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A HIGH-GRADIENT TEST OF A 30 GHZ MOLYBDENUM-IRIS STRUCTURE

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Abstract

The CLIC study is actively investigating a number of different materials in an effort to find ways to increase achievable accelerating gradient. So far a series of rf tests have been made with a set of identical-geometry structures: a W-iris 30 GHz structure, a Mo-iris 30 GHz structure (with pulses as long as 16 ns) and a scaled Mo-iris X-band structure. A second Mo-iris 30 GHz structure of the same geometry has now been tested in CTF3 with pulse lengths up to 350 ns. The structure was conditioned to a gradient of 140 MV/m with a 70 ns pulse length and a breakdown rate slope of 13 MV/m per decade has been measured.

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INTRODUCTION

The CLIC study has been investigating a number of different materials through both rf and dc-spark tests as part of an effort to determine if alternative material to copper can be found which will allow higher accelerating gradients [1, 2]. An initial part of this study was to test a series of identical-geometry 30 GHz structures with Cu, W and Mo irises in CTF2, but limited to 16 ns pulse length [1], and identical-geometry but scaled 11 GHz structures with W and Mo irises at NLCTA [4]. The 30 GHz Mo-iris test has now been repeated with a new but identical structure in the new test stand at CTF3 [3], which has allowed testing to pulse lengths up to and beyond the current CLIC pulse length of 70 ns. Details of the Mo test structure (fig. 1), its design, rf parameters and fabrication method can be found in [1].

Figure 1: 30 GHz Molybdenum-iris structure.

EXPERIMENTAL SETUP

The 30 GHz RF power used to test the molybdenum-iris structure is produced in CTF3. An electron beam (typically ~ 100 MeV and ~ 5 A) is decelerated using a Power Extracting and Transfer Structure (PETS). Part of the kinetic energy of the beam is transformed into 30 GHz RF power [3]. The RF power is transported using a low loss transfer line to a contiguous building which hosts the structure test stand.

Fig. 2 shows a picture of the test stand including the most relevant diagnostics elements. The rf power coming from the PETS is feed to the accelerating structure after going through a first measurement directional coupler, a variable power splitter and a second directional coupler. The power transmitted though the structure is dissipated in a water cooled load after going though a third directional coupler.

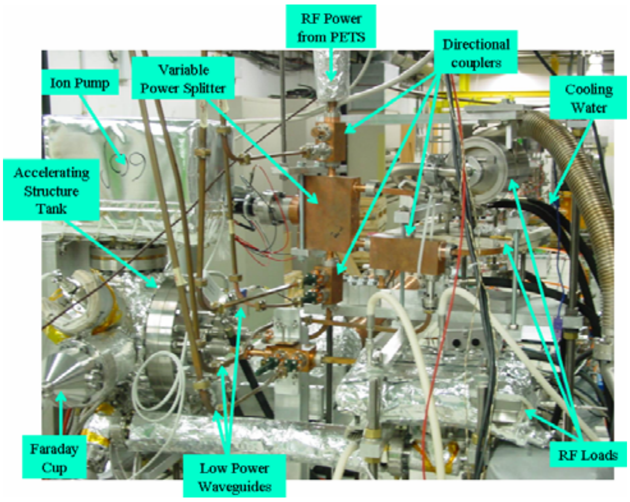

Figure 2: Structure test stand.

Signals picked up by these couplers are down-mixed and digitized. The first coupler is used to measure the power available to test the structure. The percentage of the available power used to test the structure is changed by moving the stepper motor that controls the variable power splitter and it is measured using the second coupler. This coupler is also used to measure the reflected power from the structure while the third is used to measure the transmitted power.

The other important diagnostic elements of the test stand are the Faraday cups located up and down stream of the molybdenum-iris structure. These Faraday cups collect the electron current that makes it through the irises of the structure when a breakdown occurs. That current together with the measured reflected power and the transmitted power (or lack of transmitted power) was used to determine whether or not the structure was able to hold the gradient produced by the rf pulse.

There are also several vacuum gauges distributed along the system including one in the tank that hosts the PETS and another one in the tank of the accelerating structure.

The characteristics of the rf pulses can be reproduced using the digitized signals picked up with the different directional couplers. The calibrations of the lines were performed before and after the experiments were carried out.

EXPERIMENTAL RESULTS

Conditioning of the structure

The conditioning history of the structure is shown in fig. 3. The data is plotted as a function of time rather than the number of rf pulses to include periods when rf pulsing was interrupted to allow the system to pump back down after a breakdown. This is an important distinction especially in the early stages of conditioning molybdenum when a significant amount of gas is released during breakdown. Dead times caused by external factors like maintenance and shutdowns of CTF3 have been removed from the data. The structure was conditioned with an rf repetition rate of 10 Hz.

