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Superconductivity -
Part 15: Electronic characteristic measurements - Intrinsic surface impedance of superconductor films at microwave frequencies

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

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IEC 61788-15 has been prepared by IEC technical committee 90: Superconductivity. It is an International Standard.

This second edition cancels and replaces the first edition published in 2011. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) informative Annex B, combined relative standard uncertainty in the intrinsic surface impedance is added;
b) the terms, ‘precision and accuracy’, are replaced with uncertainty;
c) results from a round robin test are added.

The text of this International Standard is based on the following documents:

Draft	Report on voting
90/550/FDIS	90/556/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 61788 series, published under the general title *Superconductivity*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

INTRODUCTION

Since the discovery of high T_C superconductors (HTS), extensive researches have been performed worldwide on electronic applications and large-scale applications with HTS filter subsystems based on $YBa_2Cu_3O_{7-\delta}$ (YBCO) having already been commercialized [1][1].

Merits of using HTS films for microwave devices such as resonators, filters, antennas, delay lines, etc., include i) microwave losses from HTS films could be extremely low and ii) no signal dispersion on transmission lines made of HTS films due to extremely low intrinsic surface resistance (R_S) [2] and frequency-independent penetration depth (λ) of HTS films, respectively.

In this regard, when it comes to designing of HTS-based microwave devices, it is important to measure the intrinsic surface impedance (Z_S) of HTS films with $Z_S = R_S + jX_S$ and $X_S = \omega\mu_0\lambda$ (here ω and μ_0 denote the angular frequency and the permeability of vacuum, respectively, X_S, the intrinsic surface reactance, and $X_S = \omega\mu_0\lambda$ is valid at temperatures not too close to the critical temperature T_C of HTS films).

Various reports have been made on measuring the R_S of HTS films at microwave frequencies with the typical R_S of HTS films as low as 1/100 to 1/50 of that of oxygen-free high conductivity copper (OFHC) at 77 K and 10 GHz. The R_S of conventional superconductors such as niobium (Nb) could be easily measured by using Nb cavities by converting the resonator quality factor (Q) to the R_S of Nb. However, such conventional measurement method could no longer be applied to HTS films grown on dielectric substrates, with which it is basically impossible to make all-HTS cavities. Instead, for measuring the R_S of HTS films, several other methods have been useful, which include microstrip resonator method [3], coplanar microstrip resonator method [4], parallel plate resonator method [5] and dielectric resonator method ([6] to [11]). Among the stated methods, the dielectric resonator method has been very useful due to the fact that the method enables to measure the microwave surface resistance in a non-invasive way and with accuracy. In 2002, the International Electrotechnical Commission (IEC) published the dielectric resonator method as a measurement standard [12].

The test method given in this document enables to measure not only the R_S but also the X_S of HTS films regardless of the film's thickness by using single sapphire resonator, which differs from the existing IEC standard (IEC 61788-7) that is limited to measure the surface resistance of superconductor films having the thicknesses of more than 3λ at the measured temperature by using two sapphire resonators. In fact, the measured surface resistances of HTS films with different thicknesses of less than 3λ mean effective values instead of intrinsic values, which cannot be used for directly comparing the microwave properties of HTS films among one another [13], [14]. Use of a single sapphire resonator as suggested in this document also enables to reduce uncertainty in the measured surface resistance that can result from using two sapphire resonators with sapphire rods of different quality.

The test method given in this document can also be applied to HTS coated conductors, HTS bulks and other superconductors having established models for the penetration depth.

This document is intended to provide an appropriate and agreeable technical base for the time being to engineers working in the fields of electronics and superconductivity technology.

The test method covered in this document has been discussed at the VAMAS (Versailles Project on Advanced Materials and Standards) TWA-16 meeting.

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[1] Numbers in square brackets refer to the Bibliography.

1 Scope

This part of IEC 61788 describes measurements of the intrinsic surface impedance (Z_S) of HTS films at microwave frequencies by a modified two-resonance mode dielectric resonator method [14], [15]. The object of measurement is to obtain the temperature dependence of the intrinsic surface impedance, Z_S, at the resonant frequency f_0.

The frequency and thickness range and the measurement resolution for the Z_S of HTS films are as follows:

- frequency: up to 40 GHz;
- film thickness: greater than 50 nm;
- measurement resolution: 0,01 mΩ at 10 GHz.

It is crucial that the Z_S data at the measured frequency, and that scaled to 10 GHz be reported for comparison, assuming the f^2 rule for the intrinsic surface resistance, R_S (f < 40 GHz), and the f rule for the intrinsic surface reactance, X_S.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-815:2024, *International Electrotechnical Vocabulary - Part 815: Superconductivity*

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