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Electromagnetic properties of bismuth oxide thin film deposited on glass and alumina

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Abstract

The bismuth oxide thin films were prepared by thermal oxidation (in air) of vacuum evaporated bismuth thin film on glass and alumina. Surface morphology shows granular structure on glass and triangular shaped grains on alumina substrates. The effect of bismuth oxide thin film overlay of different thickness on Ag thick film microstrip rectangular patch antenna was investigated in the X- band (8-12GHz). The change in the resonance frequency, amplitude, band width, quality factor and input impedance of the antenna were studied. Using the resonance frequency the permittivity and conductivity of bismuth oxide thin film was also measured. Thickness and oxidation temperature of Bi_2O_3 thin film overlay dependent changes in the patch antenna characteristics was obtained. The input impedance increases due to the overlay. The dielectric constant of bismuth oxide thin film on both substrate calculated from shift in resonance frequency shows thickness and oxidation temperature dependent values. The microwave permittivity and conductivity of Bi_2O_3 thin film on glass as well as alumina substrate have been reported for the first time using overlay on thick film patch antenna. Thickness of overlay dependent tuning of the antenna has been achieved

Key words: Bismuth oxide thin film; Microstrip patch antenna; Permittivity; Conductivity; Input Impedance; Microwave.

INTRODUCTION

Microstrip patch antennas are being increasingly used in microwaves due to their many interesting physical and electrical properties. In particular, the rectangular and circular disk structures have been extensively studied by many research workers [1, 2]. Microstrip patches are an attractive type of antenna due to their low cost, conformability, and ease of manufacture [3]. The main drawback of microstrip antennas is their inherent narrow bandwidth and, broadening the bandwidth is the most challenging task for research workers [4,5]. Thick film technology has proved to be cost effective method highly conductive to planarization. The use of thick films for fabricating antennas is still not very popular. Thick film technology has proved to be a very cost effective mode of metallization for microstrip components [6-8].

Bismuth oxide has high dielectric constant which is very suitable for microwave integrated circuits [9,10]. Very few reports are available on bismuth oxide thick film on alumina [11]**.** To the authors knowledge there are no report on microwave properties of bismuth oxide on glass in thin film form. Since bismuth oxide is a high dielectric constant material it is expected that the behavior of the microstrip component to this overlay will be different than that reported for low dielectric constant oxides [7,12,13].

This paper reports the effect of bismuth oxide thin films on glass and alumina obtained under different oxidation temperatures of various thicknesses on the X-band response of Ag thick film microstrip patch antenna. Input impedance, band width and quality factor of antenna due to bismuth oxide thin films overlay is also reported. Using the resonance frequency the permittivity and conductivity of bismuth oxide thin film was also measured.

MATERIALS AND METHODS

The Ag thick film microstrip patch antenna along with the feedline was fabricated using screen printing technology onto alumina substrate (Kyocera Japan). The microstrip patch was used as the transmitting antenna and a pyramidal horn was the receiving antenna. The distance between the two antennas was 7 cm, which ensured the presence of far field region. The output of the antenna was measured point by point in the frequency range 8.5- 10.5 GHz using the waveguide bench using appropriate SMA connector and launchers. The microwave characteristics of the microstrip patch antenna were measured using the wave guide microwave setup consisting of Gunn source, isolator, attenuator, directional coupler and detector. The output was measured in terms of voltage.

The pure (99.7%) metallic bismuth was used as the source material for the preparation of the bismuth thin films onto separate glass and alumina substrate using vacuum evaporation. Bismuth oxide has been prepared by thermal oxidation in air at a temperature of 125^0C,150^0C and 175^0C. The thickness of the bismuth oxide thin films on both substrates was from 100nm – 520 nm as measured by surface profiler. The surface morphological study was carried out by scanning electron microscope (JSM-6360 JEOL, Japan). These bismuth oxide thin films were kept as in-touch overlay on the rectangular patch with the film side in contact with the metallization of the antenna. The change in the resonance frequency and amplitude of the patch was measured. Using the resonance frequency the permittivity and conductivity of bismuth oxide thin films on glass and also on alumina was obtained. The dimension of the overlay was such that it covered the entire rectangular patch.

RESULTS AND DISCUSSION

The typical XRD patterns of bismuth oxide thin film on glass and on alumina substrate of 150^0C temperature are shown in figure 1(a) and 1(b).

