INFLUENCE OF SUPERCONDUCTOR ON PROPERTIES OF MICROSTRIP LINES LAID ON SEMICONDUCTOR SUBSTRATE.

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INTRODUCTION The starting discovery of superconductor with transition temperature in the 90 K range has generated an intensive research effort in the world. Superconductors can evidently produce microwave circuits with lower conductor loss, lower noise and wider bandwith. Furthermore, for a transmission line in the microwave frequency range, other parameters such as characteristic impedance Zc and slow wave factor (λ_0/λ_g) can be modified if the kinetic inductance (Lk) of the superconducting strip is much larger than the magnetic inductance (Lm) of the line. These different physical phenomena can be usefull for both analogical microwave devices (electrooptic wave guide modulator, travelling wave field effect transistor....) and gigabit rate speed logic circuits. The goal of our study is to show the combined influence of the superconductor nature of the strip and of the ground plane on propagation characteristics of a simple microstrip line laid on semiconducting layer. It has been shown that the penetration depth of superconductor must be greater than the thickness of the superconducting film, in order to achieve very slow phase velocities [1]. Some studies on this subject have been published based on approached analytical model in order to obtain the propagation characteristics of the microstrip line [2] where the thickness is much smaller than skin depth and penetration depth. So properties of a thin superconductor can be accounted for by a complex conductivity. Recently, researches based on more rigourous analysis have been published which only take into account the existence of a superconductor strip. In these studies, the very thin superconducting film is modelized by using a complex resistive boundary condition associated with the classical Spectral Domain Approach [3]. In this communication, we propose to show the behaviour of the propagation characteritics of a microstrip line laid on GaAs semi-insulating substrate with superconducting strip and ground plane. For this study, superconducting layers are taking into account, in a phenomenological point of view, by means of a complex conductivity : $\sigma_1 - j\,\sigma_2$, where σ_1 is the normal conductivity and σ_2 is for the superconducting electrons. Our simulation is performed for two typical superconducting materials, which exhibit very different temperature behaviours of σ_1 and σ_2, one with a low critical temperature T_c, the other one with a high critical temperature. For the second case, our σ_1 and σ_2 are experimental values [4], and shown on figure 2.

MODELIZATION In order to simulate that kind of transmission line, we use a numerical formulation which is an extension of the well known Spectral Domain Approach [3]. In this method, field components of the hybrid guided waves are written in terms $\widetilde{Ez}(\alpha,y)$ and $\widetilde{Hz}(\alpha,y)$ which are the Fourier transforms with respect to x of the axial field components Ez(x,y) and Hz(x,y). Transverse electromagnetic fields are obtained by conventionnal formulation. After some mathematical manipulations, we can express, in a coupled set of integral equations, the Fourier transforms of current densities: $\widetilde{Jx}(\alpha,y)$, $\widetilde{Jz}(\alpha,y)$, on the strip for the geometry shown in figure 1-c, and the Fourier transforms of electric field components in the plane but external to the strip, as:

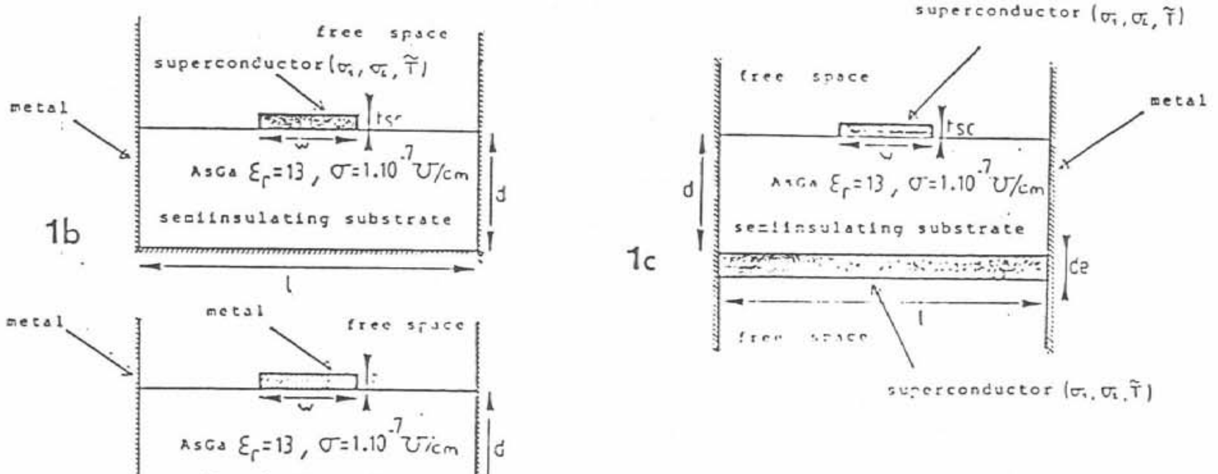
$$\widetilde{E}_x(\text{strip}) + Z.\widetilde{J}_x(\text{strip}) = \widetilde{Z}_{xx}.\widetilde{J}_x(\text{strip}) + \widetilde{Z}_{xz}.\widetilde{J}_z(\text{strip})$$
$$\widetilde{E}_z(\text{strip}) + Z.\widetilde{J}_z(\text{strip}) = \widetilde{Z}_{zx}.\widetilde{J}_x(\text{strip}) + \widetilde{Z}_{zz}.\widetilde{J}_z(\text{strip})$$

