



CLIC – Note – 1052

## DC BREAKDOWN EXPERIMENTS WITH IRIIDIUM CATHODE

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### Abstract

Electrical breakdown occurring in rf accelerating structures is one of the major disruptions of the accelerated beam in CLIC. At CERN, as complements to rf facilities, DC-spark systems have been used to study breakdown properties of many candidate materials for making rf components. In this note, measurements of conditioning speed, breakdown field and field enhancement factor of iridium are presented comparing with previously tested materials. The average breakdown field after conditioning reached 238 MV/m, which places iridium next to copper. By comparison with results and properties of other metals, the low breakdown field of iridium could be explained by its face-centred-cubic crystal structure.

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## I. INTRODUCTION

In the framework of CLIC feasibility study, breakdown and related phenomena have been studied both at radio frequency (RF) test facilities and at direct current (DC) systems. The DC experimental setups named DC-Spark systems at CERN were designed to reproduce high-gradient field conditions (up to GV/m) between two electrodes, as in high power RF accelerating structures. Thanks to its simplified setup, the testing cycle of one sample at the DC systems is much faster than that of one accelerating structure in the RF facilities. By taking advantage of that fact, breakdown characterization has been performed on ten pure metals and two alloys in the DC systems. The sequence of measured breakdown fields of tested metals revealed that it does not simply follow their work functions [1]. And, it has been suggested that the crystal structure could have an influence on the breakdown field [2].

In this note, recently measured breakdown field of iridium is reported as well as its conditioning speed and field enhancement factor. Iridium is one of the candidate materials that could be used to produce 20 Kelvin cold cathode RF gun at DESY [3]. It is also a promising candidate for a wide range of applications due to its chemical stability, high melting point (2466°C), high mechanical strength, superior oxidation resistance and high electrical conductivity. Its work function (5.27 eV) is the highest among all other materials tested in the DC spark systems. However, the crystal structure of the iridium is face-centred cubic, which is anticipated to be a factor of a low breakdown field.

## II. EXPERIMENTAL SETUP

A schematic view of the DC spark setup is shown in figure 1. The cathode sample was a solid rectangular plate of iridium which was 10 mm wide, 45 mm long and 1 mm thick. The anode tip was made of copper with a hemispherical rounded head, 2 mm in diameter. Those electrodes were located in an ultra-high vacuum (UHV) chamber at typical pressure of  $2 \times 10^{-9}$  mbar. The cathode sample can be moved laterally inside the chamber in order to test several spots on its surface. The position of the tip and therefore the gap distance between two electrodes was set to 20  $\mu\text{m}$  by using a non-contact method based on capacitance measurements [4]. Field emission (FE) measurements between the electrodes were performed by closing the S3 relay and by applying positive high voltage to the anode directly from power supply. The FE current was read by an electrometer by closing S5 relay. The voltage was ramped up from 200V with a step of 25 V until the measured FE current reached  $10^{-9}$  A. From those current-voltage characteristics and the assumption that they follow Fowler-Nordheim behavior, the field enhancement factor  $\beta$  can be calculated [5]. Data of FE current were well fitted between  $10^{-11}$  and  $10^{-9}$  A for Fowler-Nordheim plotting. The local enhanced electric field at the surface was calculated as macroscopic electric field multiplied by  $\beta$ . For measurements of the breakdown field  $E_b$ , the capacitor ( $C_1 = 60$  nF) was charged with the power supply first to a low value via the relay S1, and then connected to the anode via the high current relay S2 in typically 2 seconds. The voltage was increased and the cycle was repeated until a breakdown occurred. Breakdowns were detected either by a current flow with a 500 MHz current transformer (CT) connected to a 1 GHz scope or by a vacuum burst in the chamber. Breakdowns were repetitively produced in this way in order to condition the tested spots on the electrodes surfaces. More detail about the setup can be found in [5].

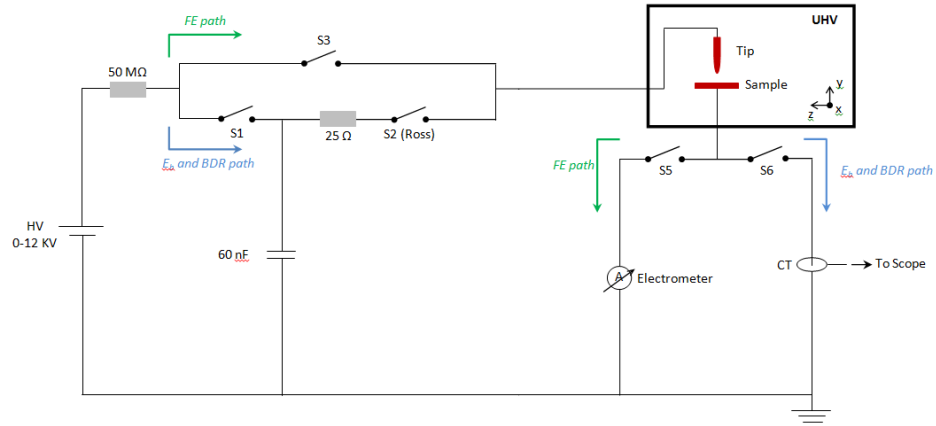


Figure 1: Schematic drawing of the DC-Spark measurement circuit.