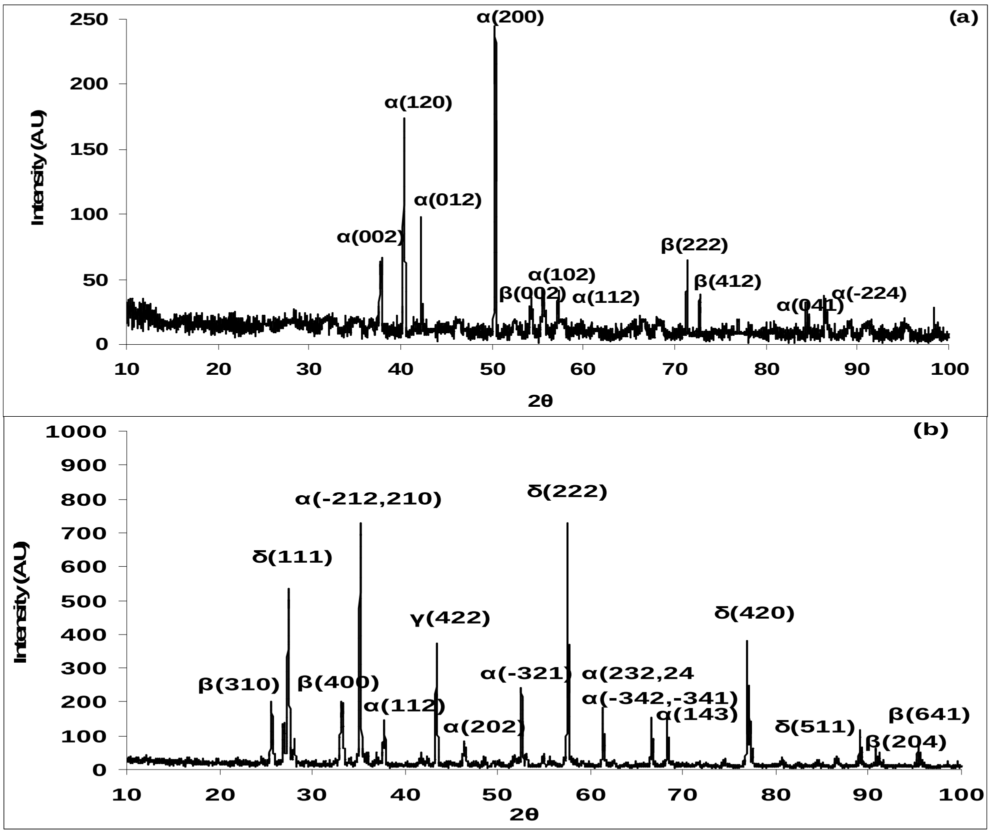


Fig. 1. XRD patterns of Bismuth oxide thin film on (a) glass (b) alumina

From both the figures, it was seen that all the diffraction peaks have been assigned to α- Bi_2O_3 by comparison with JCPDS files indicating that the bismuth oxide thin film is a monophase material and has a monoclinic structure. X-ray diffraction patterns of the bismuth oxide thin films on glass 1(a) indicate the predominance of α -Bi_2O_3 (120) mixed with β- Bi_2O_3 phase but XRD pattern on alumina 1(b) indicate the predominance of δ-Bi_2O_3 (222) mixed with α- Bi_2O_3 phase[14]. For all the temperatures, polycrystalline and multiphase structure of Bi_2O_3 were obtained. The substrate and impurity peaks are absent. The crystallite size of all the thin films was calculated using Scherrer’s formula [15]. The crystallite size of bismuth oxide thin film on glass substrate was 26nm that of bismuth oxide thin film on alumina was 48nm. As temperature of film increases the crystallite size also increases to 28 nm on glass and to ~51 nm on alumina.

The low temperature oxidation below 200^0C results in δ-phase of Bi_2O_3 but on glass substrate the δ-phase of Bi_2O_3 was not observed. The XRD patterns do not show the presence of bismuth metal in the bismuth oxide thin films obtained, indicating complete oxidation of bismuth thin films. Since the substrate temperatures have great influence on the crystal structure of the as grown thin films our results show that, pure δ-Bi_2O_3 crystalline thin films can be obtained at substrate temperature below 200 ^{0} C even on alumina substrate and not on glass. For glass substrate, the δ-Bi_2O_3 phase was observed at higher temperature that is above 250^{0}C [16].

The SEM image of bismuth oxide thin film on glass and on alumina of 150^{0}C temperature is shown in figure 2. SEM image of bismuth oxide thin film on glass substrates shows granular morphology but the morphology on alumina showed triangular shaped grains. From figure it was seen that the grain size of bismuth oxide thin film on glass substrate was less than that of grain size of bismuth oxide thin film on alumina. Grain size on glass substrate was 28nm and than that of on alumina was 556nm.

As oxidation temperature increased the grain size of bismuth oxide thin film on glass and on alumina was also increased. SEM image of bismuth oxide thin film on alumina showed grains of alumina also and on that grain there is bismuth oxide.

