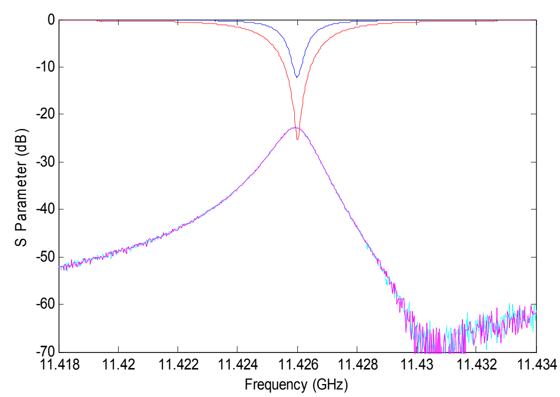

Figure 2: Cold test S-parameter measurements. The blue and cyan lines are the TE_{011} mode reflection and transmission, respectively, and the red and magenta lines are those parameters for the TEM_3 mode.

Table.1: Mode parameters from cold test measurements and HFSS field simulation data. For the input power listed, the TE_{011} mode has surface current density of 1 MA/m and the TEM_3 mode has a surface peak electric field of 200 MV/m.

Mode	TE_{011}	TEM_3
Frequency (GHz)	11.426	11.426
Unloaded Q_0	14,935	9,335
Coupling, β	0.60	1.12
Field Time Constant (ns)	260.1	122.7
$\lvert E_s\rvert_p/\lvert H_s\rvert_p$ (V/A)	84.0	355.5
Input Power (MW)	18.37	3.46

HIGH POWER TESTS

Test Setup

Two high power X-band stations in NLCTA at SLAC were used to power the cavity as shown in Fig.3. The maximum flat-top pulse width from the stations is 235 ns as a result of the SLED-II pulse compression system that is used. This system also 'leaks' power into the cavity before the main pulse and so produces some pre-pulse heating. The input rf pulse for the TEM_3 mode was shaped to obtain a flat cavity field pulse as shown in Fig. 4. In this case, the flat-top pulse width was 180 ns and the peak surface electric field was 200 MV/m. Also shown is the computed peak surface heating – the peak location is displaced from the peak electric field as shown in Fig. 1. Fig. 5 shows the TE_{011} mode input power, in this case a square pulse, and the resulting peak pulsed heating.

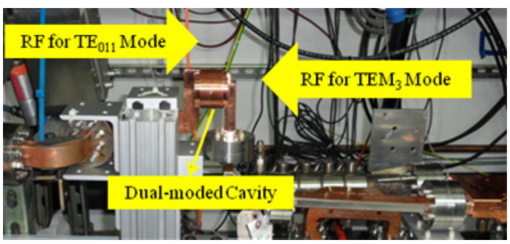

Figure 3: High power test setup of the dual-moded cavity. The rf from the left and right side excite the TE_{011} and TEM_3 modes, respectively.

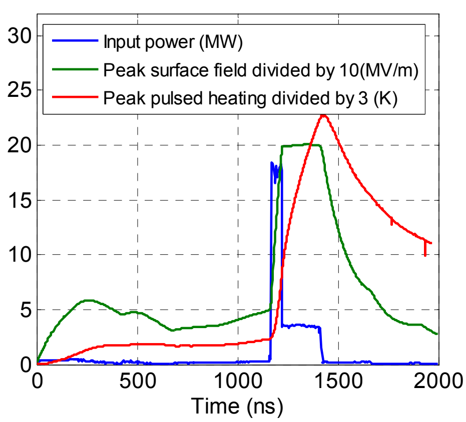

Figure 4: The measured TEM_3 input power and the calculated peak surface field and rf pulsed heating corresponding to the mode parameters in Table 1.

Although a cooling ring was attached to the cavity, we needed to reduce the pulse repetition rate from 60 Hz to 30 Hz to stay on resonance when simultaneously running the two modes. At 30 Hz, there was almost no detuning of the two modes as seen from the good agreement between their reflected power and that computed with the on-resonance parameters from Table 1 – these comparisons are shown in Fig. 6.

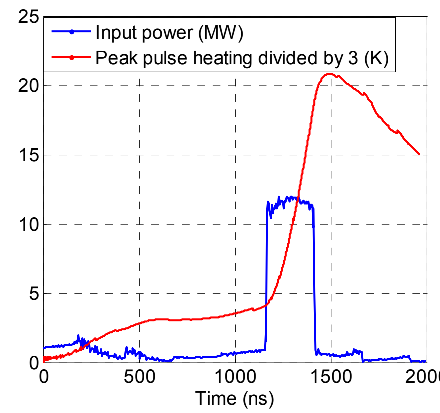

Figure 5: The measured TE_{011} mode input power and the rf pulsed heating computed using the mode parameters in Table 1.

