DC breakdown field measurements of Ti-15Mo alloy

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Abstract
The feasibility of the future 12GHz multi-TeV $e^+e^-$ Compact Linear Collider (CLIC) is nowadays under investigation at CERN. In order to limit this machine to an acceptable length, extremely high accelerating gradients of the order of 100MV/m are required. With such fields, RF breakdowns are likely to occur and to produce damages on the accelerating cavities. Therefore, a material capable of sustaining high electric fields and showing low damages after breakdowns is needed. Furthermore, in practical operation, breakdowns can also lead to the loss of the accelerated beam due to random kicks. Thus, the structures have also to produce a breakdown rate as low as possible, typically of the order of $10^{-6}$. 

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1. INTRODUCTION

The feasibility of the future 12GHz multi-TeV $e^+e^-$ Compact Linear Collider (CLIC) is nowadays under investigation at CERN. In order to limit this machine to an acceptable length, extremely high accelerating gradients of the order of 100MV/m are required. With such fields, RF breakdowns are likely to occur and to produce damages on the accelerating cavities. Therefore, a material capable of sustaining high electric fields and showing low damages after breakdowns is needed. Furthermore, in practical operation, breakdowns can also lead to the loss of the accelerated beam due to random kicks. Thus, the structures have also to produce a breakdown rate as low as possible, typically of the order of $10^{-6}$.

In order to test candidate materials and also to have a better understanding of the breakdown mechanism, a DC breakdown study is underway at CERN in parallel to RF testing. DC breakdown measurements are indeed much simpler than RF measurements. Different materials such as Cu, Mo, W and Ti have already been tested [1-3]. Molybdenum shows promising results with a relatively good DC saturated breakdown field (440MV/m) after conditioning (i.e. the improvement in the capability of holding high fields, obtained after repetitive sparking on the same spot), a good conditioning speed and a stable electrode gap after many sparks [2]. The saturated field of titanium is much higher (700MV/m), but on the other hand the electrodes are strongly eroded and the gap severely changes [3]. The goal of testing a Ti-Mo alloy was thus to see if a high DC saturated field (property of Ti) with a stable electrode gap (property of Mo) could be possibly obtained.

2. EXPERIMENTAL SETUP

The Ti-15Mo alloy (UNS R58150) used in this study contains 15% of Mo in weight, and has been provided by PX Holding. The anode is a cylindrical rod, 2.4 mm in diameter, with a hemispherical rounded tip. The cathode (sample) is a 45x10mm$^2$ rectangular plane surface, 1mm in thickness. The sample has been machined by milling. The electrodes are placed in an ultra high vacuum chamber, at a typical pressure of 5x10$^{-9}$ mbar. The gap distance between the electrodes can be adjusted with a micro-positioning device, and is set typically around 15 $\mu$m. The zero distance is found by bringing the electrodes into contact and measuring short-circuit.

The anode is connected to high voltages via a 28nF capacitor which is beforehand charged with a high voltage source (up to 12kV), and the cathode is grounded. The electrodes are exposed to high voltage during $\tau=2s$, with the use of a high voltage switch placed between the capacitor and the anode. The initial electric field $E_i$ applied between the electrodes is therefore simply calculated knowing the applied voltage and the gap distance. By measuring the remaining charge on the capacitor after the exposure time $\tau$, one can determine the charge which has eventually flown through the gap due to field emission or breakdown (spark), and one can also calculate the remaining field $E_{\tau}$ between the electrodes after the exposure time.

The applied voltage is first set to a low value (500V) and is increased by 150V steps until breakdown occurs. This cycle is repeated several times in order to have conditioning of the tested spot on the sample surface. The breakdown current peak is measured with a current transformer probe connected to an oscilloscope.

A detailed presentation of the experimental setup can be found in [1].
3. RESULTS

Figure 1 shows an example of a breakdown measurement cycle. At low applied fields, $E_\tau$ is roughly equal to $E_i$, because field emission current is negligible. At higher fields, $E_\tau$ deviates from $E_i$ and rapidly saturates due to strong field emission. At the breakdown, almost all the charges accumulated in the capacitor are discharged through the gap and produce the spark, resulting in $E_\tau$ close to zero. The breakdown field $E_b$ is determined from this curve.

![Figure 1: Typical breakdown curve of Ti-15Mo electrodes (run #17 of fig. 3).]

As with pure titanium electrodes, the gap between the Ti-15Mo electrodes is severely modified after a spark. Figure 2 shows some examples of gap variation measured after a single spark.

![Figure 2: Examples of gap variation after one spark.]

The gap generally increases (due to electrode erosion), but can decrease as well. The relative gap variation can reach as far as ±100%. A decrease in the gap is probably caused by material displacement or transfer from one electrode to the other. A complete bridging of the
gap has also been observed once. Such dramatic gap instabilities diminish drastically the chances of the Ti-15Mo alloy for a possible use in CLIC structures.

Nevertheless, the conditioning of the electrodes is rather good, as shown in figure 3. Extremely high breakdown fields are obtained after roughly 50 sparks, up to 900 MV/m. This is much higher than with pure Mo electrodes, but similar to pure Ti electrodes [3].

![Fig. 3: Conditioning curve (the gap distance is controlled between each set of measurements indicated by different symbols)](image)

However, it should be noted that these measurements are difficult and the uncertainty is large due to the high instability of the gap distance. Series of five or more sparks are seldom possible without a gap distance control and repositioning of the electrodes. Indeed, when the gap increases too much after several sparks, the high voltage source is not capable of producing the voltage necessary to reach breakdown. Then the electrodes have to be repositioned. This is the reason for the different sets of measurements in figure 3. Though the gap during the first breakdown of each set is accurately known, this is not the case for the next sparks of the same set. If the gap is larger, the breakdown field will be overestimated.

Thus, the extremely high values measured for the breakdown field have to be considered with precaution, because the first result of each set is systematically lower (around 400MV/m) than the next measurements. The first results could also be lowered due to surface modification after the gap distance control (the electrodes are brought into contact to find the zero distance).

Nonetheless, the capability of the Ti-15Mo alloy to hold very high fields seems to be real, as illustrated by the breakdown rate measurement given in figure 4. For this type of measurement, the applied voltage is kept at a fixed value. The electrodes are then exposed for 2s, and it is simply observed if a breakdown has occurred or not. This “attempt” is repeated hundreds of times.
Fig. 4: Breakdown rate measurement at 750MV/m.

At a value of 750MV/m, the first six attempts lead to breakdown. After that, the situation is relatively stable with no breakdown during long periods, interrupted with some few breakdowns in a row. This general trend is also observed at different fields between 500 and 900MV/m. Breakdown occurs systematically at the first attempt, frequently until the 5th attempt, but rarely beyond the 10th attempt. Stability is then reached. One has to go up to 1000MV/m to obtain a breakdown rate of 100%.

These results should be considered by keeping in mind the previous remarks about gap instability. An increase in the gap after the first few breakdowns can not be completely excluded. We have verified that for the measurements shown in figure 4, the gap has not been modified too much after the 130 attempts (from 12 to 11.3μm). Therefore, this measurement can be reasonably accepted.

4. 4. CONCLUSION

Globally, the Ti-15Mo alloy has similar characteristics to pure titanium under DC breakdown testing. This is not very surprising, since this alloy is mainly composed of Ti. The alloy seems to hold very high fields after conditioning, but the severe gap instability caused by erosion and material transfer after sparking counterbalances seriously this quality. As for titanium, this represents a major limitation for the use of this alloy in CLIC accelerating structures.

5. 5. ACKNOWLEDGMENT

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REFERENCES