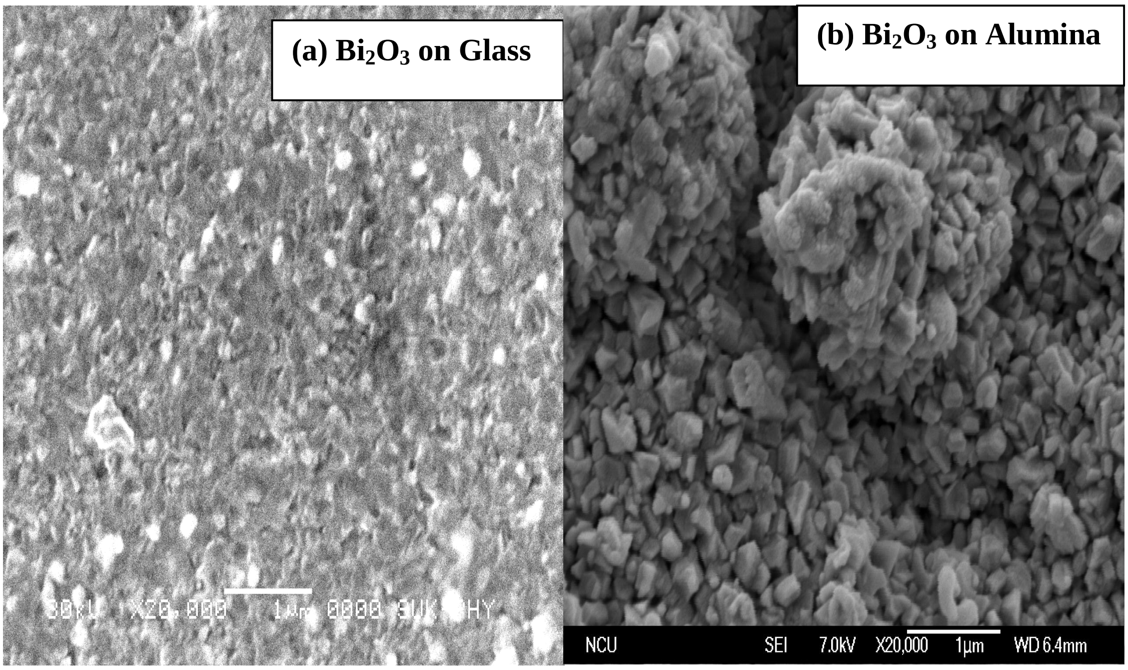


Fig.2. SEM images of bismuth oxide thin film on (a) glass and (b) alumina for 150^{0}C

Response of Ag thick film microstrip patch antenna to bismuth oxide thin film overlay

The output of Ag thick film patch antenna with overlay of bismuth oxide thin film on glass and alumina for different oxidation temperatures is shown in figure 3 and 4. The figure also shows the response of the antenna without overlay (W.O). The oxidation temperatures are also shown in the figures. The microstrip patch antenna without overlay showed peak resonance at 9.2 GHz with a peak output of 0.42.

Due to overlay of bismuth oxide thin film on both substrates, a shift in the resonance frequency towards higher frequency end was observed. As thickness of film increased the peak output decreased in both cases. The peak output due to bismuth oxide thin film on alumina was higher as compared to peak output due to bismuth oxide thin film on glass.