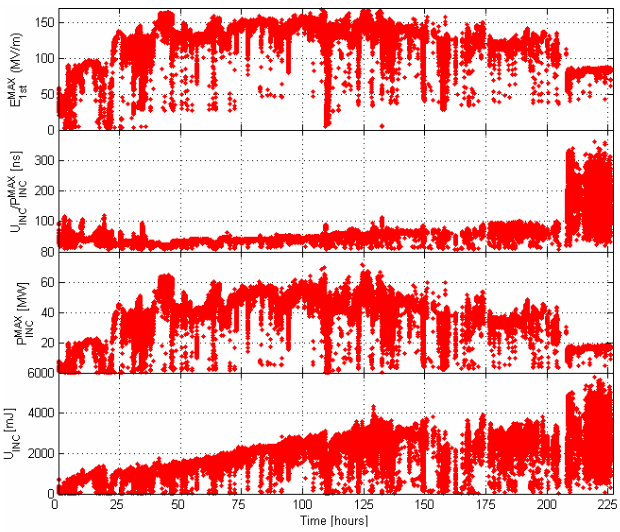

Figure 3: Conditioning history of the structure. From top to bottom are: peak accelerating gradient in the first cell, pulse length (computed as the pulse energy divided by the incident peak power), peak incident power and pulse energy.

The conditioning data shows that the energy of the pulses that the structure was able to hold increased steadily during the first 125-150 hours of conditioning, during which the pulse lengths were kept shorter than 100 ns. The structure conditioning was only interlocked on vacuum level, otherwise it was allowed to break down repeatedly. Despite this rather aggressive conditioning strategy, Mo was again observed to condition very slowly [2, 4].

The highest gradient / pulse length combination which was achieved was 140 MV/m and 70 ns. For this value, the gradient is defined as the average gradient over the 70 ns pulse length. As a consequence the value is lower than the peak gradient which is plotted in fig. 3.

The long-pulse running during the last 20 hours of the test were made to investigate the performance of the entire rf system [3]. During that time the breakdowns occurred more in the PETS and high-power transfer line than in the molybdenum-iris structure itself but the data is included for completeness.

The input power versus pulse length for the entirety of stable rf pulses observed during the conditioning process is plotted in fig. 4. The best point reached in CTF2 with the Mo structure is shown as an orange star, 93 MW and 16 ns. The three lines show plausible pulse length dependencies: constant pulse energy, constant peak power times square root pulse length and constant peak power times cube root pulse length. All three dependencies show that the most recent test achieved as high or higher performance than that performed in CTF2 [1].

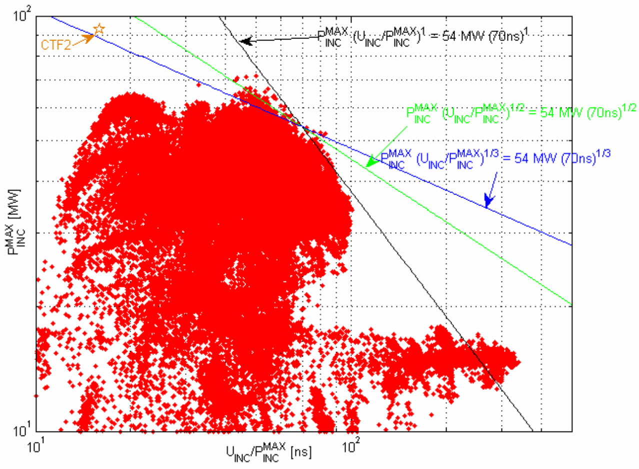

Figure 4: Peak power vs. pulse length. The red points were reached with the structure. The available power limited the achievable gradient for short pulses (<60 ns). Breakdowns in the PETS and the transmission line limited the achievable pulse length for low gradient. The region where the limit in achievable gradient was due to the molybdenum structure itself was between 60 and 100 ns.

Breakdown Rate

The gradients quoted in the previous sections are all for the conditioning limit of the structure, i.e. the typical value of gradient at which a breakdown occurs when the gradient is raised steadily from a low value. The breakdown probability at the conditioning limit is quite high but becomes lower as the gradient is lowered. The breakdown probability requirement for CLIC structures is not yet determined since it depends on the detailed machine configuration and some unknown parameters (like the transverse kick the main beam would receive when a breakdown occurs). But, since CLIC will contain about 10^5 accelerating structures, it is expected to be of the order of 10^{-6}. In order to help estimate the required gradient back-off from conditioning to stable gradient, the breakdown probability as a function of gradient for different pulse lengths has been measured near the end of the conditioning process, and the data is shown in fig. 5.