Where $\widetilde{Z}_{xx}$, $\widetilde{Z}_{xz}$, $\widetilde{Z}_{zx}$, $\widetilde{Z}_{zz}$ are Green's function elements depending on complex propagation constant and frequency. Z expresses the presence of superconducting strip by using the impedance boundary condition. For the studied structure, in the case of a superconductor thin thickness strip tsc, small as compared to the penetration depth of the superconductor and the skin depth, the surface impedance is complex and is given by: $Z = 1/[tsc \cdot (\sigma_1 - j\,\sigma_2)]$
On the other hand, for the superconducting ground plane, figure 1-c, we consider a layer with a complex conductivity $(\sigma_1 - j\,\sigma_2)$.
NUMERICAL RESULTS When superconducting strip is taken into account, the use of the complex boundary condition is an approximation in electromagnetic theory; so such modelisation must be tested, particulary when narrow strip are considered. In this mind, for a classical metallic gold strip structure, we have compared the modified S.D.A. results with finite element ones [5]. The figure 3 exhibits that the modelization of the boundary condition of conductive strip by the surface impedance give results as more rigourous that finite element analysis, including 10 μ width strip. After that verification, we can now present the evolution of the attenuation and of the slow wave factor versus the reduced temperature $\widetilde{T} = T/T_c$ for the two kinds of superconductors, exhibiting different behaviour of σ_1 and σ_2. The figure 4 shows these evolutions for several sets of geometrical cross sectionnal microstrip lines. Two kinds of structures have been simulated, one with a perfect metallic ground plane and the other one, with a superconducting ground plane. Naturally, the physical propagation phenomena associated with that kind transmission line are known. In fact, a lot of works have explained the reasons of the propagated slow wave mode. But our aim is to quantify more exactly, in an enginering purpose, these propagation phenomena in order to take into account the real nature of the hybrid mode, the real geometry of propagation structure. The observation of the curves exhibits that, for a usual superconductor (low critical temperature), we obtain, naturally for a small superconducting strip with a perfect ground plane, the hightest slow wave factor and the lowest attenuation while a superconducting ground plane reduces the slow wave factor. For the superconductor with high critical temperature,at the vicinity of the critical temperature, the presence of a superconducting ground plane makes sensitive the value of the slow wave factor for small variation near the high T_c critical temperature. We can note also that without superconducting ground plane, the slow wave factor falls down at the vicinity of the high T_c critical temperature.

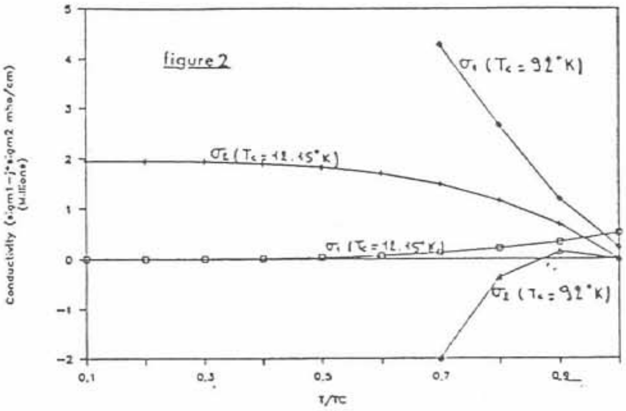
CONCLUSION We have shown in this communication the influence of superconducting strip and ground plane for two kind of superconductors on the propagation characteristics, one with low critical temperature and the other one with high T_c critical temperature.Naturally, the validity of these results are conditionned by the simplified modelization of the superconductors that we used and the above results are subjects to the usual restrictions of the application of the surface impedance boundary condition . Meanwhile, the different behaviour obtained for these two supraconductors exhibits the necessity to get more experimental data on the high T_c superconductor in the microwave frequency range, because the high value of the critical temperature does not systematically give the desired evolutions of σ_1 and σ_2 versus the reduced temperature in order to obtain low losses and a high slow wave factor in the microwave frequency range.