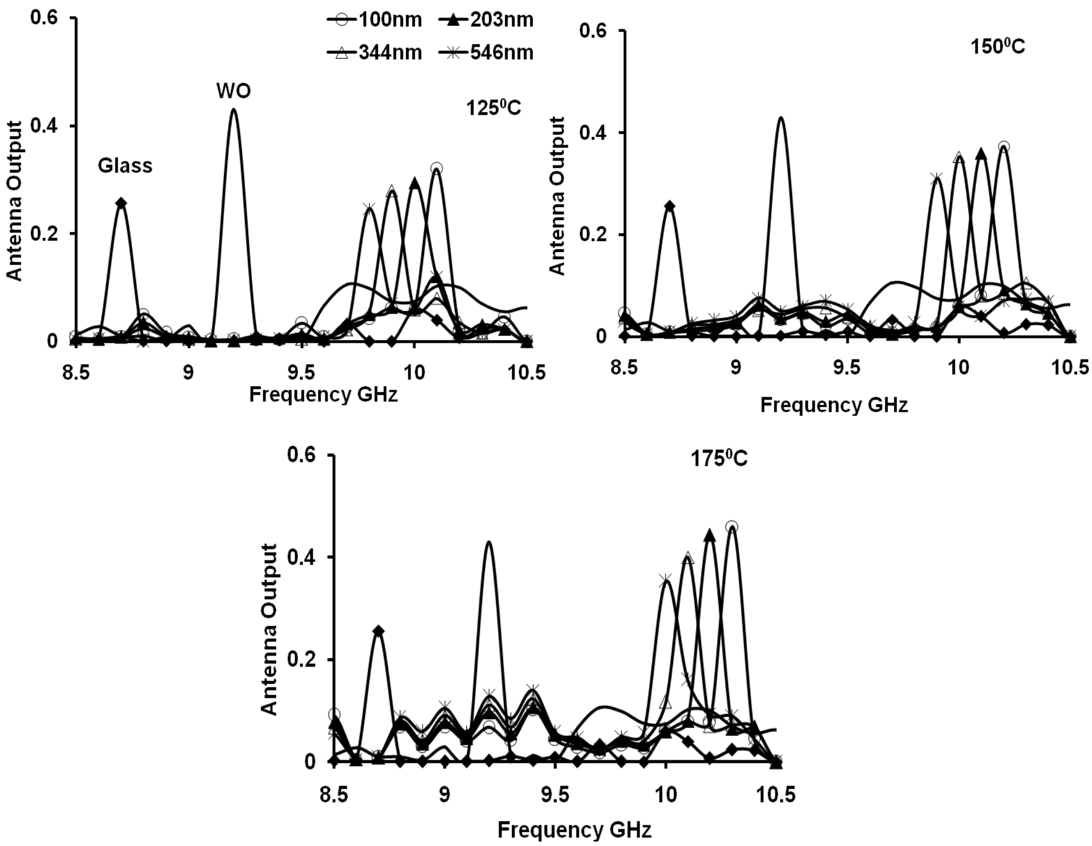


Fig.3.Output of Ag thick film patch antenna with overlay of bismuth oxide thin film on glass

Due to the film of higher thickness on glass substrate the patch antenna showed peak resonance at 9.8 GHz with peak output of 0.24 and due to the film of lower thickness showed the peak resonance shifted to 10.1 GHz with a peak output of 0.32. The effect of the bismuth oxide thin film on alumina overlay the resonance frequency shifted to 9.8 GHz and the peak output became 0.57 due to the film of higher thickness, whereas the film of lower thickness shifted the resonance frequency to 9.5 GHz and increase the output 0.64. As the oxidation temperature of the bismuth oxide thin film overlay increased the shift in frequency was more.

The resonance frequency and peak power efficiency as a function of thickness of bismuth oxide thin film overlay is shown in figure 5. Effect of thickness as well as oxidation temperatures dependent changes in the antenna resonance frequency due to Bi_2O_3 thin films overlay was observed. From the figure, it is seen that resonance frequency of microstrip patch antenna decreased with increase in thickness of bismuth oxide thin films on glass substrate and due to film on alumina resonance frequency of antenna increased with increase in thickness of films for all oxidation temperatures. In both cases, for higher oxidation temperature the film showed higher resonance frequency.

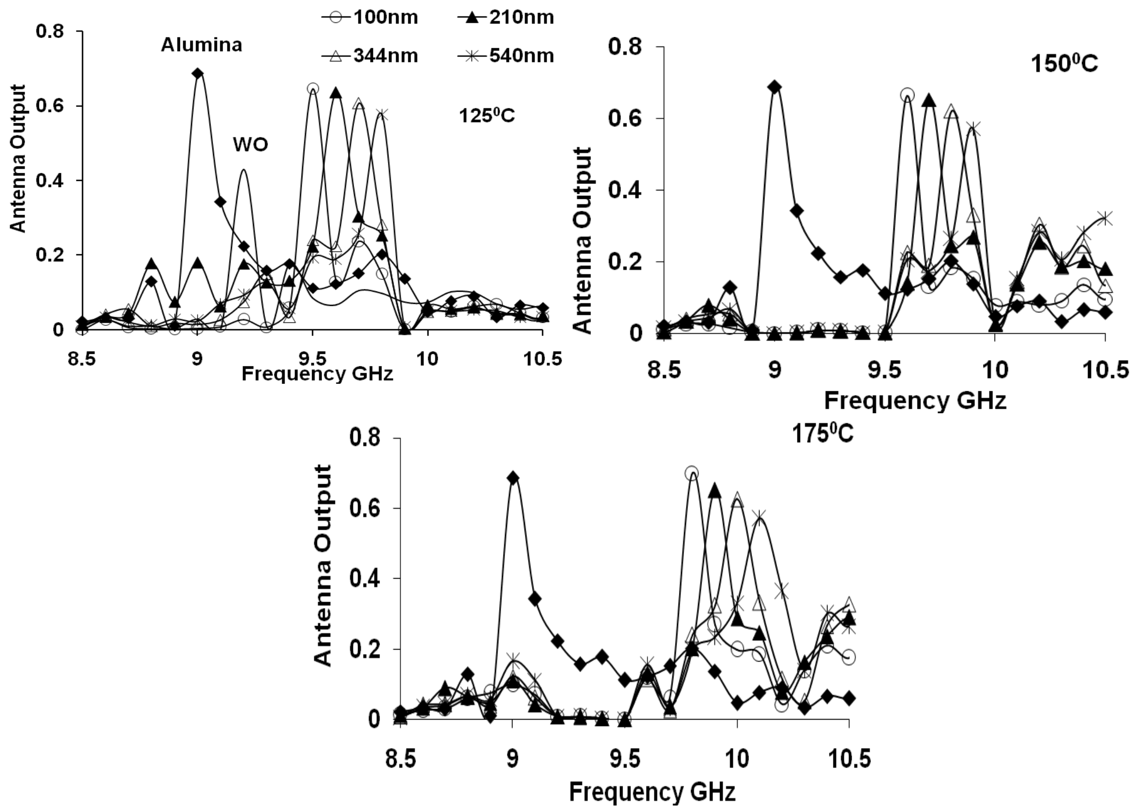


Fig.4.Output of Ag thick film patch antenna with overlay of bismuth oxide thin film on alumina

