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# BEHAVIOUR OF THIN FILM $TiO_2$ OVERLAID $\lambda/2$ MICROSTRIP REJECTION FILTER DUE TO AGEING OF THE OVERLAY

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The long term behaviour of $TiO_2$ thin film overlaid $\lambda/2$ L-section rejection filter due to the ageing of the overlay is reported in this paper. The observations are over a period of upto 600 days with exposure to moisture in between. Due to overlay, existence of double resonance peaks and shifts in resonance due to the various ageing process is observed. The circuit after 600 days show a considerable shift in the resonance frequency to higher frequency side and increase in $Q$. The long term ageing aspects of the dielectric layers used for protection, passivation and improvement of circuit properties should be taken into consideration during design and fabrication.

*Keywords:* Overlay; rejection filter; ageing

## INTRODUCTION

Due to the increased use of multilayer microstrip transmission lines interspersed with thin dielectric layers as a part of high density interconnection structures found in modern multichip modules, the performance of the dielectric layers at high frequencies is a very critical factor in the performance of the MCMs themselves. The long term ageing effects of these dielectric layers needs to be investigated. The use of dielectric overlays in the thin film form to improve the properties of

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the microstripline circuits have been reported [1 – 4]. The oxides are the most common material used for these purposes. Most of these oxides also act as protective layer for the circuit. Where these oxides are used for protection and also for crossovers, the stability of the overlay is an all important aspect which has to be taken into account. The effect of high dielectric constant overlay on the microstrip transmission line is of increasing importance where high power applications are to be considered and also where emphasis is on size reduction [5]. It has been reported [6] that the oxides in thin film form even when they are deposited by e-b evaporation tend to age on ambient exposure. To the authors knowledge there are no reports on the long term ageing of thin film overlaid microstripline circuits. This paper reports the long term (upto 600 days) air exposure and repeated moisture – air cycling effects on the properties of thin film $TiO_2$ overlaid $\lambda/2$ microstrip rejection filter. This particular circuit has been chosen for the ageing studies due to the ease of fabrication of the circuit, though being a coupled one. Also the resonant frequency changes and rejection changes are very sensitive to changes in the condition of overlay.

## EXPERIMENTAL

A $\lambda/2$ open circuit microstripline rejection filter with resonance frequency $f_0 = 9.1$ GHz was fabricated on thin film (5 μm thick) copper metallised (vacuum evaporation + electroplating) $1'' \times 1''$ alumina substrate (Kyocera, Japan). The ground plane was also of copper of same thickness. The thin film of titanium oxide overlay was deposited using electron beam evaporation. Two sets were studied, one with thickness of $TiO_2$ overlay 3000 Å and the other with overlay thickness 11000 Å. The overlay (shaded region) covered the coupling region of the L-section of the filter and also most of the main line of the filter as shown in Figure 1 (inset). The microwave transmittance before and after overlay were measured point to point using a X-band microwave bench. After the overlay was deposited and measurement taken the following ageing studies were conducted.

(a) The circuits were kept in air (protected from dust) for a period of about 180 days and transmittance properties studied.

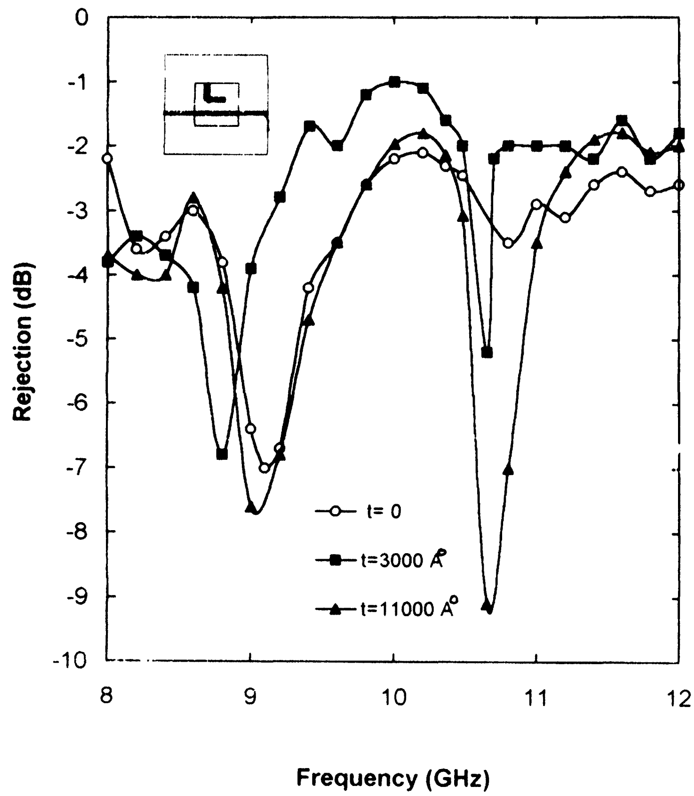



FIGURE 1 Frequency *versus* rejection filter without and with overlay of thin film $TiO_2$.