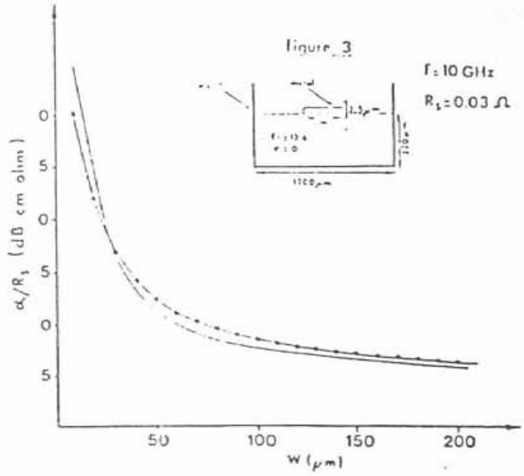
REFERENCE

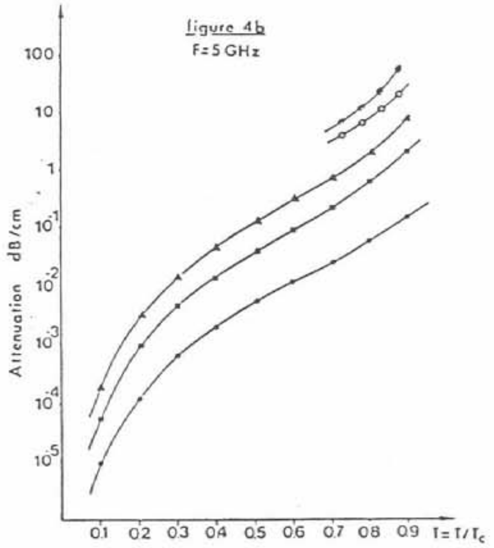
[1] J.M. POND, J.H. CLAASSEN, W.L. CARTER : " Measurements and modeling of kinetic inductance microstrip delay lines " IEEE Trans. Microwave Theory Tech., vol MTT35, pp. 1256 – 1262, december 1987. [2] R.L. KAUTZ : "Picosecond pulses on superconducting striplines" J.Appl.Physic,vol. 49, pp 308 – 314, january 1978. [3] J.M. POND, C.M. KROWNE, W.L. CARTER : " On the application of complex resistive boundary conditions to model transmission lines consisting of very thin superconductors " IEEE Trans. Microwave Theory Tech.,vol MTT35,pp. 181 – 189, january 1989 [4] L. COHEN, I.R. GRAY, A.PORCH, J.R. WALDRAM : " Surface impedance measurements of superconducting $YBA_2Cu_3O_{6+x}$" J.Phys.F: Met Phys. 17 (1987) L179 – L183. [5] GaAs Mesfet Circuit Design ARTECH HOUSE (1988) pp 483

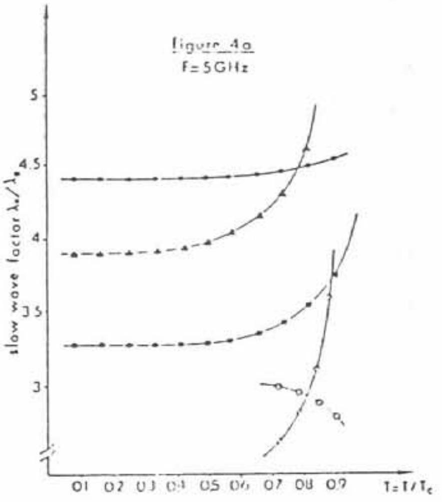


FIGURES 1









●—●: for the figure 1-b with a low critical temperature T_c=12.15°K (niobum nitride) at F=5GHz, w=10μm, d=100μm, tsc=150Å, l=100.w

▲—▲: for the figure 1-c with a low critical temperature T_c=12.15°K (niobum nitride) at F=5GHz, w=10μm, d=100μm, tsc=150Å, l=100.w, de=400Å

■—■: for the figure 1-c with a low critical temperature T_c=12.15°K (niobum nitride) at F=5GHz, w=100μm, d=100μm, tsc=150Å, l=100.w, de=400Å

○—○: for the figure 1-b with a high critical temperature T_c=92°K ($YBa_2Cu_3O_{6+x}$) at F=5GHz, w=10μm, d=100μm, tsc=150Å, l=100.w

◇—◇: for the figure 1-c with a high critical temperature T_c=92°K ($YBa_2Cu_3O_{6+x}$) at F=5GHz, w=10μm, d=100μm, tsc=150Å, l=100.w, de=400Å