Response of thin film Al$_2$O$_3$ optical waveguide to moisture in paper

R K Puri* & Vijaya Puri*

*Vacuum Technique and Thin Film Lab, USIC,

bDepartment of Physics, Shivaji University, Kolhapur 416 004, India

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The response to paper moisture of thin film Al$_2$O$_3$ optical waveguide has been studied. The changes in the transmission of thin film optical waveguide due to changes in relative humidity of paper used as in touch overlay have been reported in this paper. The output decreases due to the overlay of paper. The transmission of the waveguide depends on the moisture content, texture and colour of the paper. Higher moisture content in paper tends to saturate the waveguide output. The sensitivity to moisture changes and type of paper is more for lower moisture content. Hysteresis is observed due to all the papers studied. The larger sensitivity in the lower moisture range may provide a means for detecting and controlling moisture in paper for packing, printing and other applications, as this overlay method requires only a small piece of paper.

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Simple planar passive wave guiding elements are very important components for fabrication of optical integrated circuits. The efficient propagation of light waves through the waveguide depends on the refractive index of the guiding element along with the refractive index of the immediate environment of the wave guide. Most of the thin film optical coatings used for wave guiding purposes change their properties due to environmental changes$^{1-4}$. This aspect has been used to study the effect of paper moisture on the propagation of Al$_2$O$_3$ thin film optical wave guide.

Papers are very useful as packaging, printing and insulating materials. The moisture absorption and retention properties of paper, determine its utility for different applications. The paper has been used as in touch overlay over the Al$_2$O$_3$ thin film waveguide. An attempt has been made to study the effect of paper moisture using overlay technique on optical waveguide.

Experimental Procedure

The thin film of Al$_2$O$_3$ was deposited by electron beam evaporation using a 3 kW electron gun. The substrates used were micro slides of refractive index 1.515. The Al$_2$O$_3$ thin film of thickness 1600 Å was the planer waveguide. In order to study the transmitted output of the waveguide, prism-coupling method was used. Two special right angle prisms made of extra dense flint glass with a refractive index of 1.7 was used. The optical transmission loss was measured by measuring the output intensity of the output prism. The length of the waveguide between the two coupling prisms was 2.5 cm which was the active area of the waveguide. The light source was He-Ne laser ($\lambda= 6328$ Å). The whole set-up was mounted on spectrometer. Only the lowest mode $m=0$ was studied.

Initially, the transmitted output of the Al$_2$O$_3$ waveguide was measured. The waveguide and prism set-up were kept inside a vacuum bell jar with suitable windows as shown in Fig. 1 with provision for humidity control$^5$. The experiment was conducted at atmospheric pressure and not under vacuum. The response of the waveguide to relative humidity was first studied. For investigating paper overlay effects,

*For correspondence (E-mail: vrp_phy@unishivaji.ac.in)
the following six papers were used; filter paper (FP), bond paper (BP), brown paper (BRP), white card sheet (CSW), dark blue card sheet (CSB) and news paper (NP). These papers are different from each other in their moisture retaining capacity and their texture. The size of the papers was 2 cm × 2.5 cm. The papers were sandwiched in between glass cover slips of same size to avoid damage to paper when wet and also ensure flatness of paper. The paper with the cover slips was kept as in-touch overlay on the Al₂O₃ waveguide. The papers were dipped in water and made completely wet. The wetting time varied with the type of paper. They were dried for regular intervals of time, by exposing to infrared. The waveguide output was measured after every drying time along with the weight of paper. For the wetting cycle the paper was kept in the humidity chamber until the paper attained the required humidity and then kept on waveguide as overlay. In both the process, the percentage moisture in paper was calculated on wet basis from differences in weights. For each paper the experiment was repeated three times. An error of ~± 1 MV was obtained.

