FABRICATION OF A THIN FILM EXPONENTIAL TRANSMISSION LINES BY SUPERCONDUCTING MATERIALS FOR HIGH SPEED COMMUNICATION DEVICES

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ABSTRACT

This paper presents both experimental investigations and modelled results on high temperature superconductive exponential microstrip lines. High-*Tc* ceramic (YBCO) superconducting exponential microstrip lines have been fabricated by sputtering technique, conditions and properties for preparation of exponential microstrip lines are described. The behaviour of superconducting microstrip lines approaches that of normal state microstrip line as the strip and ground plane thickness and the substrate thickness become large compared to penetration depth. In order to verify the validity of the implemented macro model for the superconducting exponential microstrip line, a microstrip line structure connected to an inductor having one end grounded with an *AC* current source used to excite the circuit is simulated. Furthermore we have investigated how a pulse propagates on the superconducting exponential microstrip line and how the circuit parameters of transmission lines affect the propagation characteristic of the line. Simulation results show that the high-*Tc* exponential transmission lines are more promising for interconnections than the conventional transmission lines by virtue of their lower attenuation and less dispersion, even if dielectric loss of substrate is taken into consideration. This works forms a general basis for the investigation of the exponential microstrip line for use in high speed detection circuit.

I. INTRODUCTION

The use of superconducting materials in transmission lines and electronic devices has been watched closely by the need of bulky, heavy, and expensive cryogenic refrigerators. However recent advances in high temperature ceramic superconductors such as YBCO may make these materials ideal for operation as satellite components or in deep spacecraft networks[5]. Future space exploration and telecommunication techniques will require autonomous satellite systems with the state of art technology. One technology, which may satisfy these requirements, is superconductivity. Superconductors operated in the gigahertz range offer low-loss, low dispersion, ultra compact geometries, and novel effects such as kinetic inductance.

Since the discovery of high-*Tc* superconducting materials, superconducting devices have been studied with keen interests because of possibilities of applications to high performance electronic devices, circuits and systems. high-*Tc* superconductor signal transmission lines are expected to be a candidate of the most promising applications for improving computer packaging performance [2][3].

For microwave transmission lines, the largest advantage offered by superconducting technology is the ability to transmit signals with low joule losses. In normal conductors, such as copper, reducing the physical dimensions of a transmission line will result increased current densities with accompanying excessive loss and dispersion. Only with superconductors it is practical to greatly reduce the dimensions of transmission line and realise extreme devices miniaturisation[1]. Currently, thin-film superconducting exponential transmission lines offer largest electrical delays available in small package. This practice may result in potentially significant benefits in the performance per unit volume of device, not to mention the economic gains, hence complete modules or systems could be integrated onto a single substrate.

The fact that a superconductor has infinite conductance immediately presents two very important applications, namely, the transfer of radio frequency signals and electrical power with negligible losses[3]. The negligible loss in superconductors introduces the possibility of realising structures able to transfer high-frequency pulses with little or no distortion. This opens a wide range of applications, such as, the realisation of high-speed digital system. At present, the only obstacle in the widespread use of superconductors in electrical devices is the very

low temperature at which superconductivity occurs. In this paper we have produced material called high-*Tc* superconductors that currently operate at room temperature of about 100^oK[4].
Of the various transmission line structures used in the transfer of microwave signals the microstrip line is probably the most popular because of its simple geometry, small size and the ease with which it can be integrated, all very desirable properties in modern technology. In order to be able to design microstrip lines having the desired electrical properties in a given applications, certain electrical parameters, namely the distributed resistance, inductance, conductance and capacitance, must be known[5]. The use of superconductors in constructing exponential microstrip lines results in a negligible small distributed resistance, which is the main cause of losses when using normal conductors.
The transformation of the impedance of the exponential microstrip line form Z_1 to Z_2 basically requires the width of the strip to change from w_1 to w_2. However, an abrupt change in impedance at the plane discontinuity that is usually detrimental to the functioning of the circuit. A gradual, continuous change either linear or exponential, in the impedance minimises the formation of the reflected waves.

2. THIN FILM EXPONENTIAL MICROSTRIP LINES

In a thin-film superconducting microstrip lines, the kinetic inductance can be adjusted by changing the penetration depth of the magnetic field into the conductor. Therefore, if the kinetic inductance is dominant, variable phase velocities are obtainable. It has been shown that for certain extreme geometries inductance criteria can be met. This occurs when majority of the magnetic energy is stored in the superconductor rather than in the dielectric. Such is the case if the dielectric and conducting layers are thin compared with the London penetration depth. In the superconductor, this penetration is referred to as the London penetration depth, and is a function of temperature.