(b) After 180 days they were kept in saturated moisture for 1 hr. and measurements taken immediately after removal from moisture.
(c) After the moisture exposure, kept in air for few hours to enable evaporation of moisture. Again the measurements were taken.
(d) They were again kept in air for a further period of about 300 days and the changes in the rejection frequency recorded (after 300 + 180 days from initial).
(e) Kept in saturated moisture for 1 hour.
(f) They were again kept in air and the properties investigated after 1 hr. and after 24 hrs. of air exposure.

(g) These circuits were again kept in air for a period of about 100 days and again transmittance studied.

An overall time of about 600 days elapsed after the fabrication and $TiO_2$ overlaying of the $\lambda/2$ rejection filter. Care was taken that all the measurements were taken under about similar conditions of the apparatus and environment.

## RESULTS

All the results are an average of four circuits fabricated under identical conditions. Figure 1 depicts the graph of rejection *versus* frequency for the $\lambda/2$ rejection filter without and with $TiO_2$ thin film overlay. The circuit without overlay has a rejection frequency at 9.1 GHz with a rejection of $-7.0$ dB. Due to overlay two resonance frequencies have appeared irrespective of thickness. The original resonance frequency at 9.1 GHz has shifted to 8.8 GHz due to overlay of 3000 Å and to 9.0 GHz due to 11000 Å. An additional resonance dip has appeared at 10.65 GHz which is very much sharper than the original one at 9.1 GHz. The effect of air ageing for 180 days and exposure to moisture and air are given in Figures 2(a) and (b) for 3000 Å and 11000 Å thick $TiO_2$ overlay respectively. From the figures it is seen that after long term air exposure, the double rejection character is still maintained by the circuit. The resonance frequency has shifted to 8.7 GHz and 10.5 GHz for the circuit with 3000 Å thick overlay where as due to 11000 Å overlay the resonance frequency has become 8.6 GHz and 9.8 GHz. On exposure to moisture, the resonance frequency again appears at 10.6 GHz and that around the lower frequency vanishes. Again on exposure to air, the double resonance characteristics reappears at: 8.65 GHz, 10.4 GHz due to 3000 Å thick $TiO_2$ overlay 8.3 GHz, 10.4 GHz due to 11000 Å overlay. The characteristics of the overlaid $\lambda/2$ microstrip rejection filter after a period of 300 more days (*i.e.*, total 500 days) and further exposure to moisture–air is given in Figures 3(a) and (b). From the figures it is seen that the filter still has the double peak nature being at 8.5 and 10.5 GHz for the 3000 Å $TiO_2$ overlaid circuit and 8.8 GHz, 10.3 GHz for the 11000 Å $TiO_2$ overlaid circuit. The filter with 3000 Å $TiO_2$