Results and Discussion

The variation of the Al₂O₃ waveguide output with relative humidity is shown in Fig. 2. The relative humidity was varied from 10% to 90%. It is seen that the transmission decreases with increase in percentage of moisture up to around 60%, after which saturation type behaviour is obtained. The zero relative humidity indicates very low moisture content (~3% obtained by use of P₂O₅) in the humidity chamber. The effect of overlay of cover slip and as-available paper on the transmission of the waveguide is also indicated in Fig. 2 (points at 10% RH). These measurements were done in the absence of vacuum. The effect of cover slip (CS) is negligible. The brown paper and blue card sheet showed large decrease in the output (from 250 MV to 186 and 178 MV respectively). All the other papers also showed decrease, white card sheet showing the least.

The transmitted output of the Al₂O₃ thin film optical waveguide due to overlay of paper when the moisture content of paper changes from maximum to minimum and minimum to maximum is given in Figs 3 and 4 respectively.

From these figures it is seen that the response of the waveguide to relative humidity shows hysteresis. The value of 0% moisture indicates the reference point for the paper dried completely in IR. The moisture content was between 2-3% depending on the paper. It is seen that the transmitted output is higher when wet paper is dried (larger 0% values in Fig. 3) as compared to dry paper subjected to moisture (Fig. 4). From Fig. 3 it is seen that due to ~ 85% relative humidity of the newspaper and filter paper
overlay, the output of the waveguide decreases to ~50 MV. From 85% to 40% relative humidity the output shows very less increase when BP, CSW, BRP and CSB are used as overlay as compared to FP and NP overlays. Below 40% relative humidity for all the papers the waveguide show exponential increase in the output. Below 20% the changes are very prominent. In this region also due to BP and CSW overlay the waveguide shows slower changes as compared to other papers.

During the relative humidity increase cycle (Fig 4.), the FP, NP and CSB overlayed waveguide shows faster decrease in the output as the moisture increases. Here also saturation type effects are observed due to all the papers (except FP) after 40% moisture. The results indicate that the Al₂O₃ optical waveguide can be used to detect moisture content in paper. The colour and texture of paper also seems to affect the waveguide transmission.

The waveguide when directly kept in contact with moisture (shown in Fig. 2), absorbs moisture. Due to this there is an increase in refractive index of the Al₂O₃ film forming the guide. The increase in refractive index due to moisture has been reported. The energy associated with the evanescent field might get absorbed by the water. The diffusion profile of water as well as light scattering effects also contributes to the decrease in output due to moisture. Beyond 50% relative humidity, the pores might have got completely filled by H₂O, so further changes are not visible.

When papers are kept as overlay, the waveguide does not have direct contact with moisture (another identical wave guide not exposed to moisture was used). The medium in the vicinity of the Al₂O₃ waveguide changes due to overlay. It appears that the overlay acts like a cladding on the waveguide. The effects though are predominantly moisture in paper dependent, the colour and texture of paper also seems to play a role in the output of the guide. The changes occurring in paper due to moisture, changes the refractive index of the boundary at the waveguide. Darker papers (BRP, CSB) and porous papers (FP, NP) seem to change the refractive index more than BP and CSW.

The presence of hysteresis (compare Figs 3 and 4) indicates the effect of water on paper is not pure absorption-desorption type of phenomenon. Papers are basically made of cellulose. The type of fibrous structure present in the paper makes the paper a complex heterogeneous medium. The dielectric constant of the paper when wet, dry and undergoing heat treatment (IR) might be changing differently for the different papers. It has been reported that the internal structure of fibers in the papers are damaged when the chain like structure of cellulose molecules are broken by water molecules.

Conclusions

The Al₂O₃ thin film optical waveguide is sensitive to changes in the immediate environment of the waveguide. The technique of overlay seems to be more sensitive to moisture content of paper in the range of relative humidity less than 20%. The changes in transmission are quite large in this region. Although moisture seems to play an important role, the other properties of the paper also seem to affect the output of the waveguide. These types of measurements may provide a direct method for paper moisture determination. The sensitivity in the low moisture range may be very useful for controlling moisture in paper for packaging, printing and other moisture sensitive applications of paper.

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References