Experimental studies of electron emission properties under magnetic field for copper samples: effect of the surface morphology

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Introduction.

Multipactor is a resonance effect between the RF electric field and the motion of the electrons which can decrease the performance of Radio-Frequency (RF) systems functioning under vacuum [1]. It highly depends on the electron emission properties of the RF component materials. Applications using these kind of components are telecommunication satellite [2], fusion experimental reactors with Tokamak [3] or particle accelerators [4] among others. Many experimental [5] and theoretical [6]–[9] works have been conducted to study this undesirable phenomenon. The aim of these approaches is to determine the multipactor power threshold. Above this threshold, multipactor can appears and eventually damage RF systems.

In some applications concerned by the multipactor effect, RF components are submitted to DC magnetic fields. For instance, in telecommunication satellite, magnetic fields of a few tenths of Tesla produced with permanent magnets are used in circulators and isolators. In fusion reactors, rectangular copper waveguides are located under intense magnetic fields of few Tesla generated by toroidal and poloidal coils. Multipactor simulations codes are used to calculate the threshold that would trigger the electron density growth by following the electrons under the RF wave electromagnetic field [7], [8]. Multipactor modeling can also take into account an external magnetic field, which induces gyratory motions of electrons within the simulated RF structure. Studies have been made on the effect of external magnetic field on multipactor discharge [10]. However, to our knowledge, there are no multipactor simulation codes which consider the influence of DC magnetic field on the electron emission process itself.

Electron emission due to an incident electron beam is a phenomenon which lies on the surface first tens of nanometer [11]. Then the Total Electron Emission Yield (TEEY) highly depends on surface condition (topography, contaminants adsorbed) and surface treatment (drying, irradiation, erosion) [11]–[15]. The presence of a uniform DC magnetic field influences the electrons trajectories by giving them cylindrical helix trajectories depending on the direction of the magnetic field as well as on the energy of the electrons. To study the effect of the magnetic field on the TEEY, a new experimental setup has been developed. A special attention to the design of the experimental setup and to the choice of the measurement methodology has been taken to circumvent the possible artefacts that are related to the high sensitivity of incoming and emitted electrons trajectories to the DC magnetic field. The new developed experimental setup and the measurement methods are described in details in [16] as well as the validation procedure of the TEEY measurement methodology based on both experiments and modelling with SPIS code [17].

In this paper TEEY measurements on copper under a DC magnetic field perpendicular to the sample surface are presented. We have studied various surface morphologies such as laminated and polished and have observed TEEY increase as well as decrease depending on the magnetic field amplitude and the surface morphology [18]. With incident electron at first cross-over energy (E_{C1}), DC magnetic field has a greater influence on the laminate surface than the polished one (respectively TEEY decreased to 45% and 5%). Such impact of the magnetic field is discussed in regards of multipactor effect simulations codes.

TEEY measurements under uniform magnetic field.

We made TEEY measurements under magnetic fields on three samples with different surface morphology. The first sample, named N, has been chosen among a batch of twenty laminate copper samples (disc of 0.5 mm thickness and 10 mm diameter). This sample has not received any other treatment except a cleaning process common to all samples. From the same batch, we took other samples on which we applied mechanical polishing with 1 µm abrasive grains. This kind of polishing on copper creates a strain hardening layer near the surface. To clean this layer, we polished the surface by vibrations. We used this process on five samples from the batch and we finally choose the sample that presented the narrower surface features, sample J, for TEEY measurements. We also studied surface morphologies from other copper samples which don't come from the same batch as samples N & J. We studied CERN copper samples which have been polished with an electrochemical process. We made TEEY measurements on sample CERN P2.3 because it presents the narrower surface features. At each step of our different polishing treatments we measured the surface features of our samples with a surface profilometer. Table 1 summarizes the surface parameters for the three samples at their respective states when we made TEEY measurements.

