# High-Gradient Test Results of W-Band Accelerator Structures

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***Abstract***—We report initial high-gradient testing results of a 110 GHz single-cell standing wave accelerating cavity powered by a 1 MW gyrotron. The cavity is fed with 10 ns, 100s of kilowatt pulses, and achieved a field gradient up to 225 MV/m. We also report the observation of rf breakdowns and cavity processing for >$10^5$ pulses.

## I. INTRODUCTION

THERE is a growing interest in linear accelerator technology operating at 100s of GHz and THz frequencies for various applications, due to their potential high efficiency and small form factor relative to their S- and X-band counterparts. High-frequency structures have been tested with relativistic beams at SLAC in the picosecond [1]–[4] and nanosecond [5], [6] timescales. Vacuum rf breakdowns in normal conducting cavities is a critical limiting factor in the operation of these accelerators and a careful characterization of breakdown statistics is required. In this work, we report the preliminary results of the first high-gradient tests of an externally driven 110 GHz single-cell standing wave accelerating cavity made of copper, for the purpose of measuring the rf breakdown probability. A 110 GHz gyrotron that can produce up to 1 MW is used as the rf power source for the cavity.

## II. INITIAL RESULTS OF HIGH GRADIENT TESTING AT W-BAND

The high-power experimental setup is shown in Fig. 1, where a microsecond pulse from the 110 GHz gyrotron is transported to the accelerating structure in a free-space Gaussian beam. The gyrotron produces 3 μs high power pulses at 1 Hz repetition rate. Therefore, the rf pusles require shortening to reduce the pulsed heating in the cavities. A single silicon wafer is used as a refelector triggered by an intense 532 nm, 8 ns laser pulse [7], and otherwise almost transparent. Absorbed photons increase the effective conductivity of the semiconductor through photoconductivity with a rise time of a few nanoseconds until the Si wafer becomes an effective rf reflector with more than 70% reflectivity [7], [8]. The chopped high-power pulse at 110 GHz is delivered to the accelerating cavity with forward pulse full-width half-maximum (FWHM) of 10 ns. The cavity's π-mode frequency in our setup is thermally tuned in order to align it to gyrotron frequency. This is accomplished using a chiller clamped onto the accelerator structure.

The accelerator cavity and mode convertor were cold tested using a quasi-optical setup [9], [10] that demonstrated

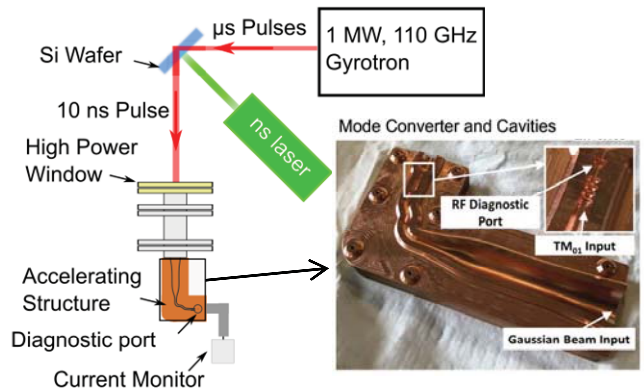


**Fig. 1**. Schematic of the high-gradient experimental testing setup for the W-band accelerator cavity (in the inset). The rf signals are sampled using mm-wave diodes at the forward, reverse and transmitted paths, as well as a Faraday cup for dark current measurement.

excellent coupling of power from a Gaussian beam to the cavity accelerating mode.

In order to characterize high-gradient performance of the cavity, we have measured the rf signals: the forward power, reflected power, transmitted power through the diagnostic window of the cavity using mm-wave diodes, as well as the field emitted currents using a current monitor (Faraday cup). The maximum achievable power that can be coupled to the accelerator cavity for this setup is about 590 kW. An example of the measured rf pulses is shown in Fig. 2 given a forward power level of about 470 kW.

The modeled time domain response of the accelerating cavity is also superimposed in Figs. 2 and 3 utilizing the measured rf pulse after the switch to drive the cavity. The S-parameters obtained from cold test varying with frequency are used to calculate the temporal evolution of fields in the cavity, the reflected, and transmitted rf signals. Good agreement between the measured rf pulse profiles and HFSS modeled response is reported in Figs. 2(b) and (c). The maximum achieved gradient was about 225 MV/m given 590 kW of peak input power as seen in Fig. 3(a), and the pulsed heating effect due to surface magnetic fields causes a temperature rise of less than 25 $^{o}$C as seen from the simulation result in Fig. 3(b).