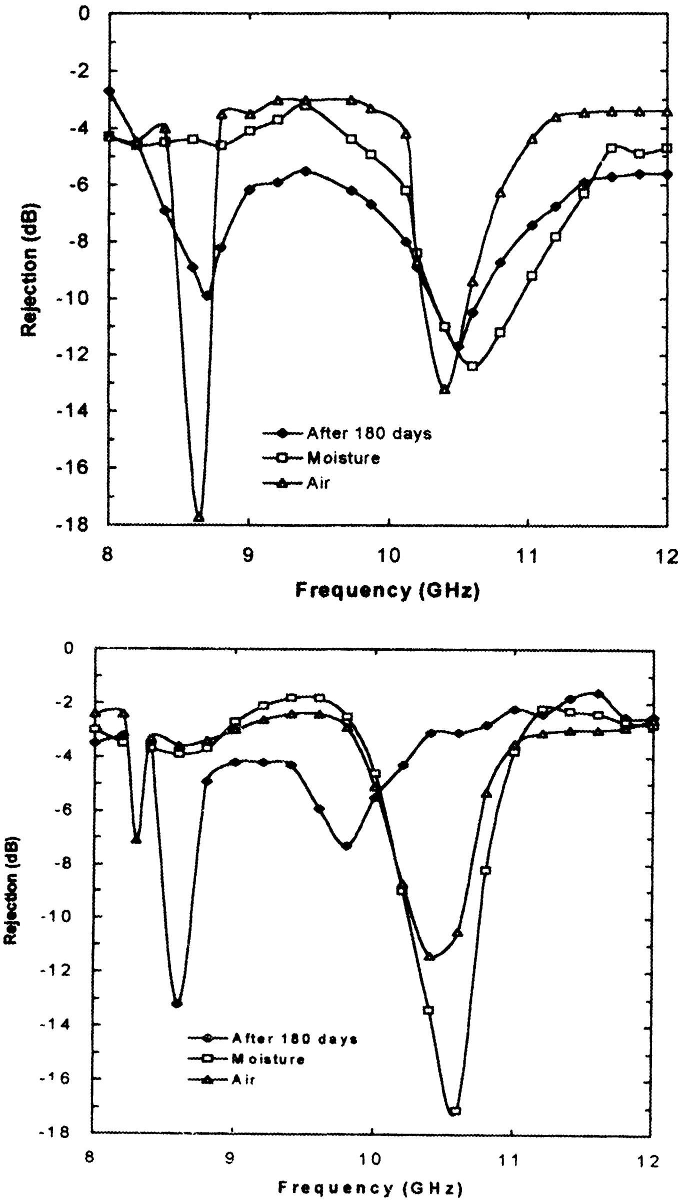
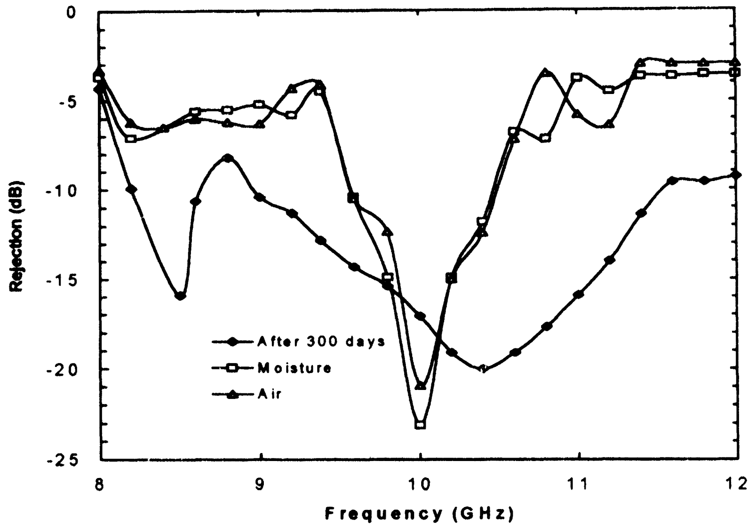



FIGURE 2 Frequency *versus* rejection of filter with overlay of $TiO_2$. (a) For 3000 Å thick $TiO_2$ overlay; (b) For 11000 Å thick $TiO_2$ overlay.



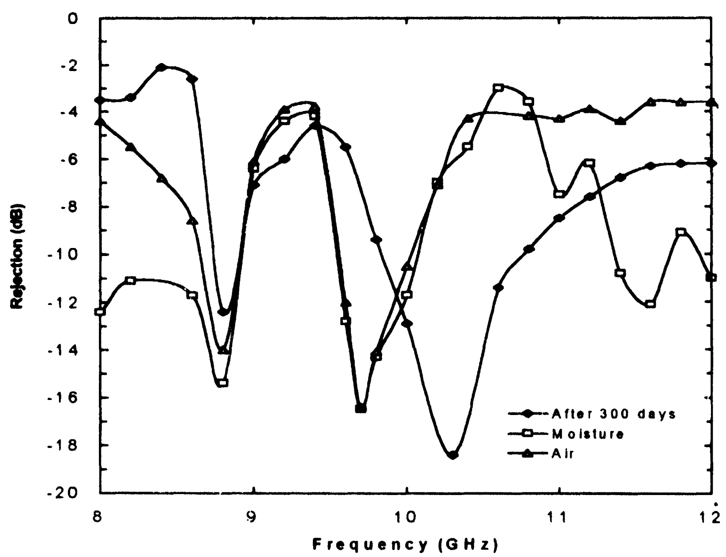




FIGURE 3 Behaviour of rejection filter after 500 days. (a) For 3000 Å thick $TiO_2$ overlay; (b) For 11000 Å thick $TiO_2$ overlay.

