VACUUM BREAKDOWN AT 110 GHz

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Abstract

A 1.5 MW, 110 GHz gyrotron is used to produce a linearly polarized quasioptical beam in 3 µs pulses. The beam is concentrated in vacuum to produce strong electric fields on the surfaces of dielectric and metallic samples, which are being tested for breakdown threshold at high fields. Dielectrics are tested in the forms of both windows, with electric fields parallel to the surface, and sub-wavelength dielectric rod waveguides, with electric fields perpendicular to the surface. Currently, visible light emission, absorbed/scattered microwave power, and vacuum pressure diagnostics are used to detect discharges on dielectric surfaces. Future experiments will include dark current diagnostics for direct detection of electrons. Dielectrics to be tested include crystal quartz, fused quartz, sapphire, high resistivity float-zone silicon, and alumina. Metallic accelerator structures will also be tested in collaboration with SLAC. These tests will require shortening of the microwave pulse length to the nanosecond scale.

INTRODUCTION

Research has begun to test the feasibility of RF linear accelerators operating at W-band frequencies and above (>100 GHz). Experiments have been performed at SLAC to test metallic wakefield structures in which W-band and higher frequency fields are excited [1,2]. At MIT, we are beginning to experimentally test breakdown limits of materials and cavities subject to intense W-band RF, in high vacuum conditions (10^{-8} Torr). A 1.5 MW, 110 GHz gyrotron is used to power the experiments with 3 µs RF pulses. Ongoing experiments are testing multipactor breakdown thresholds of various dielectric materials. Future experiments will test breakdown thresholds of metallic cavities.

EXPERIMENT DESIGN

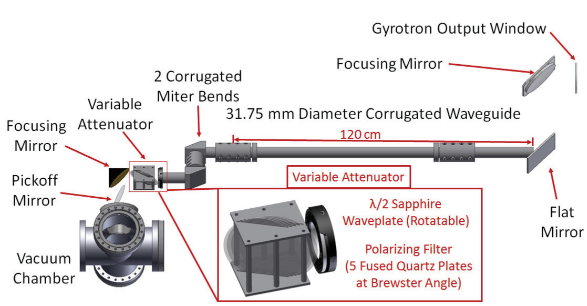

Figure 1: Experimental Apparatus

The overall configuration of the experiment is laid out in Fig. 1. The 110 GHz, 1.5 MW gyrotron outputs a linearly polarized, gaussian beam. The beam is focused into a length of 31.75 mm diameter corrugated waveguide. The output from the waveguide (a 98% gaussian beam) is fed through a variable attenuator, then focused into a vacuum chamber, where structures under test are placed. Two structures have been designed to be installed in the vacuum chamber for testing dielectric materials. They are described in the following subsections.

Parallel E Configuration

To test multipactor breakdown thresholds with RF E-fields parallel to the surface of dielectric samples, a Fabry-Pérot cavity was constructed. The cavity is formed between a dielectric mirror and a metal mirror. The dielectric mirror consists of multiple, optically polished, 25.4 mm diameter, dielectric wafers clamped at the edges. The end of the cavity is a 6 mm focal length spherical mirror in an optical mount that allows fine axial translation, for frequency tuning. A half-wavelength thick dielectric sample is placed at the second field maximum within the cavity. This structure is shown in Fig. 2. The RF gaussian beam is focused to a 2 mm spot size on a dielectric mirror. The electric field of the incident gaussian beam is polarized in the y direction.

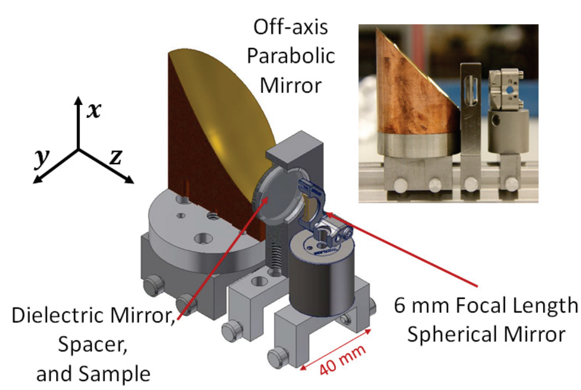

Figure 2: Section view and photograph of parallel E-field dielectric testing configuration.

The complex magnitude of the electric field in the Fabry-Pérot cavity is shown in Fig. 3. The maximum field on the surface of the sample, with 1 MW of power delivered to the dielectric mirror, is 150 MV/m. In Fig. 3, dashed lines show the locations of the boundaries in the dielectric mirror. Dotted lines show the boundary of the sample under tests, a sapphire wafer in this example. The solid curve at the right of the image indicates the location of the spherical mirror at the end of the cavity.