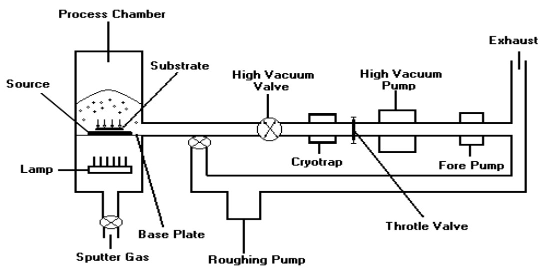

Figure1. *Sputtering equipment for preparation of thin film superconducting microstrips*

The London theory, relating the microscopic electric and magnetic fields through the London equations, assumes that the number of superconducting electrons n^*_{sc} varies continuously from zero at the critical temperature *Tc* to a limiting order of n, the number of valence electrons, at $T \approx 0^oK$. It gives only the local relations between the field and currents, neglecting the presence of normal electrons, and is valid only for week fields. In local electrodynamics, the coherence length $\xi_o << \lambda(T)$, the actual penetration depth, and $\xi_o/\lambda(T) \approx 0$. The London penetration depth, valid only under this condition, is defined as:

$$\lambda(T) = (m_c / 2\mu_0 n^*_{sc} e^2)^{1/2} \qquad (1)$$

note that $n_{sc}=2\ n^*_{sc}$. At $T=0^oK$, n^*_{sc} is half the number of conduction electrons at which $\lambda(T)$ acquires its minimum value of $\lambda_L(0)$. As T increases, the number of Cooper pairs decreases causing the penetration depth to increase until at $T=T_c$ there are no Cooper pairs and the metal reverts to

$$\lambda(T) = \lambda(0)[1 - 2\int_{\Delta(0)}^{\infty} (-\delta f / \delta\varepsilon)\frac{\varepsilon}{(\varepsilon^2 - \Delta^2(0)^{1/2}}\delta\varepsilon]$$

being a normal conductor. The temperature dependence of London penetration depth is given by:

$$\tilde{\sigma} = \sigma_1 - j\sigma_2 = \sigma_n \,|\, T_C^+ (\frac{T}{T_C})^2 - j\frac{1}{\omega\mu_0\lambda_L^2} \qquad (2)$$

For low temperature and $\sigma_n \,|\, T_C^+$ frequencies where the losses are small, the two fluid model leads to a complex conductivity that can be written as [4]

$$\lambda_L(T) = \lambda_L(0)[1 - (\frac{T}{T_C})^4]^{-1/2} \qquad (3)$$

where is the normal state conductivity at temperature just above *Tc*, ω is the frequency of operation, and λ_L is the intrinsic London penetration depth. The two fluid model results in temperature dependent penetration depth of :

(4)

Where $\lambda_L(0)$ is the intrinsic penetration depth at $T=0$.
Recently, an interest in kinetic inductance transmission lines has been renewed by Pond [4]. His work concentrated on controlling the phase velocity as a function of temperature. The transmission line under consideration is shown in fig.2 to obtain the propagation characteristic of this device, the surface impedance of each conductor must be known. By including the London equations for two-fluid model in the appropriate constitutive relations, Maxwell's equations can be solved for this waveguide resulting in total series impedance *Z* that includes both the top and bottom plates as:

$$Z = 2Z_s + j\omega\omega_0\left(\frac{d}{W}\right) = 2j\frac{\omega\mu_0}{W\Gamma}\coth(\Gamma t) + j\omega\mu_0\frac{d}{W}(\Omega m) \qquad (5)$$

Note that Z_s is the surface impedance of a single strip, which increases with decreasing film thickness [5]. In this equation ,

$$\Gamma = \sqrt{\frac{1}{\lambda^2(T)} + j\frac{2}{\delta^2}} \qquad (6)$$

Where λ represents a penetration depth increased by impurities above the intrinsic value of λ_L, and δ is the skin depth of a superconductor calculated using the percent of electrons in the normal state. Examination of Γ suggests that the superconducting penetration depth $\lambda(T)$ competes with normal penetration depth $\delta(\omega)$ as a function of frequency, temperature or any depairing mechanism such as a magnetic field.