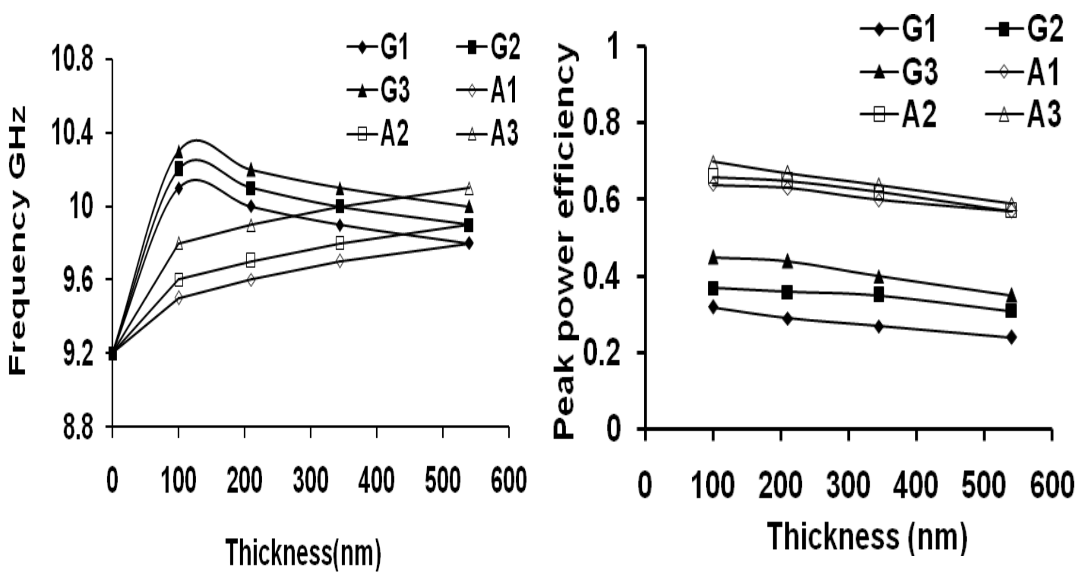
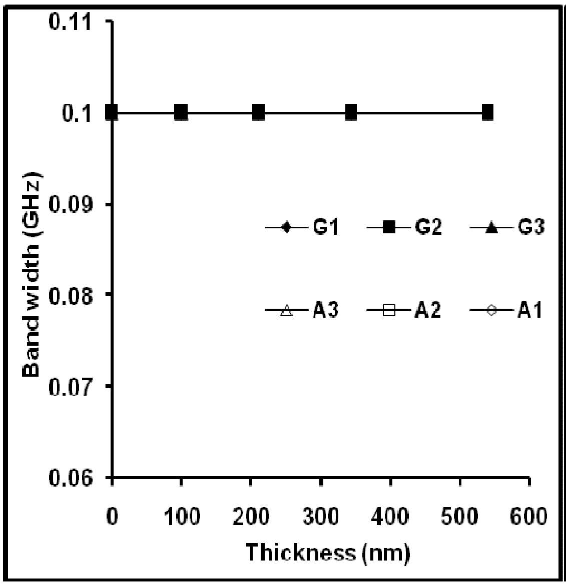


Fig.5. Resonance frequency and peak power efficiency as a function of thickness of Bi_2O_3 thin film overlay (G1=A1=125^{0}C, G2=A2=150^{0}C and G3=A3=175^{0}C)

It is also seen that peak power efficiency of antenna increases to ~ 0.70 due to bismuth oxide thin overlaid on alumina and that on glass it was 0.45 for lower thickness (100 nm). As the thickness of the bismuth oxide thin film overlay increases, the power efficiency decreases in both cases but the value being larger than no overlay antenna in case of alumina substrate and the power efficiency was less than no overlay antenna due to film on glass substrate. Due to the oxide overlay oxidized at higher temperature larger changes in the peak power response is obtained.

The band width and quality factor of Ag thick film patch antenna due to bismuth oxide thin film overlay as a function of thickness for different oxidation temperature is shown in figure 6. From the figure it is seen that the bandwidth does not change due to the overlay of bismuth oxide thin film oxidized at all temperatures on both substrates.

It is also seen that the quality factor decreases with thickness for all oxidation temperature due to overlay of bismuth oxide thin film on glass whereas quality factor increases with increase in thickness due to bismuth oxide on alumina substrate. As temperature of oxidation increases the quality factor of antenna increases.