overlay has a tendency to lose its narrow band rejection characteristics. On exposure to moisture, the higher frequency resonance point becomes more sharper with very large rejection and shifts to 10.0 GHz and 9.7 GHz for the circuit with 3000 Å and 11000 Å thickness of overlay respectively. Below 9.2 GHz and above 11.0 GHz the characteristics show high attenuation and also oscillatory behaviour at higher frequency in the filter with 11000 Å thick overlay where as the filter with 3000 Å overlay again shows sharp narrow band rejection characteristics. On exposure to air for 1 hr. and further 24 hrs., the observations of transmittance taken after both the time periods, the resonance frequency does not shift further. Figure 4 depicts the condition of the filter after a further period of 100 days in air. From the figure it is seen that the filter shows a single resonance frequency at 10.7 GHz and 10.4 GHz respectively for both the circuits. The filter shows very narrow band characteristics with very high rejection values.

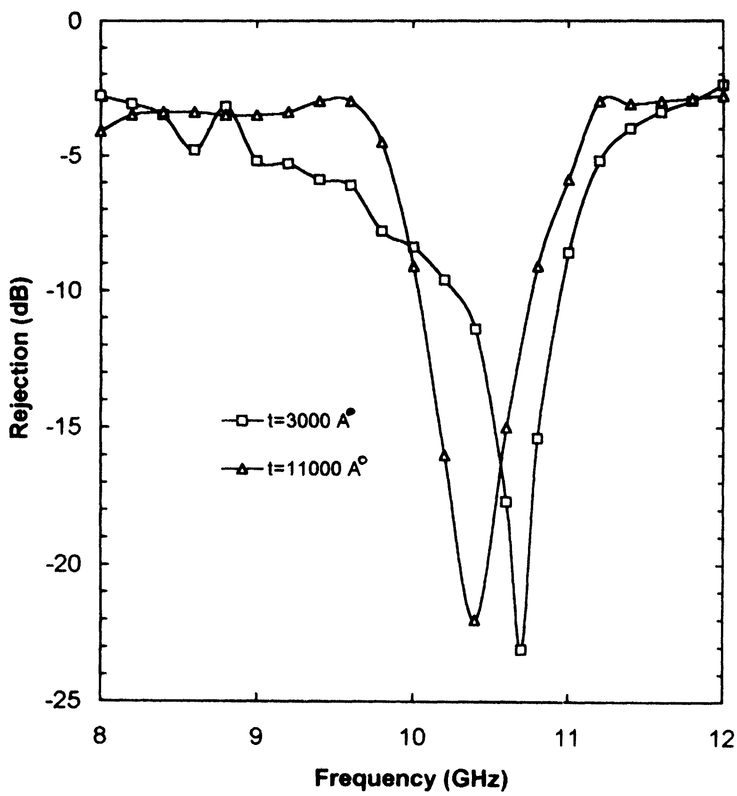



FIGURE 4 Frequency behaviour after a total period of 600 days.

The $Q$ values of the filter after every ageing sequence is tabulated in Table I.

From the table, it is seen that the $Q$ is high for the resonance frequency at the high frequency side. Finally after a period of 600 days, the $Q$ has increased to 107 and 52 from the without overlay value of 15.1. Due to the various ageing sequence no definite trend about the behaviour of $Q$ could be deduced.

## DISCUSSION

From the above results it is seen that the change in the characteristics of the $TiO_2$ thin film overlay changes the filter characteristics to a very substantial extent. The fact that the overlay contributes exclusively to the changes has been verified by studying the characteristics of an identical circuit without overlay which was subjected to all the ageing sequences. There was an increase in attenuation of about 1 dB at almost all frequencies without any shift in resonance frequency.

