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ADVANCES IN X-BAND TW ACCELERATOR STRUCTURES OPERATING IN THE 100 MV/m REGIME

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Abstract

A CERN-SLAC-KEK collaboration on high gradient X-band accelerator structure development for CLIC has been ongoing for three years. The major outcome has been the demonstration of stable 100 MV/m gradient operation of a number of CLIC prototype structures. These structures were fabricated using the technology developed from 1994 to 2004 for the GLC/NLC linear collider initiative. One of the goals has been to refine the essential parameters and fabrication procedures needed to realize such a high gradient routinely. Another goal has been to develop structures with stronger dipole mode damping than those for GLC/NLC. The latter requires that the surface temperature rise during the pulse be higher, which may increase the breakdown rate. One structure with heavy damping has been RF processed and another is nearly finished. The breakdown rates of these structures were found to be higher by two orders of magnitude compared to those with equivalent acceleration mode parameters but without the damping features. This paper presents these results together with some of the earlier results from non-damped structures.

INTRODUCTION

Significant progress over the past few years has been made towards demonstrating the feasibility of one of the most crucial RF performance specification of CLIC [1] – an acceleration gradient of 100 MV/m with the nominal pulse width of 240 ns (flat top of 156 ns) and a breakdown rate of a few 10^{-7} /pulse/m. To optimize the structure parameters, results from previous high gradient experiments were used as a guide along with such parameters as 'Sc' to design a structure that should perform well at high gradients and be CLIC compatible [2].

An international collaboration on high gradient X-band accelerator structure development was started in 2007 and has been mainly lead by CERN, SLAC and KEK. CERN has mostly contributed to the RF design, targeting CLIC, while SLAC and KEK have fabricated structures and evaluated their high gradient performance. A milestone last year was the experimental confirmation of stable 100 MV/m unloaded gradient operation of prototype undamped CLIC structures [3, 4]. The focus since then has been the experimental study of structures with the heavy damping features needed for CLIC. In this paper, these results are compared to those from the undamped structures, and the possible role of pulse heating (or the associated magnetic fields) is considered to explain the performance differences. The influence of pulse heating has been observed in single cell SW cavity experiments at SLAC [5].

ACCELERATOR STRUCTURE DESIGN

The recent structures have names such as 'TD24' where "T" refers to its tapered cell design, "D" means it is heavily damped and "24" refers to the number of cells.

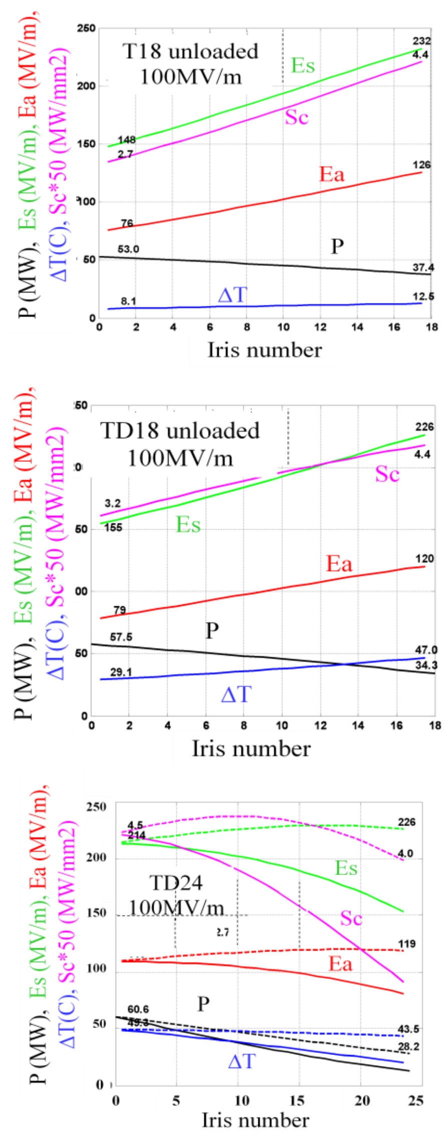

Figure 1: CLIC structure cell parameters; Top=T18, middle=TD18 and bottom=TD24.

