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INITIAL RESULTS OF HIGH-GRADIENT BREAKDOWN TESTS FOR W-BAND ACCELERATING STRUCTURES

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Abstract

We report progress on high power testing of a 110 GHz single-cell standing wave accelerating cavity powered by a 1 MW gyrotron. The pulsed power is coupled into the accelerating structure using a Gaussian to TM_{01} mode converter. The cavity is fed with 10 ns, 100s of kilowatt pulses using a fast laser-based switch. At such power levels and pulse length the cavity achieved an accelerating gradient of about 150 MV/m.

INTRODUCTION

There is an ongoing interest in linear accelerators operating at 100s of GHz and THz frequencies due to their small size and potentially high accelerating gradient, above 100 MV/m. High-frequency structures have been tested with relativistic beams at high gradient on single cycle [1]–[3] and nanosecond time-scales [4] at SLAC. Understanding vacuum rf breakdown in such normal conducting accelerators is critical to realizing unprecedented high gradient performance. Accordingly, it is imperative to diagnose the rf breakdown event probability to quantify the high-gradient performance of accelerator structures [5]. In this work, we report initial results of high-power tests of a 110 GHz single-cell standing wave accelerating cavity powered by a 1 MW gyrotron for the purpose of studying breakdown physics.

PRELIMINARY RESULTS OF HIGH GRADIENT TESTS AT W-BAND

The accelerating structure under test consists of a single-cell standing wave cavity that allows for direct comparison with our X-band experiments [5]. It consists of three coupled cavities, with the on-axis electric field in the central cell twice as high as in the adjacent cells. This was done to ensure that most of the breakdowns occur in the central cell [6]–[8]. The high-power structure is made in two halves, where each half is milled into oxygen-free copper blocks as shown in the inset of Figure 1. Then the two halves are diffusion-bonded. The vacuum assembly incorporates a high-power window with a lens to focus the incoming Gaussian beam into the structure's smooth-walled horn with a ~4.5 mm beam waist. In turn, the horn converts the Gaussian mode into the TE_{11} mode of a circular waveguide

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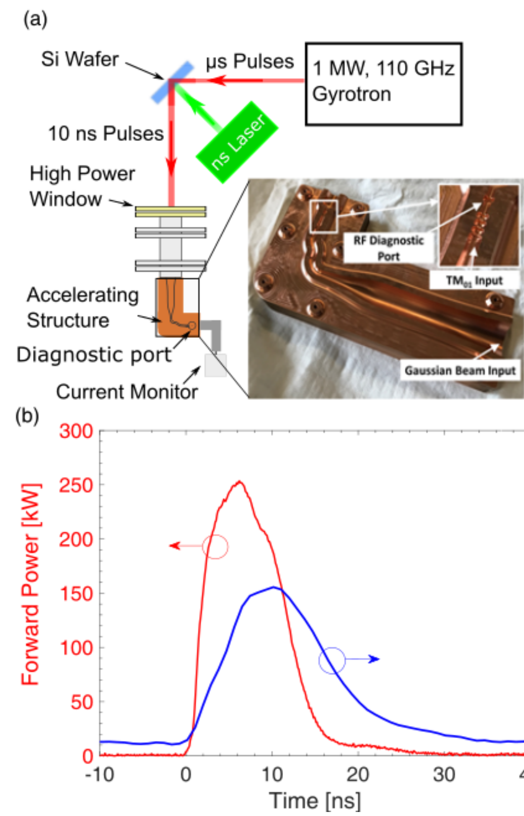

Figure 1: (a) The W-band high-gradient test experimental setup, and a photo of high-power accelerator structure is shown in the inset. The rf signals are measured with fast mm-wave diodes for the forward and reflected rf signal. An additional low power diagnostic port measures the power transmitted through to the cavity. (b) Sample of the forward power pulse at 250 kW and the calculated field gradient.

with ~99% conversion efficiency, followed by a TE_{11} to TM_{01} mode converter, which includes a 90° bend with a 97% power conversion efficiency and a bandwidth exceeding 2 GHz [6], [7]. We first performed low-power rf measurements using a vector network analyzer on the assembled vacuum structure. The π-mode resonance for the structure is found to be at 110.08 GHz with a loaded Q of about 1600. At π-mode resonance the cavity has reflection coefficient < -25 dB with a transmission through the diagnostic port of ~ -41.5 dB. We also have found remarkable agreement between the designed value of the modeled and measured transmission (not shown here).

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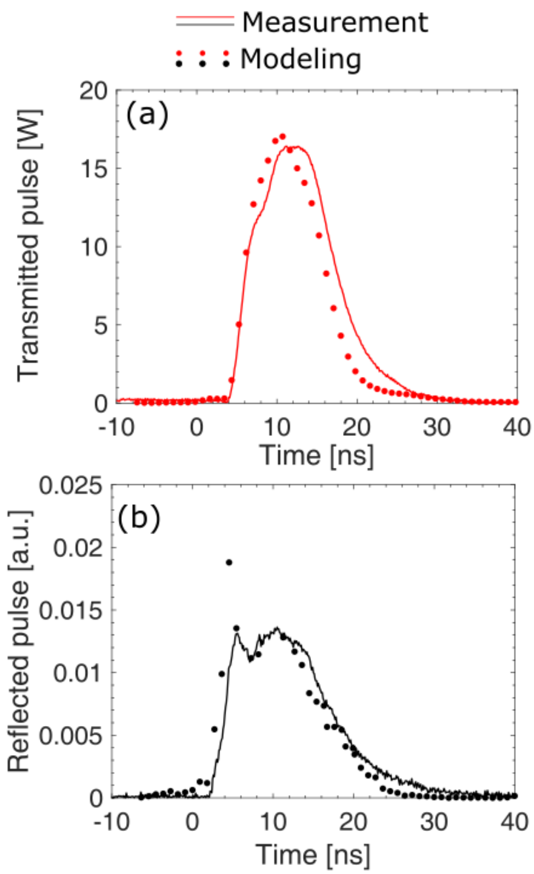

Figure 2: (a) Transmitted and (b) reflected waveforms measured in the experiment showing a good agreement with the full-wave model, for a forward power of 250 kW.