TABLE I Data of quality factor

| *Condition* | *Q* | |
|---|---|---|
| Without $TiO_2$ overlay | 15.1 | |
| | *Thin film $TiO_2$ overlaid rejection filter* | |
| | 3000 *Å Thickness* | 11000 *Å Thickness* |
| After overlay | 17.6 (8.8 GHz)<br>71.0 (10.65 GHz) | 11.3 (9.0 GHz)<br>35.5 (10.65 GHz) |
| After 180 days | 13.4 (8.7 GHz)<br>15.0 (10.5 GHz) | 86.0 (8.6 GHz)<br>12.3 (9.8 GHz) |
| Moisture | 16.3 (10.6 GHz) | 42.4 (10.6 GHz) |
| Air | 86.5 (8.65 GHz)<br>34.7 (10.4 GHz) | 83.0 (8.3 GHz)<br>26.0 (10.4 GHz) |
| After 300 days | 42.6 (8.65 GHz)<br>12.4 (10.5 GHz) | 58.7 (8.8 GHz)<br>34.3 (10.3 GHz) |
| Moisture | 50.0 (10.0 GHz) | 32.3 (9.7 GHz) |
| Air | 50.0 (10.0 GHz) | 44.0 (8.8 GHz)<br>48.5 (9.7 GHz) |
| After 100 days | 107.0 (10.7 GHz) | 52.0 (10.4 GHz) |

Total period of observation: 600 days.

The thin film $TiO_2$ deposited by e-b evaporation has a dielectric constant $\sim 30$. Oxides deposited by e-b evaporation has been reported [7] to have an amorphous structure. The oxide films show changes in refractive index on exposure to moisture [8, 9]. When the refractive index changes, the dielectric constant is also expected to change.

The dielectric constant of the thin film $TiO_2$ is very much higher than the substrate dielectric constant ($\sim 9.8$). The field above the microstrip circuit travels initially in the high dielectric ($\varepsilon_r$) and at thin film air interface, where they face drastic changes in $\varepsilon_r$, therefore the field gets reflected back to the thin film dielectric and further goes to ground. The thickness of microstrip is $\sim 5\,\mu m$ where as the thickness of the high dielectric constant overlay is 3000 Å, 11000 Å which is very less compared 5 μm. In the coupling region the fields encounter dielectric regions whereby the fringing field capacitance changes in a complex manner.

The overlay changes the electrical length by varying the phase velocity *via* the dielectric overlay. The dielectric constant of $TiO_2$ overlay being very large, the electrical length has changed to such an extent that overcoupling phenomena takes place in the circuit due to which two resonances are observed. The high dielectric constant material also changes the characteristics impedance of the circuit. It has been reported [10] that the characteristics impedance is extremely sensitive to the dielectric around the microstrip. Since there is not much drastic change in the resonance frequency due to keeping in air for 180 days, the overlay also does not change its characteristics in air which is also seen from the refractive index data of electron beam deposited oxide films [11]. On the exposure to moisture, the films have a tendency to absorb moisture and the pores in the film tend to fill with water. Due to the water which has a very high dielectric constant ($\sim 80$), the situation near the coupling region tends to become highly complex. Due to physisorbed water and its probable dissociation due to the electromagnetic field existing in the region, the electrical conditions at the overlay region, coupling region and interface of overlay and metal region changes drastically. Khanna *et al.* [12] have reported changes in permittivity of the medium due to presence of $H_2O$ in electromagnetic field in the pores. The changes in permittivity might be such that the dominance of the lower frequency peak is lessened. As the water in the pores evaporates, the lower frequency resonance peak becomes more sharper for the 3000 Å thick overlaid filter as compared to 11000 Å thick overlaid filter. Thinner films tend to be more porous than thicker films and the filter not retaining its pre-moisture characteristics, indicates that apart from physisorption some permanent chemical changes are also taking place in the overlay material. Repeated moisture absorption and air exposure seems to continue the ageing process of the thin film overlay further whereby the filter properties have completely changed from the original one (Figs. 3 and 4).

The $Q$ of the circuit showing random variations indicate the conditions of the overlay material during the ageing sequence. The $Q$ depends on the $\tan\delta$ and $\varepsilon$ of the overlay material. The higher value of $Q$ after about 600 days indicates a change in the coupling due to changes in $TiO_2$ layer. The off resonance regions both on the higher and lower side has also stabilised indicating lesser losses.

## CONCLUSION

The significant changes of $Q$ and resonance frequencies are very important for packaging considerations as multichip modules employ microstrip interconnects with many dielectric layers. Our results have shown that care should be taken while using thin film dielectric for protection of the circuit. The long term ageing aspects of these dielectric layers should be given importance while designing the circuits. Since the dielectric overlay on the microstriplines interconnects affects the field distribution surrounding the microstrip conductor, the ageing effects on the dielectric overlay would tend to disturb all the neighbouring circuits also. Due to this, the very function of the dielectric overlay for protection, passivation, improvement becomes useless. It is felt that adequate care should be taken about the deposition technology of these thin film dielectric overlays to minimise these long term ageing effects. More investigations are needed in this direction with materials of different dielectric.

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