The data has been fitted with lines that give constant pulse dependence for all breakdown probabilities – which means that the slopes are inversely proportional to the gradient at a fixed breakdown probability. This same inverse proportionality fits well with data of the X-band Mo-iris structure [4].

The data show that a back-off of about 40% is needed to go from the conditioning gradient to the gradient which gives a breakdown rate of the order of 10^{-6}. The breakdown rate slope appears to be lower by a factor of two than for copper NLC structures [5]. Some possible causes for the lower slope, and consequently larger required back-off, have been identified: the slope is material dependent, the slope is material purity or preparation dependent, the low slope of the Mo iris structure is a consequence of assembly by clamping, or the slope is a consequence of the rather extreme surface state created during conditioning (discussed in the next section). A clear priority for the CLIC high gradient testing program is to determine the origin of this lower slope. A consequence may be that although higher conditioning gradients can be achieved with Mo than with Cu, at low breakdown rates the advantage from Mo may be small or non-existent.

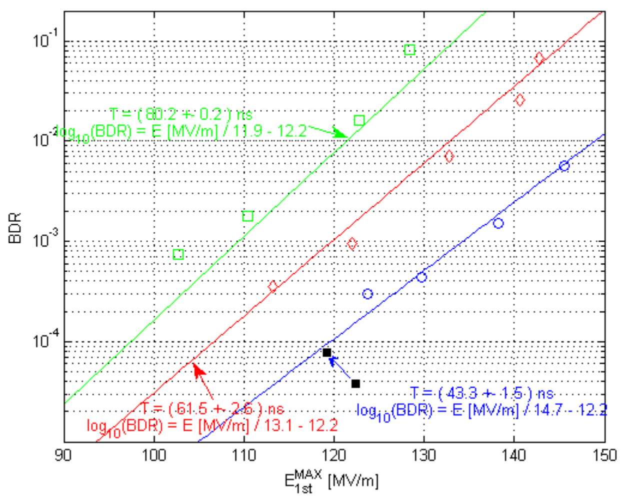

Figure 5: Breakdown probability for different pulse lengths.

Structure Inspection after Conditioning

The irises and cells were systematically inspected at the end of the experiment and scanning electron microscope (SEM) images of the first and last irises of the structure are shown in fig. 6. SEM images of previously tested Mo irises can be found in [4]. The first iris shows dramatic re-melting and a modified surface while the last iris shows re-melting but with little change to its shape.

It is not known when during the tests the surfaces were modified. The surface modification may be due to an excessively aggressive conditioning strategy (which was adopted to speed the slow conditioning of Mo), it may have occurred only during the period when the structure was conditioned and the gradient did not improve or it may only have occurred at the longest pulse lengths. These questions will be addressed in the future tests.

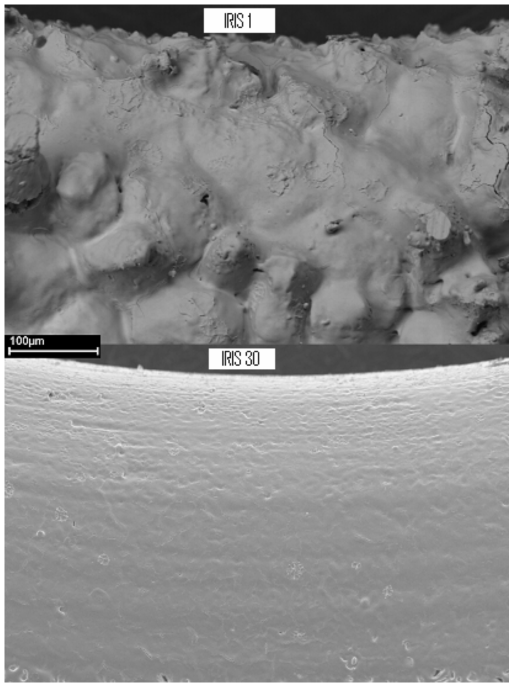

Figure 6: SEM picture of the first and last iris.

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[3] C. Achard et al., "30 GHz Power Production in CTF3", PAC 2005.

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[5] S. Döbert et al., "High Gradient Performance of NLC/GLC X-Band Accelerating Structures", PAC 2005