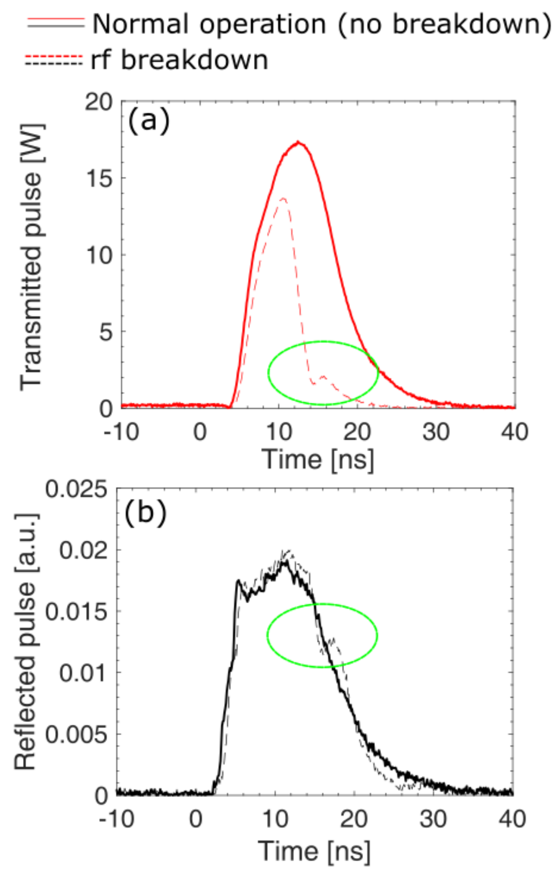

Figure 3: (a) Transmitted and (b) reflected waveforms measured in the high gradient test setup in the presence of a breakdown (dashed lines) compared to the normal operating conditions where there is no breakdowns (solid lines) for a forward power of 250 kW.

The high-power experimental setup is shown in Figure 1(a) with a 110 GHz gyrotron producing high power pulses that are transported to the accelerating structure with a free-space Gaussian beam. The pulse length of the gyrotron is ~3 µs which will result in excessive pulse surface heating and therefore requires shortening.

To shorten the pulse, we have built a laser-triggerd rf switch which uses a single silicon wafer. The wafer is excited by a high energy 532 nm nanosecond laser pulse. Absorbed photons increase the Si conductivity until it becomes an effective reflector at 110 GHz. The shortened high-power pulse has full-width half-maximum (FWHM) pulse length of about 10 ns. The structure alignment to the high-power beam is carried out by optimizing the transmitted and reflected signals to match the expected values. Moreover, we adjusted the temperature of the accelerator structure to tune its resonance frequency in order to match that of the gyrotron. Here we have used a clamp-on blocks that are connected to a chiller to fix the temperature of the accelerator structure at 3 °C. In order to characterize high gradient performance of the cavity, we have measured the rf signals, consisting of the forward power coupled to the structure, reflected power, transmitted power, as well as the dark current using fast mm- wave diodes and a current monitor (Faraday cup), respectively.

An example of the high-power forward pulse at about 250 kW is shown in Figure 2(b). Due to the short pulse length and the long fill time of cavity, the accelerating gradient excited by the 10 ns pulses reached only 150 MV/m with 250 kW peak forward power. In contrast, the expected gradient for a much longer pulse would reach a steady state value of about 200 MV/m. However, here the peak pulsed heating is less than 2 °C. The transmitted and the reflected waveforms measured through the fast diodes are shown in Figure 2. The modeled time domain response of the accelerating structure is also shown utilizing the measured pulse after the switch to drive the cavity. The full S-parameters as measured from cold test are used to calculate the fields, and the rf signals as a function of time for the given forward pulse. The FWHM tends to increase with increasing forward power as the microwave contributes to the excited electron population in the Si wafer rendering it more conductive. We have also noticed that consistent reflections of the rf power to gyrotron caused it to detune its frequency.

We have also observed rf breakdowns when operating at such high gradients. An example of a breakdown event is depicted in Figure 3, where the transmitted pulse is clipped, and reflected signals features a sudden peak in comparison

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to the normal operation where there is no breakdowns. We have also observed dark currents when operating at higher gradients. Further analysis of the rf signals and field-emitted currents is needed to understand the breakdown probability in this regime.

CONCLUSION

We started high gradient testing of a single-cell accelerating structures at 110 GHz using a gyrotron as the rf power source. We have demonstrated good coupling of power into the accelerating structure achieving at least 150 MV/m of accelerating gradient at 10 ns pulse length. Current efforts are directed at achieving the highest possible gradient through increasing the gyrotron power, utilizing longer pulses from a GaAs switch that produces >30 ns pulses, as well as measurement of corresponding the rf breakdown rates.

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