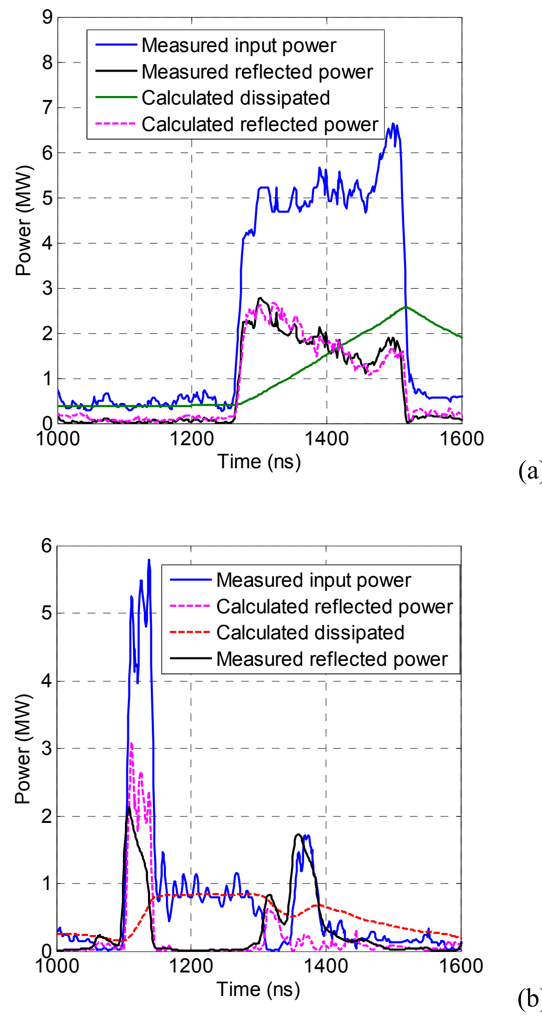

Figure 6: Comparison of the (a) TE_{011} and (b) TEM_3 measured and computed reflected power. Also shown are the input power and computed dissipated power.

High Power Test Results

Two sets of experiments have been carried out so far with the dual-moded cavity. For these experiments, the relative timing of the modes was set so the peak pulsed heating from the TE_{011} mode was within the flat top of TEM_3 mode.

For the first set, the correlation of the BDR with the peak pulsed heating from the TE_{011} mode was studied at a fixed peak surface electric field from the TEM_3 mode. The results are shown in Fig. 7, where the TEM_3 peak surface electric field was 200 MV/m and the flat top width was 180 ns. The TE_{011} mode heating was increased up to 80 °C and the BDR increased as expected. Note that if only the TE_{011} mode was powered, the BDR measured with 80 °C heating was 25 times smaller than the rate shown in Fig. 7.

Fig. 7 also shows a fit to the data motivated by the fact that the number of pulses needed to fracture the copper surface is expected to depend on the peak pulsed heating temperature T as

$$N = \frac{C}{\exp(kT^2) - 1}, \quad (1)$$

where C and k are unknown constants [9]. Thus, one might expect the BDR rate to be inversely proportional to N, and Fig. 7 shows that such a temperature dependence fits the data reasonably well, where the fit coefficient T_0 represents the peak pulsed heating from theTEM_3 mode.

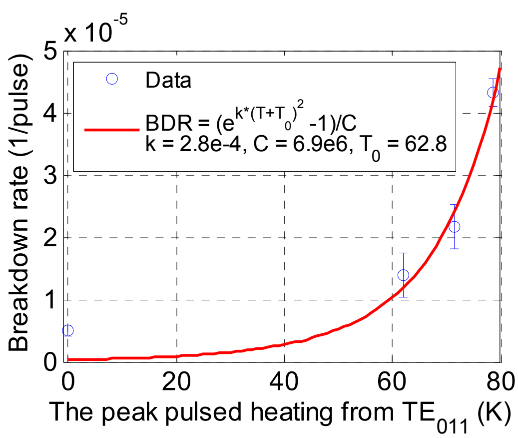

Figure 7: Rf breakdown rate dependence on the peak pulsed heating from the TE_{011} mode.

For the second set of measurements, the TE_{011} mode pulsed heating was increased until the BDR increased by at least an order of magnitude for different TEM_3 field levels - the results are shown in Fig. 8. The dashed lines indicate the measurement sequence in which about three million pulses occurred at each step.

The TEM_3-mode-only BDR does not show the strong dependence on surface electric field that one might expect. It may be that the interleaved operation of the TE_{011} mode helped condition the surface as the TEM_3 field was increased.

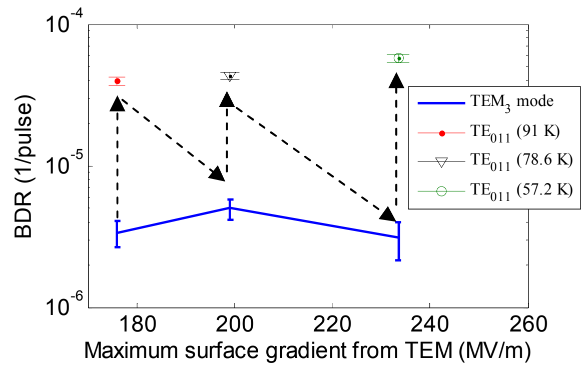

Figure 8: The TE_{011} mode peak pulsed heating required to increase the BDR by at least an order of magnitude as a function of the TEM_3 field level.

Figure 8 also shows that the TE_{011} peak pulsed heating required to increase the BDR by more than a factor of ten decreases as the TEM_3 peak electric field increases. This may be due to the overlap of the pulsed heating from the two modes as can be seen from the field plots in Fig. 1. That is, there is a larger area with high pulse heating as the TEM_3 field increases.

SUMMARY

Tests of an X-band dual-moded coaxial cavity showed that the rf breakdown rate increased with increased pulsed heating but constant peak electric field. This is consistent with our earlier experimental results with a standing-wave accelerator cavity [6], although in that case the peak electric and magnetic field locations did not coincide.

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