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Electron emission under uniform magnetic field of materials for fusion and space applications

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HIGHLIGHTS

- New experimental setup developed to measure the TEEY under DC magnetic field.
- Calibration and validation procedures based on both experiments and modeling.
- Assessment of DC magnetic field influence on the electron emission proprieties.
- Improve understanding and predictability of multipactor effect.
- Decrease of the TEEY when the magnetic field is applied.

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ABSTRACT

The power handling capacity of RF components can be limited by a resonant process known as Multipactor effect. Multipactor-induced breakdowns can be critical to microwave systems in space communication payloads or in experimental fusion devices. Multipactor simulations can be used to predict power thresholds but the results highly depend on the electron emission properties of the RF component materials. Moreover, in both space and fusion applications, the RF devices can be subjected to DC magnetic fields. This magnetic field may affect the electron emission properties. In order to improve understanding and predictability of the multipactor effect, the assessment of DC magnetic field on the electron emission properties is required; an experimental setup has been developed to measure the Total Electron Emission Yield (TEEY) under DC magnetic field. The aim of this paper is to describe the newly developed experimental setup and the associated TEEY measurements techniques. The effect of DC magnetic field on the TEEY of copper is investigated.

1. Introduction

The multipactor effect can decrease the performance of Radio-Frequency (RF) systems functioning under vacuum. Multipactor is a resonance effect between the RF electric field and the motion of the electrons [1]. It highly depends on the electron emission properties of the RF component materials. Applications using these kinds of components are telecommunication satellites [2], Tokamak-type fusion experimental reactors [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, the multipactor effect can appear and damage RF systems.

In some applications concerned by the multipactor effect, RF components are subjected 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. It 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].

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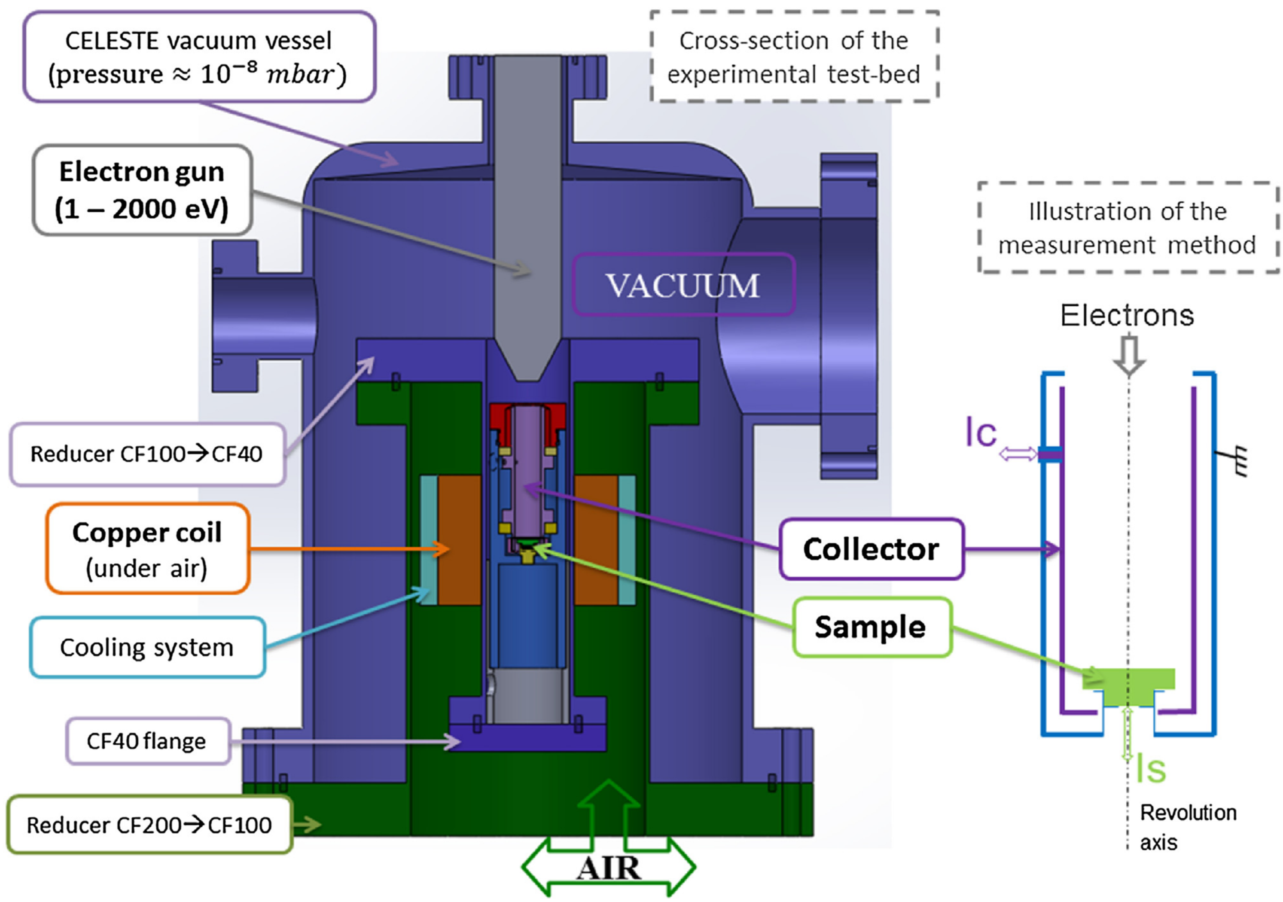