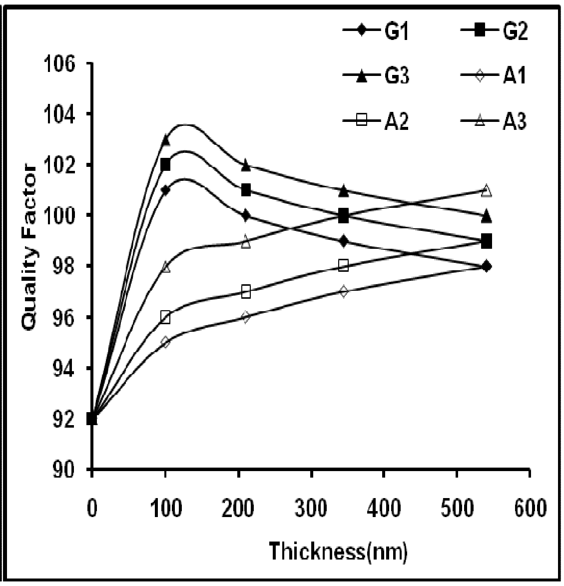


Fig.6. Bandwidth and Quality factor of antenna due to bismuth oxide thin films overlay as a function of thickness (G1=A1=125^{0}C, G2=A2=150^{0}C and G3=A3=175^0)

The input impedance of the microstrip patch antenna due to bismuth oxide thin films overlay as a function of thickness for different oxidation temperatures was obtained from the reflectance studies and is shown in figure 7.

The input impedance of the microstrip patch antenna without overlay was 54.69. Due to overlay of Bi_2O_3 thin film on alumina the input impedance decrease to ~53.5 with not much change with thickness of the overlay. The effect of Bi_2O_3 thin film on glass showed interesting thickness and oxidation temperature dependent effects. Due to overlay of thickness 200nm the impedance increases drastically even going up to 95.5 due to the film oxidized at 200^0C. As thickness increases the impedance decreases but still being higher than without overlay situation.

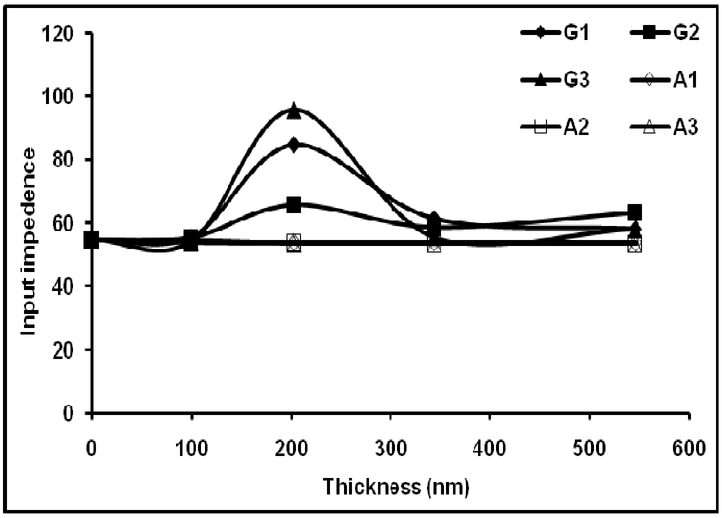


Fig.7. Input impedance of Ag thick film patch antenna as a function of thickness of overlay (G1=A1=125^{0}C, G2=A2=150^{0}C and G3=A3=175^{0}C)

Permittivity

The dielectric constant of the bismuth oxide thin films on glass and on alumina was calculated by the following formula, $\varepsilon' = 1 + \frac{C_0}{K}\left\{\left(\frac{f_a}{f_r}\right)^2 - 1\right\}$ Where the ratio C_0/K is constant term related to standard alumina sample given as, $\frac{C_0}{K} = \frac{\varepsilon_s' - 1}{\left(\frac{f_a}{f_s}\right)^2 - 1}$ and the dielectric loss of the bismuth oxide thin films on glass and also on alumina was calculated by the following formula, $\varepsilon'' = \frac{N'}{f_r r_0}$ where the ratio N' is constant term related to standard alumina sample given as, $N' = \varepsilon_s' f_s r_{0s}$ and ε_s' is the dielectric constant of the standard sample and f_a, f_r and f_s are the resonant frequencies without overlay, with overlay of thin film and standard alumina sample respectively. Using this equation the obtained values of dielectric constant (ε') and the dielectric loss (ε") of bismuth oxide thin film as a function of thickness are plotted in figure 8.

The dielectric constant (ε') of the bismuth oxide thin film on glass lies in the range 28 to 52 and than that of the film on alumina lies in the range 14-31. From the figure, it is seen that dielectric constant (ε') and dielectric loss increased with increase in thickness as well as for increasing oxidation temperatures of the bismuth oxide thin films on both substrates. The dielectric loss varied from 1.6 to 2.24 for bismuth oxide thin film on glass and it varied from 0.4 to 0.9 for the film on alumina.