For low loss situations temperatures and fields reasonably below the critical values $\Gamma \approx 1/\lambda(T)$ and it can be shown that the characteristic impedance is [4][5][6],

$$Z_0 = \frac{d}{W}\eta_{eff} = \frac{377}{\sqrt{\varepsilon_r}}\frac{d}{W}\sqrt{1 + \frac{2\lambda}{d}coth(t/\lambda)} \qquad (7)$$

Where d is the dielectric thickness and the top and bottom conductors have equal thickness and penetration depth. This equation indicates that an increase in the London penetration depth will increase the impedance of the transmission line. This expression also shows that the superconductors increase the effective relative permeability of the structure. This approximation becomes more exact as the frequency, temperature and normal state conductivity are reduced [6]. The prominent feature of this equation is the slower phase velocities can be obtained with the use of thinner superconducting and insulating films (as in our case).

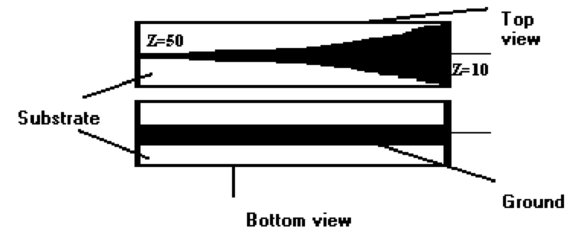

Figure 2. *Top and bottom view of the thin film superconducting microstrip lines*

Thin film exponential microstrip lines have been made by a sputtering technique. fig.1 shows the schematic diagram of the sputtering equipment for preparation of thin film superconducting microstrips. In the fabrication by sputtering, a superconducting thin film was made on the one side of the substrate and then turning over the substrate we have deposited a thin film on the reverse side of the substrate as ground superconducting plane by sputtering. fig.2 shows the schematic the final result of the deposition. After fabrication of the line, we have measured the characteristic impedance of the microstrip line by digitising oscilloscope. The obtained results are in good agreement with the characteristic impedance's by design at room and low temperature. Furthermore, we have made an experiment to the propagation constant of the line, mainly attenuation constant, for microwave signal with frequencies from *30MHz* to *30GHz*, in order to investigate the properties of the fabricated microstrip lines.

3. EXPERIMENTAL RESULTS

3.1 Comparison with a normal state microstrip

In order to verify experimentally the efficiency of the ETL in the coupling of high speed photodiodes a comparison its made between response of PIN photodiode when coupled to the exponential transmission line made by thin film sputter technique and when coupled to uniform transmission line, the excitation by short pulses . The PIN photodiode with very low capacitance was connected to the end of microstrip transmission lines. The detected pulses are shown in Figure 3.

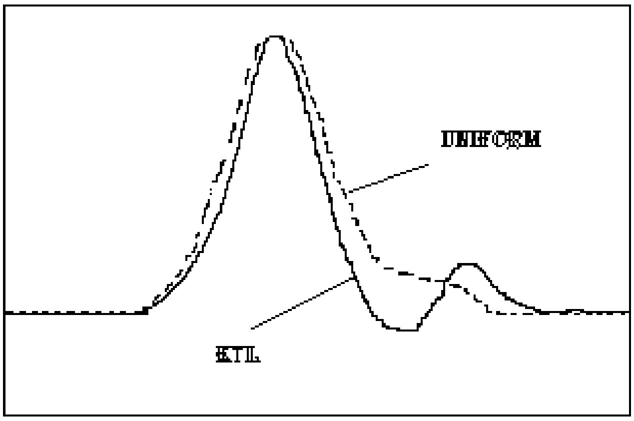

Figure 3. Difference in time response of PIN photodiode when coupled to ETL(solid) and when coupled to uniform transmission line (dashed).

If we look closely the figure above we can see that rise and the fall times detected pulses are bit shorter when the PIN photodiode was coupled to exponential transmission line as illustrated in figure 4. This indicates that the lower the series resistance of the PIN photodiode and the faster rise time the more efficient the ETL will be.

3.3 Active superconducting region

We have considered a superconducting microstrip line onto which a high-energy particle collides. The energy possessed by the particle causes the energy gap to diminish and reduces the number of Cooper pairs in a small region in the strip. This in turns increases the penetration depth and also the inductance of this region in the microstrip line. Once all the energy possessed by the particle is imparted to and dissipated in the strip, the reverse of the process describe begins to occur.