Fig. 1. Illustrations of the experimental setup. I_S is the sample current while I_C is the collector current.

However, to our knowledge, there are no multipactor simulation codes which take into account the influence of DC magnetic field on the electron emission process.

To study the effect of the magnetic on the Total Electron Emission Yield (TEEY), a new experimental setup has been developed. The measurement of the TEEY under magnetic field is challenging since the magnetic field affects the trajectory of the electrons. 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. In this paper, the new developed experimental setup and the measurement methods are described in details. Thereafter, the validation procedure of the TEEY measurement methodology based on both experiments and modeling with SPIS code [11] is given. In the last section the measured TEEY on copper under a normal DC magnetic field is presented.

2. Experimental setup

The experimental setup presented hereafter aims to measure TEEY with magnetic field. First we introduce the setup and its operation. Then we explain the validation procedure that has been made with the help of both measurements and modeling.

2.1. Description

We use an available vacuum chamber of 34 mm^3. Working with magnetic field implies to deal with a certain amount of magnetic energy. To obtain the higher magnetic field amplitude as possible while using the lowest coil current, we need to work with the smallest coil as possible.

We also need to avoid outgassing in vacuum, so the coil has been placed outside the vacuum vessel, as close as possible to the sample (see the two reducers on Fig. 1).

A 41 mm-diameter copper solenoid coil has then been directly built on the reducer CF100 → CF40 tube. A cooling system can be added to prevent overheating of the coil if higher fields are required. The 10 mm-disc sample is located in a 110 mm-high cylinder composed of eight pieces with a cylindrical collector. Both are isolated from each other and from the ground. We measure the sample current (I_S) and the collector current (I_C) independently. By connecting the sample and the collector together, the system becomes a Faraday cup, which is used to measure the incident current (I_F).

The sample surface was placed in the plane at the center of the solenoid coil in the plane perpendicular to its axis in such way that the field was normal to the surface and nearly uniform around the sample (we calculated magnetic field non-uniformity below than 1% across the whole sample). The magnetic field amplitude has been measured along the coil axis thanks to a Gaussmeter and a hall-effect sensor longitudinal probe. A 1A-current on the coil generates an 11.3 mT magnetic field at the sample surface.

The vacuum vessel can reach a pressure of 10^{-8} mbar thanks to turbomolecular pump. A 1eV–2 keV ELG 2 Kimball Physics electron gun was used to provide a quasi mono-energetic incident electron beam. The output electron gun diaphragm was placed as close as possible to the sample surface to minimize the influence of the magnetic field on the incident electrons trajectories. The electron gun can operate in continuous or pulsed mode. In this paper, all measurements presented have been made in continuous mode.

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