"Surface Impedance of Superconducting Radio Frequency (SRF) Materials"

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Abstract

Superconducting radio frequency (SRF) technology is widely adopted in particle accelerators. There remain many open questions, however, in developing a systematic understanding of the fundamental behavior of SRF materials, including niobium treated in different ways and various other bulk/thin film materials that are fabricated with different methods under assorted conditions. A facility that can measure the SRF properties of small samples in a range of 2~40 K temperature is needed in order to fully answer these questions. The Jefferson Lab surface impedance characterization (SIC) system has been designed to attempt to meet this requirement. It consists of a sapphire-loaded cylindrical Nb TE011 cavity at 7.4 GHz with a 50 mm diameter flat sample placed on a non-contacting end plate and uses a calorimetric technique to measure the radio frequency (RF) induced heat on the sample. Driving the resonance to a known field on this surface enables one to derive the surface resistance of a relatively small localized area. TE011 mode identification has been done at room temperature and 4 K, and has been compared with Microwave Studio® and SuperFish simulation results. The variable input and transmitted RF couplers have been characterized. RF loss mechanisms in the SIC system are under investigation. A VCO phase lock loop system has been used in both CW and pulsed mode.
Two calorimeters, with stainless steel and Cu as the thermal path material for high precision and high power versions, respectively, have been designed and commissioned for the SIC system to provide low temperature control and measurement. A power compensation method has been developed to measure the RF induced power on the sample. Simulation and experimental results show that with these two calorimeters, the whole thermal range of interest for superconducting radiofrequency (SRF) materials has been covered. The power measurement error in the interested power range is within 1.2% and 2.7% for the high precision and high power versions, respectively. Temperature distributions on the sample surface for both versions have been simulated and the accuracy of sample temperature measurements have been analysed. Both versions have the ability to accept bulk superconductors and thin film superconducting samples with a variety of substrate materials such as Al, Al2O3, Cu, MgO, Nb and Si. Tests with polycrystalline and large grain bulk Nb samples have been done at <15 mT magnetic field. Based on BCS surface impedance, least-squares fittings have been done using SuperFit2.0, a code developed by G. Ciovati and the author. Microstructure analyses and SRF measurements of large scale epitaxial MgB2 films have been reported. MgB2 films on 5 cm dia. sapphire disks were fabricated by a Hybrid Physical Chemical Vapor Deposition (HPCVD) technique. The electron-beam backscattering diffraction (EBSD) results suggest that the film is a single crystal complying with a MgB2(0001)//Al2O3(0001) epitaxial relationship. The SRF properties of different film thicknesses (200 nm and 350 nm) were evaluated using SIC system under different temperatures and applied fields at 7.4 GHz. A surface resistance of 9±2 μΩ has been observed at 2.2 K.
Based on BCS theory with moving Cooper pairs, the electron states distribution at 0K and the probability of electron occupation with finite temperature have been derived and applied to anomalous skin effect theory to obtain the surface impedance of a superconductor with moving Cooper pairs. We present the numerical results for Nb.