Spectral Domain Modeling of the Effect of Film Purity for Superconducting Slotline

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***Abstract*—A computation technique is presented to analyse the electromagnetic response of High Temperature Superconducting (HTS) film purity using a slotline. The complex conductivity of HTS films for three different material purity is modeled using Coffey-Clem (CC) unified theory. By using the surface impedance calculated by CC model, the dyadic Green's functions in Spectral Domain Method (SDM) are formulated for the slotline. The Galerkin's procedure is employed for the computation of the propagation parameters when HTS slotlines of different purities are guiding a fixed frequency microwave signal. Changes in the propagation parameters are analyzed for the variation of the film thickness at different working temperatures. The paper presents a modeling method for studying the microwave response of the HTS film purity.**

***Index Terms*—Electromagnetic propagation, Green's function methods, Transmission lines, High Temperature Superconductors.**

I. Introduction

The High Temperature Superconducting (HTS) films of different purity are manufactured using various techniques and are reported in the literature [1], [2]. Material purity of the HTS film used as the thin strip on inhomogeneous transmission lines significantly changes the complex conductivity and the propagation parameters [3]. Based on the experimental data regarding purity, YBCO thin films can be broadly classified into three types [3]. The high purity films, the medium purity films, and the low purity films are differentiated based on the phenomenological description of complex penetration depth. In this paper we present a modeling methodology to study the relationship between HTS film purity with electromagnetic wave propagation using a slotline for a wide range of temperature and strip thickness.

The modeling of HTS transmission lines without considering the vortex effects when no dc magnetic field is applied may appear straight forward [3]. But HTS films like YBCO are extreme type II materials and they will be in mixed state even at very low magnetic field values [4]. The microwave signal itself may make them in vortex state. At liquid nitrogen temperatures, the HTS films will have significant vortex activities like flux creep and flux flow [5]. For the accurate computation of conductivity of the HTS films and the propagation parameters of the slotline we need to employ a theory which takes into account the fields due to microwave signal, applied dc field and vortex generated fields [5]–[7]. Accordingly, the modeling of inhomogeneous HTS transmission lines are quite challenging. Again, the inhomogeneous structure of striplines make their field derivations and formulation of dyadic Green's functions mathematically complicated [8]–[13]. The HTS contribution of the slotline have to be properly incorporated into the dyadic Green's functions for making the HTS film purity analysis accurate [14].

The HTS microstrip line, resonator, slotline and Coplanar waveguide have been modeled and their propagation parameters have been analyzed in our earlier works [9], [10], [12]–[15]. In this work we study the impact of HTS film purity on the microwave signal propagation by incorporating flux dynamics which include creep effect, flux flow phenomenon and vortex pinning and present a computation technique to specifically analyse this film purity effect on the wave propagation. We take a slotline with HTS material of varying film purity on a substrate like sapphire and place it in an applied dc magnetic field. For the sake of simplicity, we neglect the anisotropic natures of the permittivity of the substrate and the conductivity of the HTS material.

II. Modeling Technique

In Spectral Domain Method (SDM), by matching the electromagnetic boundary conditions of the different interfaces of the slotline, we obtain the fourier transformed coupled equation as $[\tilde{\mathbf{Y}}][\tilde{\mathbf{E}}] = [\tilde{\mathbf{J}}]$ where $\tilde{Y}$'s are the admittance elements, $\tilde{E}$'s are the unknown electric fields and $\tilde{J}$'s are the strip currents. The detailed discussion of the method is available elsewhere [8]. To incorporate the HTS contribution, we expand the unknown electric field as $\tilde{E} = \tilde{E}^e + Z_s\tilde{J}$ where $\tilde{E}^e$ is the Electric field distribution at the interface excluding the region of the strip, Z_s is the surface impedance due to HTS material and $\tilde{J}$ represent the strip current. Accordingly, our algebraic equation will be modified as $[\tilde{\mathbf{Y}}'][\tilde{\mathbf{E}}] = [\tilde{\mathbf{J}}]$ where $\tilde{Y}'$'s are the modified admittance Green's functions [10]. The propagation parameters are computed using Galerkin procedure.

The Coffey-Clem (CC) model gives a self-consistently determined penetration depth $\tilde{\lambda}(\omega, B, T)$ in terms of field dependent penetration depth λ, normal fluid skin depth δ_{nf} and the complex effective skin depth $\tilde{\delta}_{\mathrm{vc}}$ [5] as

$$\tilde{\lambda}(\omega, B, T) = \left(\frac{\lambda^2 - (\mathrm{i}/2)\tilde{\delta}_{\mathrm{vc}}^2}{1 + 2\mathrm{i}\lambda^2\delta_{\mathrm{nf}}^{-2}} \right)^{1/2} \tag{1}$$

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