### III. RESULTS AND DISCUSSION

One of typical current-voltage diagrams of the tested iridium cathode is shown in figure 2 both in linear I-V format and in Fowler-Nordheim (F-N) plot. The field enhancement factor  $\beta$  was calculated by fitting the linear part of F-N plot, where the measured currents were in the range of  $10^{-11}$  to  $10^{-9}$  A.

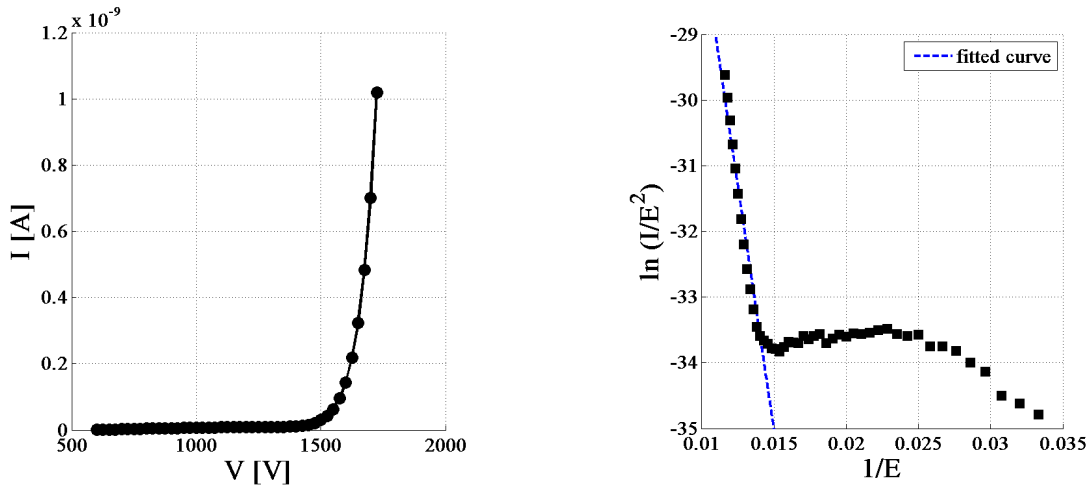


Figure 2: Typical current-voltage behavior of tested iridium.

Those field emission behaviors and the breakdown fields ( $E_b$ ) were measured alternatively. Thus, one can discuss the correlation between surface characteristics that are expressed as  $\beta$  values and successive breakdown fields. The evolutions of  $E_b$  and  $\beta$  for the first 50 breakdowns at one spot on the surface are shown at figure 3. Those two curves generally shows symmetric behaviours i.e. when the iridium surface was in high  $\beta$  conditions the breakdown fields were smaller and inversely, the breakdown fields were higher when the surface was in states of low  $\beta$ . This correlation is also seen with previously tested materials [1] and supports the conclusion that  $\beta \cdot E_b$  is generally constant and that locally enhanced breakdown field depends on the cathode material.

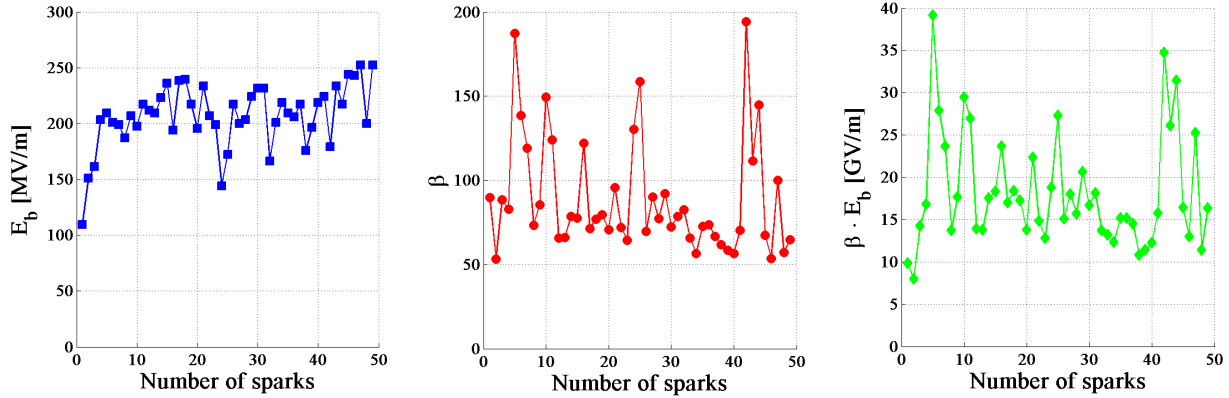


Figure 3: Evolution of the subsequent breakdown field  $E_b$  (left) and the field enhancement factor  $\beta$  (middle) during the first 50 sparks. Corresponding locally enhanced breakdown field  $\beta \cdot E_b$  is also plotted (right).