This active region on the strip has been modelled using *Π*-circuit with two shunt capacitors and a series time-dependent inductance. The circuit is analysed so that both capacitors are calculated so that impedance of the circuit seen by microstrip lines on either side is the same as the characteristic impedance of the microstrip line before the change of inductance occurs. The circuit has been terminated in *50Ω* resistive load so that result may be possibly compared with measurement data. The inductance pulse begins at *t1=100ns* with rise-time constant of *100ps* and has a fall time of *40ps*. A peak inductance value of *3μH* was used.

The result is shown in fig.4 and shows that some time is taken before the circuit attains steady state conditions during which inductance stores energy in the magnetic field, which is seen as logarithmic increase in the output voltage. At *t1=100ns*, when the inductance began to increase, it was expected that the output voltage would increase similarly. As can be seen both voltage and current drop exponentially to a minimum value attained at *t2=100.30ns*, after which it rises less rapidly.

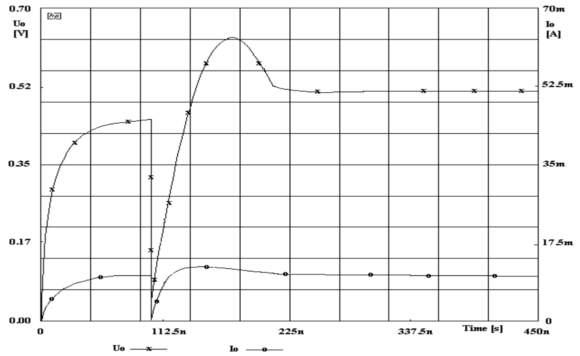

Figure 4. *Effect of a small active region in the superconducting microstrip line*

Another surprising phenomenon is that the voltage overshoots its initial value and then drops exponentially to its final value (that equals the initial value). The drop in the voltage at t1 is consequence of the effective voltage divider formed by *L* and the resistive load impedance. The voltage overshoot, on the other hand occurs due to discharging of energy stored in the magnetic field by *L(t)*.

4. CONCLUSION

We have made a detailed analysis to examine the high-*Tc* superconducting strip line by using sputtering technique. One of the largest benefits of superconducting microwave devices is the extreme miniaturisation and high performance possibilities.

The implemented model was first compared to a microstrip line in a normal state and made by the same method. The reason behind this comparison is that the superconducting microstrip line behaviour approaches that of microstrip line in the normal state when strip thickness is large compared to the penetration depth of magnetic field. The result of comparison shows that the inductance of the analysed structure is in the close agreement up to *3GHz*, which is satisfactory result. The difference occurring at higher frequencies are due to dispersion in the impedance in the normal state. Next the propagation of pulse was compared with that in [7], steady state analysis was used with sufficiently long period to provide a Fourier analysis method so that the result could be compared. It turned out that the frequency dependence of the effective microstrip permittivity was neglected in [7]. The result show that we can not ignore the dielectric loss, however it seems that high-*Tc* superconducting transmission line is more promising for interconnection than the conventional transmission lines. In this research, it has been determined that these attributes are limited not by the conductors but by the quality of the dielectric films. Hence in order for the technology of kinetic inductance transmission lines to reach full potential, it will be necessary to first improve the properties of the insulating layer.

References

1. S. A. Reible, “Wideband analog signal processing with superconductive circuits”, IEEE Ultrasonic Symp.,pp190-201,Aug.1982
2. R.S. Withers and R.W. Ralston, “Superconductive analog signal processing,” Proc. IEEE, vol.77,pp1247-1263,Aug.1989.
3. R.E.Troxler, G.P.Rodrigueand and P.N.Peters “Field response of ultra-thin type II superconducting transmission lines” IEEE trans.Applied superconductivity, vol. 4. pp 65-75, June 1994.
4. O.K.Kowen, B.W.Langley,R.F.W.Pease and M.R. Beasley. “Superconductors as very high-speed system level interconnects”, IEEE Electron Device Letters, EDL-8 12, pp582-585 (1987)
5. R.L.Kautz “ Picosecond pulses on superconducting striplines”,J.Appl.Phy.,49 (1), pp308-314 (1978)
6. M.Morisue,S.Furusawa,J.Asahina and A. Kanasugi, “ Analysis of Pulse Propagation on High-*Tc* Superconducting Transmission lines” IEEE Tran., on Magnetics, vol27 pp2805-2808, March 1991.