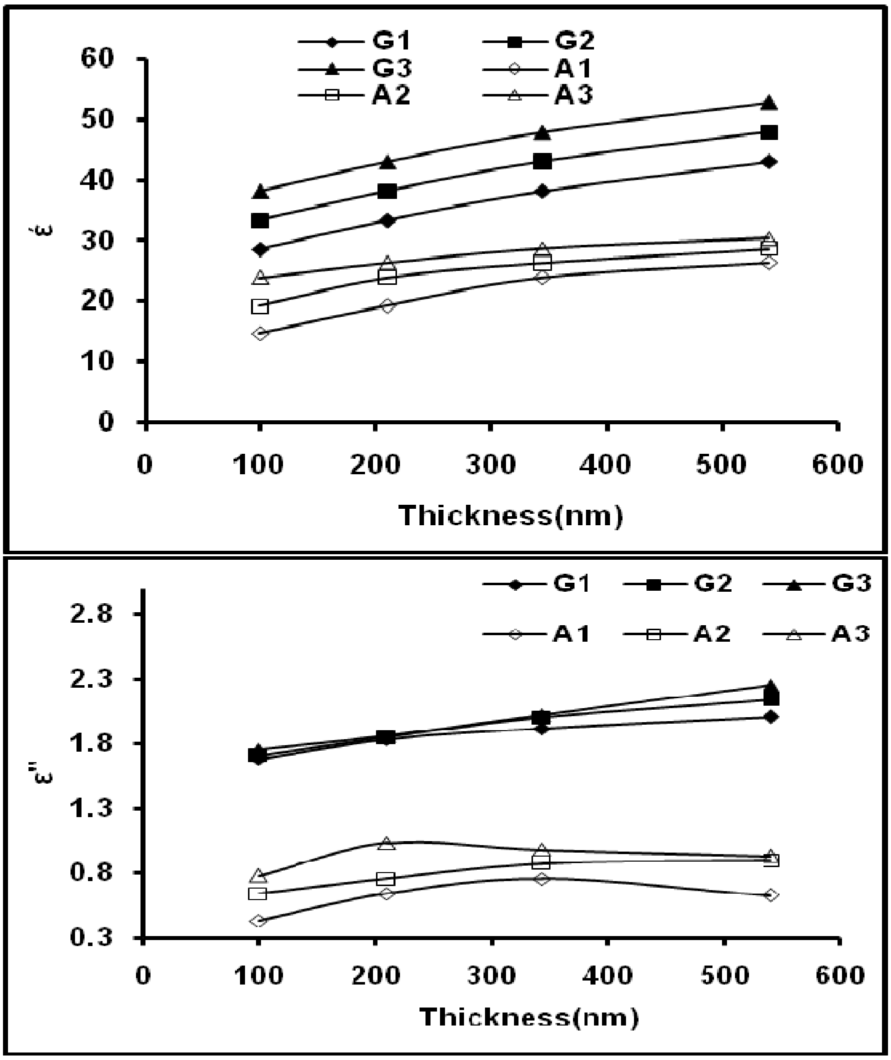


Fig.8. Permittivity of bismuth oxide thin film as a function of thickness

The microwave conductivity of the bismuth oxide thin film was calculated using the equation according to Nelson et al [17] using the dielectric loss data.

$\sigma = \omega \varepsilon''\varepsilon_o$, $\omega = 2\pi f$ where f is resonance frequency due to overlay, ε_o = permittivity of free space = 8.85 x 10-12 SI unit, ε" = dielectric loss

The microwave conductivity obtained by using the above method is shown in figure 9. It varied from 9.41×10^{-10} S/cm to 1.24×10^{-9} S/cm for the bismuth oxide thin film on glass and it varied from 2.24×10^{-10} S/cm to 5.16×10^{-10} S/cm. The microwave conductivity of glass was 2.9×10^{-13} S/cm and that of alumina was 4.5×10^{-12}

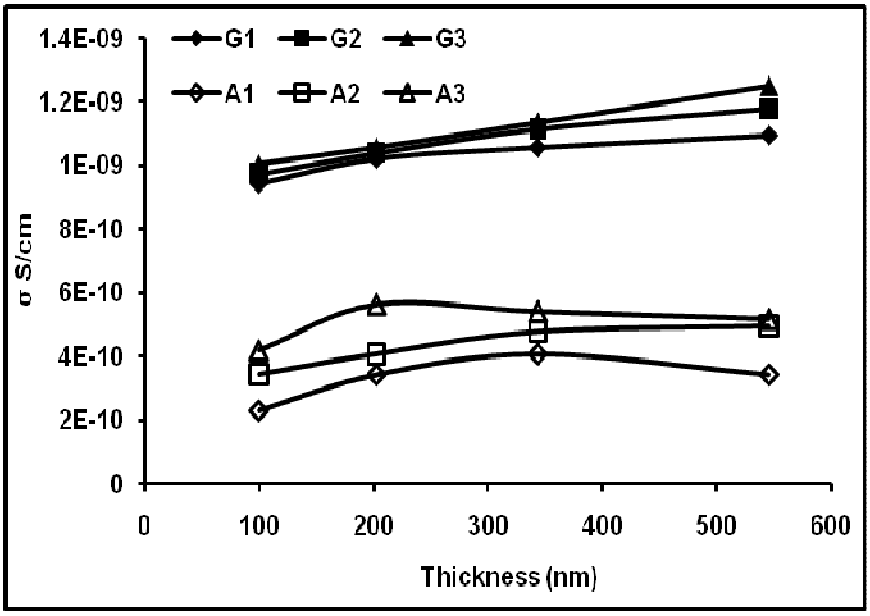


Fig.9. Microwave conductivity of bismuth oxide thin film as a function of thickness for different oxidation temperatures

Due to the bismuth oxide thin film the microwave conductivity of both glass and alumina have increased.