We have observed rf breakdowns when operating at such high gradients. An rf breakdown event is manifested when the transmitted power experiences pulse shortening, and reflected power features an abrupt surge, in comparison to the normal operation where there are no breakdowns [11]. In addition to

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that, a spike in the measured dark current is observed during breakdowns, in particular for gradients >180 MV/m. Up to the highest measured gradient of about 225 MV/m, we did not observe a steady dark current in the absence of breakdowns in the setup. Nonetheless, the measured current represents only a very small fraction of the actual field-emitted electrons from the cavity walls and we expect to measure considerable dark currents for higher gradients.

Figure 4 shows the processing timeline of the W-band accelerator cavity, including the measured peak gradient in the cavity and the number of accumulated rf breakdowns after around $1.4\times10^5$ pulses. Note that the accumulated breakdowns do not exhibit substantial growth after $10^5$ pulses indicating rapid cavity processing at gradients up to 225 MV/m. Further breakdown statistics are needed to accurately obtain the breakdown rate, however an initial upper bound at 225 MV/m, which corresponds to about 0.52 GV/m of peak surface electric field, is estimated to be $10^{-1}$/pulse/m and this rate is expected to decline for longer operation.

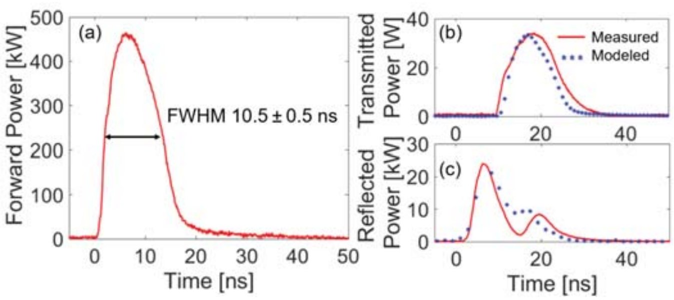


**Fig. 2**. (a) Example of the measured forward rf pulse at around 470 kW of input power. (b) Transmitted and (c) reflected power from the accelerator.

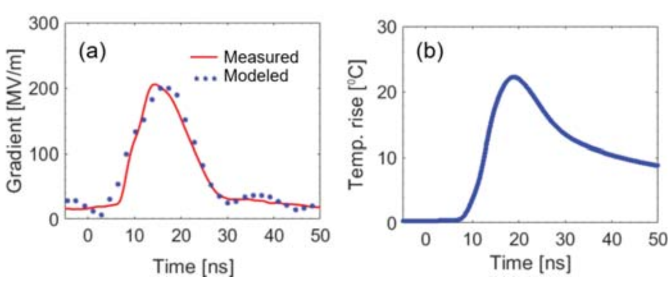


**Fig. 3**. (a) Measured versus modeled electric field gradient in the accelerator cavity as a function of time for 590 kW of input power, and (b) calculated temperature rise of the cavity walls based on the measured gradient.

## III. CONCLUSION

We have demonstrated progress in high-gradient testing of a single-cell accelerating cavity at 110 GHz using a gyrotron as the rf power source. We have shown excellent coupling of high power into the accelerating structure and achieved a gradient of 225 MV/m given 590 kW of peak input power. Continuous testing will further allow us to characterize the breakdown statistics and achieve a steady-state breakdown rate for the maximum possible gradient in this setup. Furthermore, the setup will be upgraded by utilizing longer pulses from a single wafer GaAs that could produce >30 ns pulses.

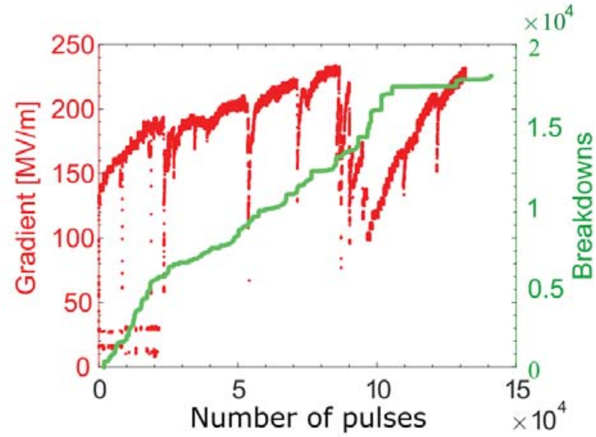


**Fig. 4**. The processing history for the W-band accelerator cavity: the red curve is peak field gradient in the cavity and the green curve is the accumulated breakdowns.


## IV. ACKNOWLEDGMENT

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