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The cell parameters of the prototype CLIC structures T18, TD18 and TD24 are plotted in Fig. 1. The top two plots show only the unloaded parameter profiles while the bottom plot for TD24 shows both the unloaded (dashed lines) and loaded (solid lines) profile for the CLIC beam current. In each case, the average gradient is 100 MV/m (unloaded for T18 and TD18 and loaded for TD24). Plotted are the RF power (P), peak surface electric field (Es), acceleration field (Ea), peak pulse temperature rise (ΔT) and a variable considered relevant to the breakdown probably (Sc).

Table 1 also lists parameters of these structures for an unloaded gradient of 100 MV/m. Note that the pulse heating temperature rise of the TD18 downstream cells is fairly high (~ 50 degC is considered to be the threshold of pulse heating damage), although the peak temperatures occur well outside of the high field region on the irises.

Table 1: Relevant Parameters of Tested Structures.

Structure	T18	TD18	TD24
Damping	Non	Yes	Yes
a [mm]	4.0 ~ 2.7	4.0 ~ 2.7	3.3 ~ 2.5
v_g/c [%]	2.6 ~ 1.0	2.3 ~ 0.9	1.6 ~ 0.8
Ea [MV/m]	76 ~ 126	79 ~ 120	94 ~ 102
ΔT* [C]	13 ~ 19	45 ~ 73	38 ~ 34

* For a 240 ns square pulse.

PREPARATION OF TEST STRUCTURES

The techniques used to fabricate the structures are the same as developed for the GLC/NLC structures in the early 2000's [6, 7]. These include machining the parts with the combination of milling and diamond turning, diffusion bonding the cells in a hydrogen furnace and a final 650 degC vacuum bake for ten days.

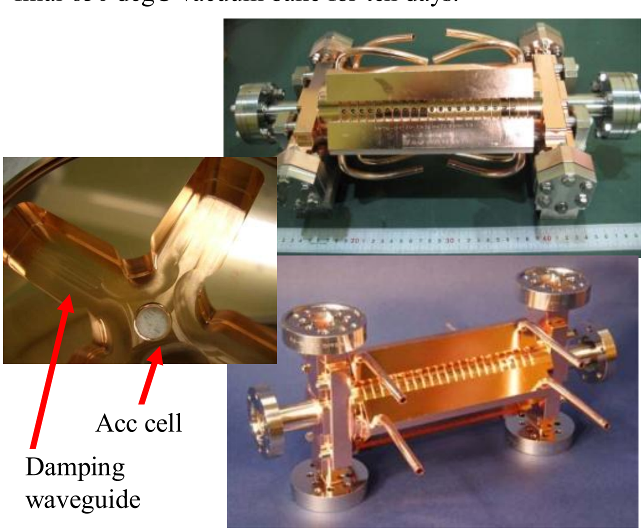

Figure 2: TD18 structures (with cell detailed view) tested at KEK (top) and SLAC (bottom). They differ only in their waveguide flange type.

Two heavily damped structures, one tested at SLAC and one being tested at KEK are shown in Fig. 2. Both were assembled at SLAC with cells provided by KEK. Before these structures, four T18's were fabricated in the same manner. Two of these have been fully processed, and one has been partially processed.

RF PROCESSING RESULTS

Processing Rate

The high gradient tests have been performed at two facilities, NLCTA at SLAC [4] and Nextef at KEK [8]. For the TD18 RF processing at KEK, a series of progressively wider pulses were used, each until a particular gradient level was reached. At SLAC, the TD18 processing began with 50 ns pulses but once 100 MV/m with 100 ns reached, the pulse was progressively widened at this gradient (with some higher gradient excursions). Fig. 3 shows the processing history in both cases. The initial processing at KEK went very slow for reasons not fully understood, but thought to be partly related to breakdown in a load that was subsequently changed.