As thickness of film increased the microwave conductivity increased. For higher oxidation temperature microwave conductivity was more.

Metallization is an important aspect in the radiation efficiency of the microstrip patch antenna. Radiation from a patch occurs mainly from the fringing fields between the edges of the patch conductor and the ground plane. The cross section of the patch and feedline is less rectangular in thick film antenna due to the ink slump after printing, causing errors in edge definition. The rough surface edges of the thick film substrate can cause diffraction/scattering. These inherent problems associated with thick film technology can degrade the antenna performance causing lower radiated power.

When overlay is kept on the patch, the effective dielectric constant of the system changes which results in changes in the resonance frequency, gain, bandwidth, Q and impedance of the antenna. Bismuth oxide being a high dielectric constant material has more influence on the normalized lumped capacitance of the patch. More field lines tend to move towards the superstrate of high permittivity [18]. If only increase in effective dielectric constant contributes to change in resonance frequency, it is expected that the frequency shift to the lower frequency end. The bismuth oxide thin film on both the substrates when used as overlay shifts the frequency to the higher frequency end. When the overlay is in touch with the antenna, in the close proximity, the antenna radiation fields exhibits complex characteristics, because of reactive component due to the electrostatic zone in the radiated field of the antenna. According to Wong et al [19] higher superstrate permittivity can increase the magnetic field intensity on the surface of the patch antenna. This increases the possibility of electromagnetic induction, which causes influence in the radiated field. As thickness of the overlay is increased more material is present for interaction, hence larger changes are expected.

CONCLUSIONS

Our work has shown that bismuth oxide thin film on glass and on alumina can be used as overlay on Ag thick film microstrip patch antennas to tune the resonance characteristics of the antenna. Using the changes observed in the resonance frequency the thickness and oxidation temperature dependent microwave dielectric constant of the bismuth oxide thin film has been obtained. High dielectric constant and high losses are observed in the case of bismuth oxide thin film on glass substrate. As film thickness increased, dielectric constant and dielectric loss of all thin films increased for all temperatures. The dielectric constant obtained are in the range expected for bismuth oxide thin film. The input impedance of the patch increases due to the bismuth oxide overlay on glass and that on alumina it is constant. Due to overlay of bismuth oxide thin film, as thickness and oxidation temperatures increases the microwave conductivity increases. Thin film high dielectric constant materials as in-touch overlay on thick film microstrip antenna can be a very cost effective method for obtaining frequency agility without costly designing and fabrication techniques.

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REFERENCES

[1] DN Khanra; SK Chowdhury; AK Mallick, *IETE Jour. of Reser*., **1998,** 44, 48.
[2] JS Roy, *Microw. and Opti. Techno. Lett.*, **1998,**19,307.
[3] SD Targonski; RB Waterhouse; DM Pozar, *IEEE Trans. on Ante. and Prop.*, **1998,** 46, 1245.
[4] ZN Chen; WK Toh; X Qing, *Microw. and Opti. Techno. Lett*., **2008,** 50,1885.
[5] JT Bernhard; E Kiely; G Washington, *IEEE Trans. on Ante. and Propa.*, **2001**, 49, 597.
[6] S Rane; V Puri, *Acti. and Pass. Elect. Compn.*, **2000**, 24, 163.
[7] S Rane; V Puri, Microelec. *J*, **2001**,32, 649.
[8] S Rane; V Puri, *Microelec. Reliabi.*, **2002,** 42, 1953.
[9] J Fu, *J. Mat. Sci. Lett.*, **1997**,16, 1433.
[10] AK Axelsson; M Sebastian; N McN Alford; *J. Kor. Cer. Soc.* 2003, 40, 4340.
[11] S Patil; V Puri, *Adven. Scie. Lett.*, 2010,3, 1.
[12] U B Lonkar; V Puri, *Microelec. Inter.*, **2007,**24, 55.
[13] V Surve; V Puri, *Microelec. Inter*., **2007**,24, 35.
[14] S Patil; D Kulkarni; V Puri, *Jour. of Phys.: Conference Series*, **2008,** 114, 012040.
[15] BD Culity, "Elements of X-ray diffraction, Addison Wesley, London," **1978**,102.
[16] R B Patil; J B Yadav; R K Puri; V Puri, *Jour. Of Phys. And Chem. Of Solids.*, **2007**, 68, 665.
[17] S O Nelson, *IEEE. Trans. On Instr Meas.*, **1992**, 41, 116.
[18] A K Verma; Z Rostamy, *Theo. And Tech.*, **1995**, 43, 1144.
[19] K L Wong; W L Chen, *IEEE. Trans.Electromag. Comp.*, **1992**, 34, 17.