Table 1. Samples description for TEEY measurements.
Rc is the quadratic mean of the surface features heights. PSm is the quadratic mean of the surface features widths

Sample	Surface treatment	Height parameter: Rc (µm)	Width parameter: PSm (µm)
N	**As Received (Laminate)**	$\mathbf{1,117 \pm 0,080}$	$\mathbf{27,606 \pm 2,874}$
J	**1µm mechanical polishing**	$\mathbf{0,231 \pm 0,011}$	$\mathbf{6,565 \pm 0,615}$
CERN P2.3	**Electro-polishing**	$\mathbf{0,156 \pm 0,012}$	$\mathbf{71,767 \pm 9,311}$

The mechanical polishing with the polishing by vibrations reduces the height of the surface features as well as their width as it can be seen by comparing the surface parameters of samples N and J from Table 1.

For the three samples, we have measured TEEY under uniform DC magnetic field perpendicular to the macroscopic surface with incident electron at the first cross-over energy (E_{c1}) (Figure 1), at the energy of the maximum TEEY (E_{max}) and at 1900 eV (energy close to the second cross-over energy, E_{c2}). In this paper we focus on only one energy but the results for the other energies can be found in [18]. We present the results at E_{c1} because the multipactor power threshold highly depends on the TEEY at E_{c1} [19]. In order to compare TEEY measurements from the three samples, we have normalised the TEEY under magnetic field with the TEEY without magnetic field (Figure 1).

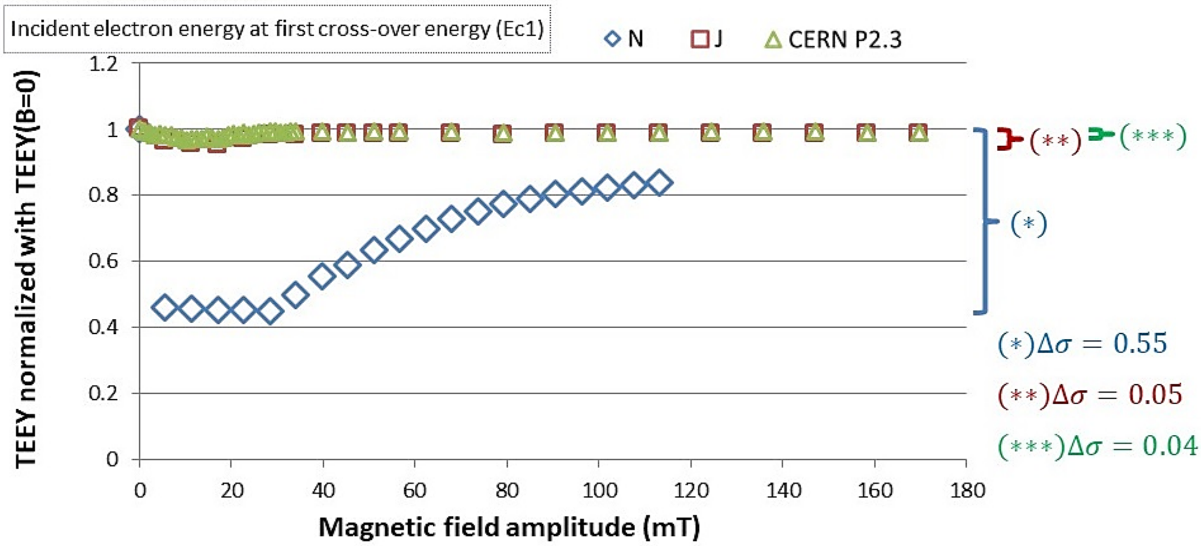

Figure 1. TEEY under magnetic field normalised with TEEY without magnetic field. Incident electron energy at first cross-over energy (E_{c1}). Magnetic field normal to the macroscopic surface of the samples. TEEY of three samples (polished with J - red square - and CERN P2.3 – green triangle - and non-polished with N – blue diamond). On top, for each sample a 2D surface profile has been plotted.