The Fabry-Pérot cavity has been assembled and tested at low power. The measured S_{11} is shown in Fig. 4. Coupling of 30 dB was achieved, with a 52 MHz 3 dB bandwidth and a

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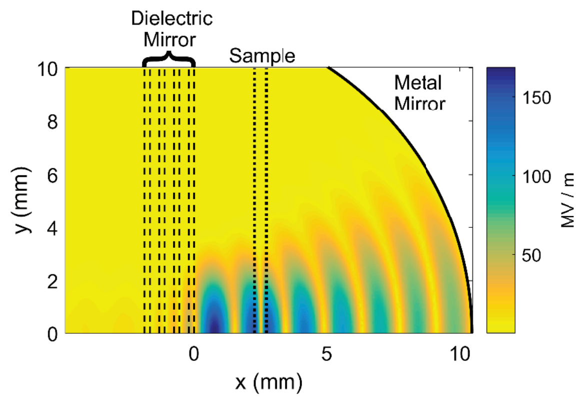

Figure 3: Complex magnitude of E-fields in the parallel E-field dielectric testing configuration. Fields strength is shown with 1 MW of RF power incident from the left.

Q_0 of 2100. These values are expected to vary with sample material. Materials currently on hand for testing in this configuration include: fused quartz, single crystal quartz, 96% alumina, 99.9% alumina, single crystal sapphire and High Resistivity Float Zone (HRFZ) Silicon.

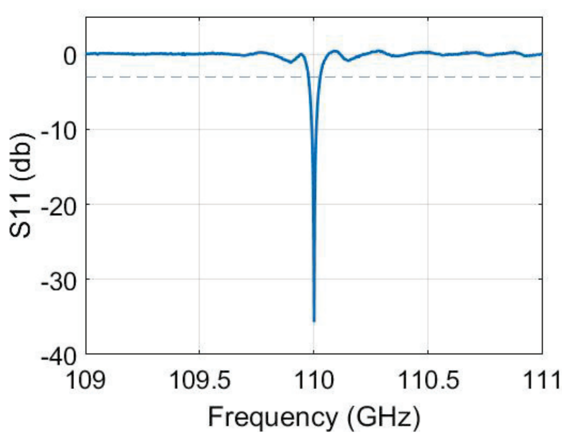

Figure 4: Measured S_{11} of the parallel E-field dielectric testing configuration.

Perpendicular E Configuration

A second configuration has been constructed to allow testing of multipactor breakdown thresholds with the RF E-field perpendicular to the surface of the sample. This design is shown in Fig. 5. In this configuration, the incoming gaussian beam is focused to a 1.5 mm spot size with a waist at the end of a dielectric rod. The dielectric rod is the sample under test. A 0.5 mm diameter rod is used to test sapphire and 99.8% alumina, and a 0.8 mm rod is used to test fused quartz. In each case, the rod is small enough to support only one confined mode at 110 GHz.

About 90% of the incident beam power couples to the fundamental mode of the dielectric rod waveguide. Alumina

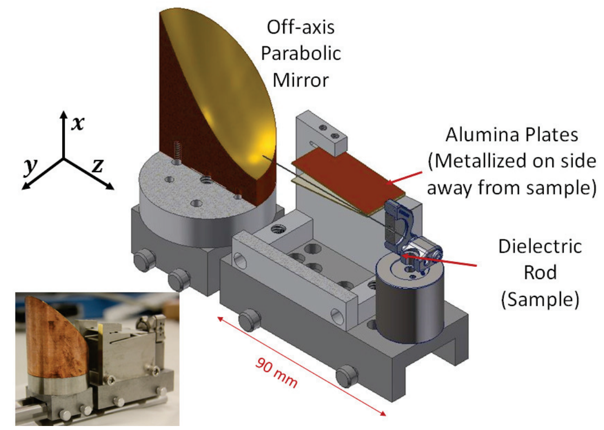

Figure 5: Section view and photograph of perpendicular E-field dielectric testing configuration.

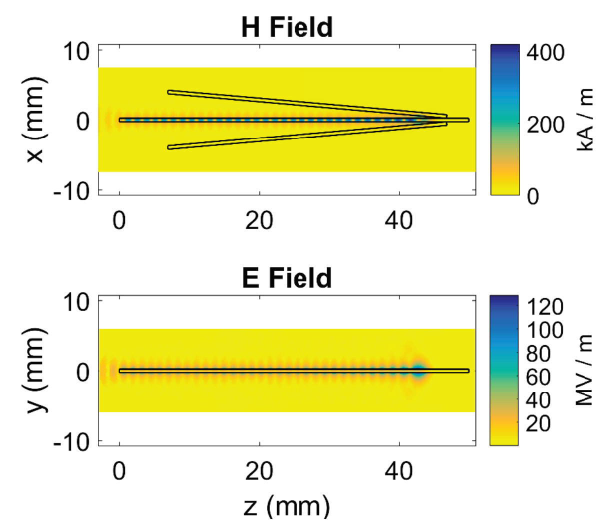

Figure 6: Complex magnitude of the H-fields and E-fields in the perpendicular E-field dielectric testing configuration. Fields strength is shown with 1 MW of RF power incident from the left.

plates (99.9%) are placed above and below the rod, in the x direction. The incoming gaussian beam is polarized in the y direction. The 40 mm square, 0.5 mm thick alumina plates interact primarily with the magnetic field of the dielectric rod waveguide mode. The back side of each alumina plate is metalized with silver. Each plate is tilted at a 5° angle, to compress the mode excited on the rod. Near the ends of the plates, the mode of the dielectric rod is cut off by the metal-backed alumina plates and reflects, creating a standing wave on the rod.