As shown in figure 4, the conditioning process and the breakdown field saturation were observed in the longer  $E_b$  evolution. The breakdown field increased rapidly during the first 15 sparks then it still rose but slowly for next 100 sparks and finally it reached the saturation field. The average of saturated breakdown field  $\bar{E}_b$  of the iridium was 238 MV/m ( $\pm 18\%$ ).

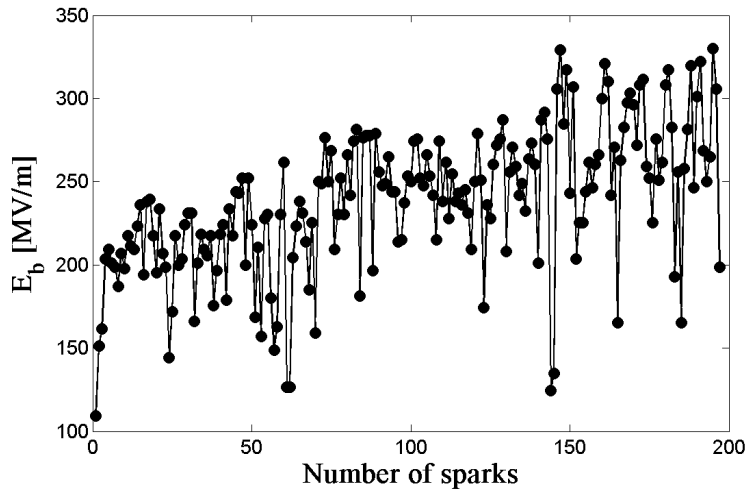


Figure 4: Evolution of subsequent breakdown field  $E_b$ .

That value is ranked at the lowest category among previously tested metals as seen in figure 5. Even though there would be many physical quantities that involve in the breakdown process (melting point, heat of fusion, thermal conductivity, electrical conductivity, vapor pressure, surface tension, work function, etc.), this result strengthens our assumption of a correlation between the crystal structure and the saturated breakdown field. Figure 5 shows that metals with face-centred cubic structures (fcc) have lower breakdown fields than metals with body-centred cubic structures or with hexagonal structures. However, the high work function of iridium may also play a role in its highest saturated field among the fcc metals. The average value of corresponding  $\beta$  was 75 ( $\pm 33\%$ ) and it is also very similar to copper, which is one of the fcc metals [6].

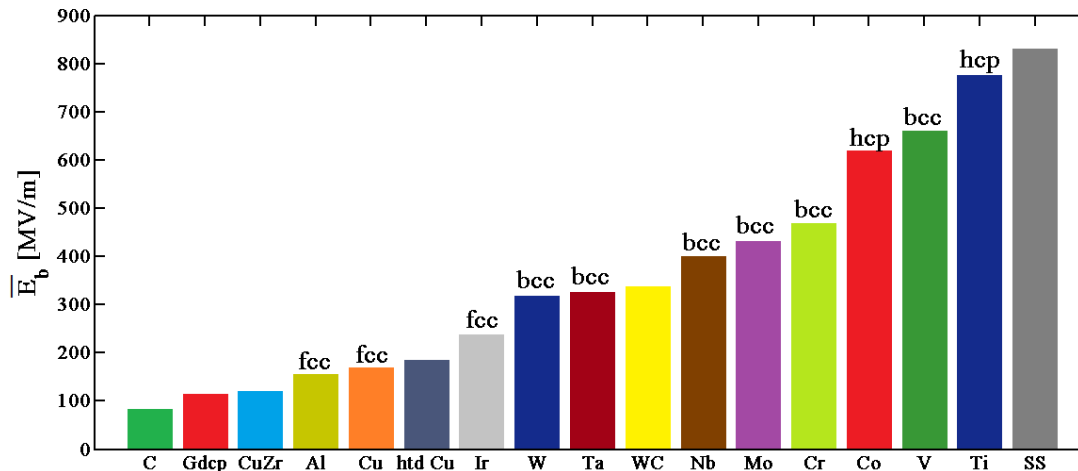


Figure 5: Average breakdown fields after conditioning of iridium shown with that of the materials previously tested in [1]. For pure metals, their crystal structures are indicated (fcc = face-centred cubic, bcc = body-centred cubic, hcp = hexagonal closest packing) on the top.

## CONCLUSION

Breakdown properties of iridium were investigated at DC-spark system at CERN. It is shown that breakdown field increases rapidly for the first 15 sparks then continues rising gradually for next 100 sparks then reaches to the saturated field. The average breakdown field for iridium is around 238 MV/m, which is the highest measured among the metals with the face-centred cubic crystal structure, but relatively low as compared with all previously tested materials. These results support our assumption of a correlation between the breakdown field of metals and its crystal structure on top of other metal aspects.

## REFERENCES

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