From the Figure 1, we can first observe that for the three samples and for the magnetic fields studied, the TEEY with magnetic field is lower than the TEEY without. The TEEY of sample N decreases to 45% with magnetic field amplitude while TEEY of sample J is weakly influenced by these magnetic fields (decrease to 5%) which means that the polishing treatment applied to obtain sample J has reduced the influence of magnetic fields on TEEY.

We observe for the three samples that TEEY decreases and then increases with the magnetic field amplitude increasing. The TEEY minimums are reached at 28.3 mT, 16.98 mT and 11.32 mT respectively for sample N, J and CERN P2.3. In respect of the Rc parameters from Table 1, the higher the surface features are, the higher the magnetic field amplitude has to be for emitted electrons to escape the surface.

The magnetic field has an impact on the TEEY, it modifies the trajectories of the emitted electrons and therefore their probability to be recollected by the surface (Figure 2). The impact of these magnetic field amplitudes (up to hundreds of millitesla, mT) on the electron trajectories inside the materials is negligible because the mean free paths of electrons of few electron-volts in solids is at least five orders of magnitude smaller than the electron cylindrical helix trajectory dimensions due to the magnetic field [18]. It means that an electron inside the materials would interact with material elements (electrons, nucleus, plasmons) before having his trajectory modified by the magnetic field.

Multipactor threshold depends mainly on the first cross-over energy of the RF component materials [19]. If these materials are copper with polished surfaces such as samples J or CERN P2.3, then the effect of DC magnetic field perpendicular to the surface is weak. But if the surface in not polished such as sample N, the magnetic field would have an effect on the TEEY and then on multipactor threshold. Decreasing the TEEY at first cross-over energy would increase the multipactor threshold [19] which would increase the transmitted power and the performance of the RF systems limited by the multipactor phenomenon which finally would be a positive effect for many applications [2]–[4].

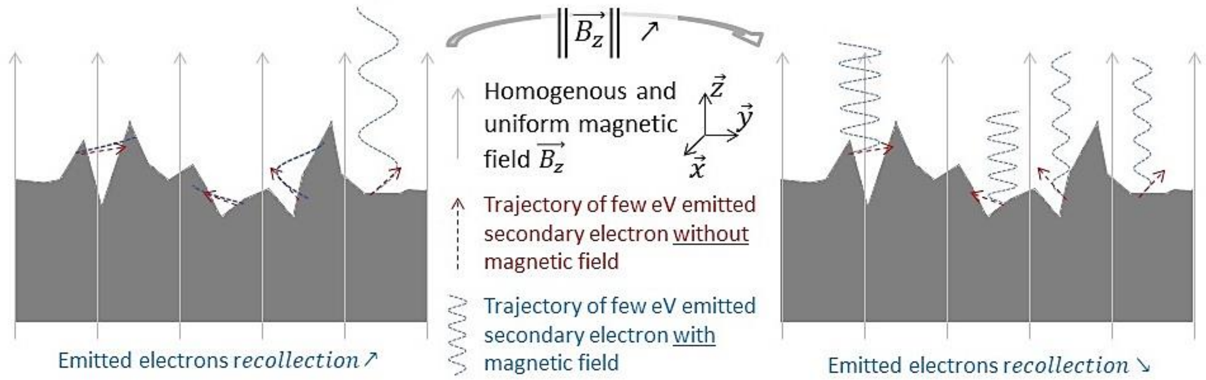

Figure 2. Schematic of our theoretical concept of trajectories of emitted secondary electrons from a surface with random features under magnetic field. The amplitude of the magnetic field increases from left to right which reduces the Larmor radius of the electrons trajectories and then decreases the probability of recollection.

Conclusion and future work.

We observe an influence of the magnetic field perpendicular to the macroscopic surface on TEEY. Its variation depends on the magnetic field amplitude, the energy of the incident electrons and the surface morphology of the sample.

Further work using both measurements and modelling work should study specific and controlled surface morphologies such as stripes or checkerboard pattern surfaces. For these surfaces the features dimensions should be controlled to analyse the link between the magnetic field and the dimensions of the surface features. Thanks to this work one could determine a TEEY model which could take into account the influence of DC magnetic field on the TEEY.

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