The electric field of the dielectric rod waveguide mode is polarized in the y direction. The strongest electric fields and breakdowns are expected to occur along the sides of the rod, away from the alumina plates. This creates a relatively simple geometry for studying the breakdown, and allows easy access for optical diagnostics. The complex magnitudes of the E-fields and H-fields are shown in Fig. 6. With

1 MW of incident power, the peak surface electric field on the dielectric rod, sapphire in this example, is 125 MV/m. The peak field will be similar when testing alumina and lower when testing the lower refractive index fused quartz rods.

HIGH POWER TESTING

High power testing has begun on the perpendicular E-field configuration with a 99.8% alumina rod sample. During testing, the base pressure in the vacuum chamber is kept near $1{\times}10^{-8}$ Torr. When a breakdown occurs, pressure rises to the low 10^{-7} Torr scale. Breakdowns can be detected on traces from a reverse power RF diode that is used with the pickoff mirror shown in Fig. 1. An example RF diode trace is shown in Fig. 7.

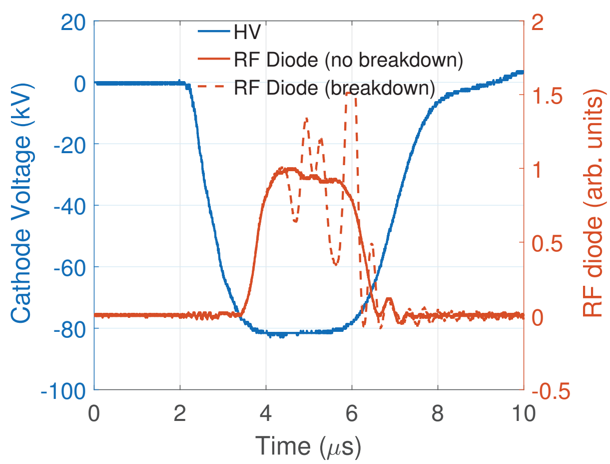

Figure 7: Reverse power traces from an RF diode with and without a breakdown. The voltage shown is the high voltage pulse on the gyrotron cathode.

Breakdowns are accompanied by a bright flash of visible light. Black and white visible light images of breakdowns are shown in Fig. 8. The top photograph shows the assembly in the vacuum chamber lit by background light. The alumina rod is seen horizontally across the image. Above and below the rod, alumina plates are placed at an angle. The bottom three images are examples of breakdowns. Near the point where the alumina plates approach the rod, and the fields are strongest, breakdown repeatably occurs at the same locations along the rod. This is consistent with the standing wave pattern on the dielectric rod seen in Fig. 6. Some of the structure of the light seen in the photographs is due to reflection from the polished surfaces of the alumina plates.

Thus far, testing on the alumina rod has only progressed up to surface fields of 25 MV/m. Breakdowns observed are due to outgassing of the sample surface. As the incident microwave power is increased, these breakdowns occur. The breakdown rate, however, drops to zero in less than 100 pulses at a fixed power level, as the surface is cleaned. The threshold intensity for multipactor breakdown has not yet been reached. Testing is ongoing.

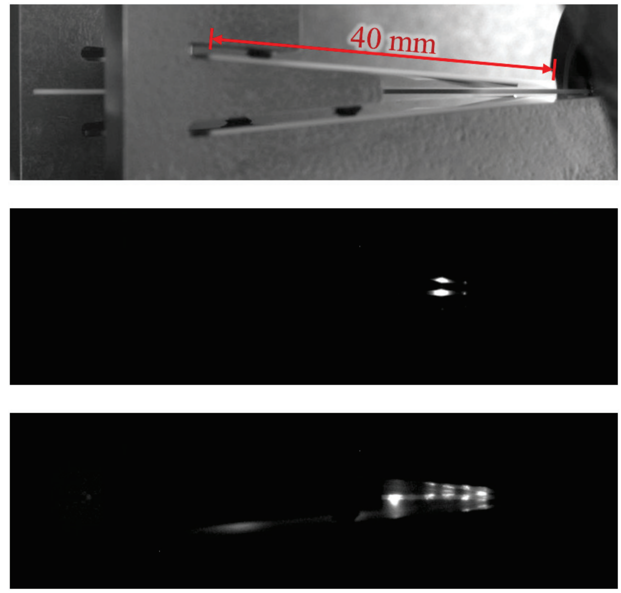

Figure 8: Black and white visible light images of breakdowns in the perpendicular E-field configuration with a 99.8% alumina rod sample. The top image shows the assembly lit by background light.

FUTURE WORK

High power testing will continue in order to measure multipactor breakdown thresholds of various dielectric materials that are of interest in future accelerator or high power microwave applications. Future experiments will include additional diagnostics, including a photodiode and a dark current probe. An all metal resonant cavity is planned to be tested in collaboration with SLAC. For this test, the RF pulse from the gyrotron will have to be shortened from microseconds to a few nanoseconds in length. This part of the experiment is still being designed.

ACKNOWLEDGMENTS

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