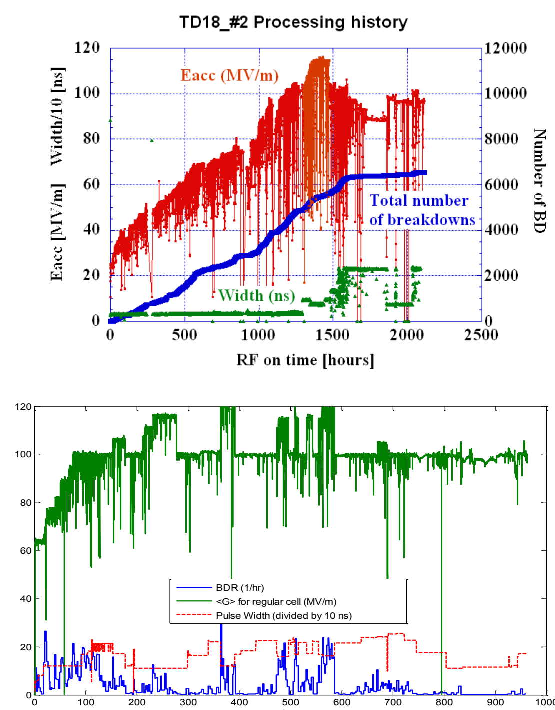

Figure 3: Processing history of the TD18 structures tested at KEK (Top) and SLAC (Bottom).

The TD18 dark current was measured at KEK and found to be stable from pulse to pulse. The level decreased by three orders of magnitude during the 200 hour to 1300 hour processing period. This was associated with a reduction of the field enhancement factor β from 70 to 40 were the β's were computed by fitting the current data with the modified Fowler-Northeim formula.

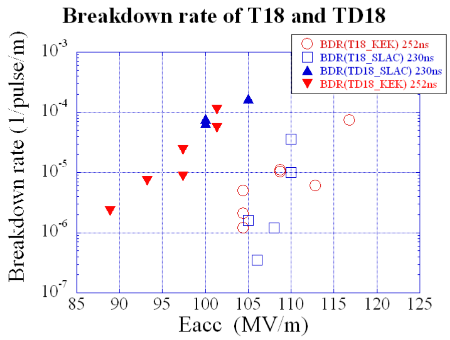

Figure 4: Breakdown rates of T18 (open symbols) and TD18 (solid ones) for pulse widths of 230-250ns. The blue symbols are SLAC results while red ones are KEK results.

Breakdown Rates

The breakdown rates versus gradient for the TD18 structures are shown in Fig. 4 together with the T18 results. Despite the difference in the processing procedure and history, the rates for the two TD18 structures are in very good agreement. The two T18 structures were processed in a more similar manner and their rates also agree fairly well.

As is clear in the figure, the TD18 breakdown rates are larger than those for the T18 structures by about two order of magnitude. The mechanism to explain this difference is not understood. We speculate that it is related to the higher pulse heating temperature rise as discussed earlier. That is, at 100MV/m it is about 73 degC for the damped structures versus 19 degC for the undamped ones, as listed in Table 1.

This conjecture is reinforced by an experiment at SLAC in which the breakdown rates were measured at a fixed gradient but two different pulsed temperature increases that were controlled by a 'pre-heating' pulse [9]. The dependence on temperature is consistent with the overall TD18 pulse heating versus breakdown rate slope shown in Fig. 5. In this plot, the T18 data fall nearly on the TD18 curve, which again suggests the differences are pulse heating related.

DISCUSSION AND IDEAS FOR FUTURE IMPROVEMENTS

The breakdown rates of the un-damped structures meet the CLIC requirement of a few 10^{-7}/pulse/m in the 95~105 MV/m gradient range. For TD18, the range is 80~85 MV/m. During the next year, a TD24 structure will be tested at both SLAC and KEK. This structure is designed to have smaller pulse heating and yet be more efficient for CLIC. If it does not meet the breakdown requirements, perhaps a different means to achieve the HOM damping can be used, such as a combination of damping and detuning as in the NLC/GLC structures or choke-mode damping.

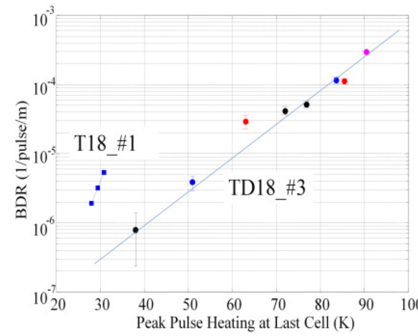

Figure 5: Breakdown rates of the T18 and TD18 structures measured at SLAC as function of the peak pulse heating temperature rise .

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