Transparent MgO films deposited on glass substrates by e-beam evaporation for AC plasma display panels

Sudheer Kumar, S. Premkumar, K.R. Sarma

PDP Lab, Samtel Color Limited, Chhapraula, Bulandshahar Road, Ghaziabad – 201 009,

Satyendra Kumar

Samtel Centre for Display Technologies, IIT Kanpur, Kanpur -208 016, INDIA

Phone: +91-120-467 4550; email: drsudheerpdp@rediffmail.com (Sudheer Kumar)

Abstract

Transparent MgO thin films were deposited on glass substrates by electron beam evaporation of MgO (99.99%) under O_2 atmosphere at 150-250 °C. These films were characterized for their useful properties such as thickness, transmission, and refractive index using ultraviolet / visible (UV/VIS) spectrophotometer, scanning electron microscopy (SEM), and Spectroscopic Ellipsometry. The thickness of MgO films were measured by alpha step instrument and found to be 600 nm to 1000 nm and are meeting the stoichiometry. The transmission spectrum of these films shows transmittance values ~92%..

Key Words: *Plasma Displays, MgO Coatings, Scanning Electron Microscopy (SEM), glancing angle XRD, Ellipsometry*

1. Introduction

Plasma display panels (PDPs) are already manufactured on a commercial scale and expected to be the leading flat panel display system of large area in the consumer television market[1]. However, PDP technology still needs improvements to compete more widely in terms of display quality and production cost. There are three major areas for reducing the cost of PDP displays; (1) lower operating voltage (2) lower peak current and (3) a reduced number of high voltage drivers. In order to cut down the production cost of drive electronics, PDP needs good protective layers with low firing voltage characteristics and low sputtering yields. MgO thin films have been identified for use as a surface protecting layer for dielectric materials because of its very low sputtering yield, low work function (3.1 –4.4 eV), and large band gap (~7.3 eV)[1-4]. Thus MgO protecting layers can play an important role in enhancing the panel lifetime and reducing the power consumption of ac PDP because it has good sputtering erosion properties and a large secondary electron emission coefficient. Also, the large band gap energy of MgO can possibly put itself to a practical use as a surface transparent protecting layer in ac PDPs (hanging TV on the wall). A number of techniques have been used to deposit the MgO thin films such as metalorganic chemical vapor deposition (MOCVD)[5-6], pulsed laser deposition (PLD)[7-10], sputtering[11-14], e-beam-assisted molecular beam epitaxy (MBE)[15], and sol-gel[16]. We have succeeded to deposit such films by a simple e-beam evaporation technique with careful optimization of process parameters.

In this article, we present some of the studies on MgO thin films. We have deposited these films on high strain point glass as well as on soda-lime glass substrates by e-beam evaporation method with careful variation of process parameters. The surface morphology and elemental compositions of these films are also presented. Optical properties of the MgO films using ellipsometry studies are also reported in this paper.

2. Experimental

Magnesium oxide (MgO) thin films were grown on glass substrates by PVD technique using the MgO evaporation materials of 99.99 % purity. The process chamber was evacuated using the rotary and turbo pump combination. The base pressure of the vacuum chamber was maintained at ~1 x 10^{-6} torr. Glass substrates (NPX-7) used in this study, were cleaned following standard cleaning procedures for electronic processing and placed on a substrate holder. MgO thin films were deposited by evaporating the MgO pallets in oxygen atmosphere. Substrate temperature was kept between 150 to 250°C.

Thickness and composition of the films were characterized using a surface profilometer . The surface morphology of the films was investigated by scanning electron microscopy (SEM) using LEO-440, UK at NPL, New Delhi.

Spectroscopic ellipsometry (SE) data were recorded on the samples using a phase modulated spectroscopic ellipsometer (UVSEL, Jobin Yvon Horiba) with a wavelength range from 260 to 1700 nm. The data were recorded either at 0.025 eV or 5 nm intervals in energy or wavelength scanning modes, respectively. The substrates were roughened on the backside to avoid backsurface reflections and have meaningful interpretation of the data. The spectral dependence of refractive indices of the high strain point glass substrates were first determined on bare substrates using SE data and modeling using appropriate dispersion relations.

Ellipsometry measurements yield a complex reflectance ratio:

$$\rho = r_p / r_s = \tan\psi \exp(\iota\Delta)$$

where r_p and r_s are the complex Fresnel reflection coefficients of the sample in parallel (p) and perpendicular (s) directions to the plane of incidence. In order to obtain the complex refractive index, $\tilde{N}(\lambda) = n(\lambda) + i\,k(\lambda)$, of the MgO film on glass, a minimum of three phase (ambient/film/substrate) model was employed.

Multilayer models along with the effective medium approximations were employed to account for surface roughness and structural inhomogeneities in the samples. In case of phase modulated SE the measured signal is given by $I(\lambda,t) = I_0\{1 + I_s Sin\delta(t) + I_c Cos\delta(t)\}$ where $I_s = Sin2\psi Sin\Delta$, and $I_c = Sin2\psi Cos\Delta$ allow determination of the ellipsometric angles (ψ,Δ) in the configuration of our measurement set-up[17].

3. Results and Discussion

Fig. 1 shows the X-ray diffraction pattern of an as-deposited MgO films on glass substrates. Film thickness is ~600 nm. Sharp peaks at 2θ=36.82° and 78.34° are observed that are attributed to MgO (111) and (222) orientations, respectively. The full width at half maximum of the predominant (111) peak is of the order of standard instrument broadening. This indicates a high degree of crystalline behavior in e-beam evaporated thin films. It may be pointed out that Choi et al reported the maximum value of secondary electron emission coefficients from (111) oriented MgO films as compared to other directions[18]. Fig. 2 shows a surface SEM micrograph. A reasonably large grain sizes ~150 nm are observed. The grains are uniformly distributed over the surface.

It is tempting to demonstrate the role of nondestructive optical characterization using SE in optimizing the film properties. In Fig. 3, we show the SE data (ellipsometric angles Ψ and Δ) as a function of energy. The crosses show experimental data while solid lines represent the results of a five-layer model. Each MgO layer is considered as a mixture of MgO material and voids. The effective dielectric constants are calculated using the Bruggmann effective medium approximation. An excellent fit with a multilayer model is obtained over a large spectral range. The SE data modeling on this film deposited under unoptimized deposition conditions show inhomogeneities in the MgO film density along the film thickness. The top layer is more density deficient (~68% porosity) than the bottom layer. The density (ρ) of film is calculated using Lorentz-Lorenz Equation that is given by[18]

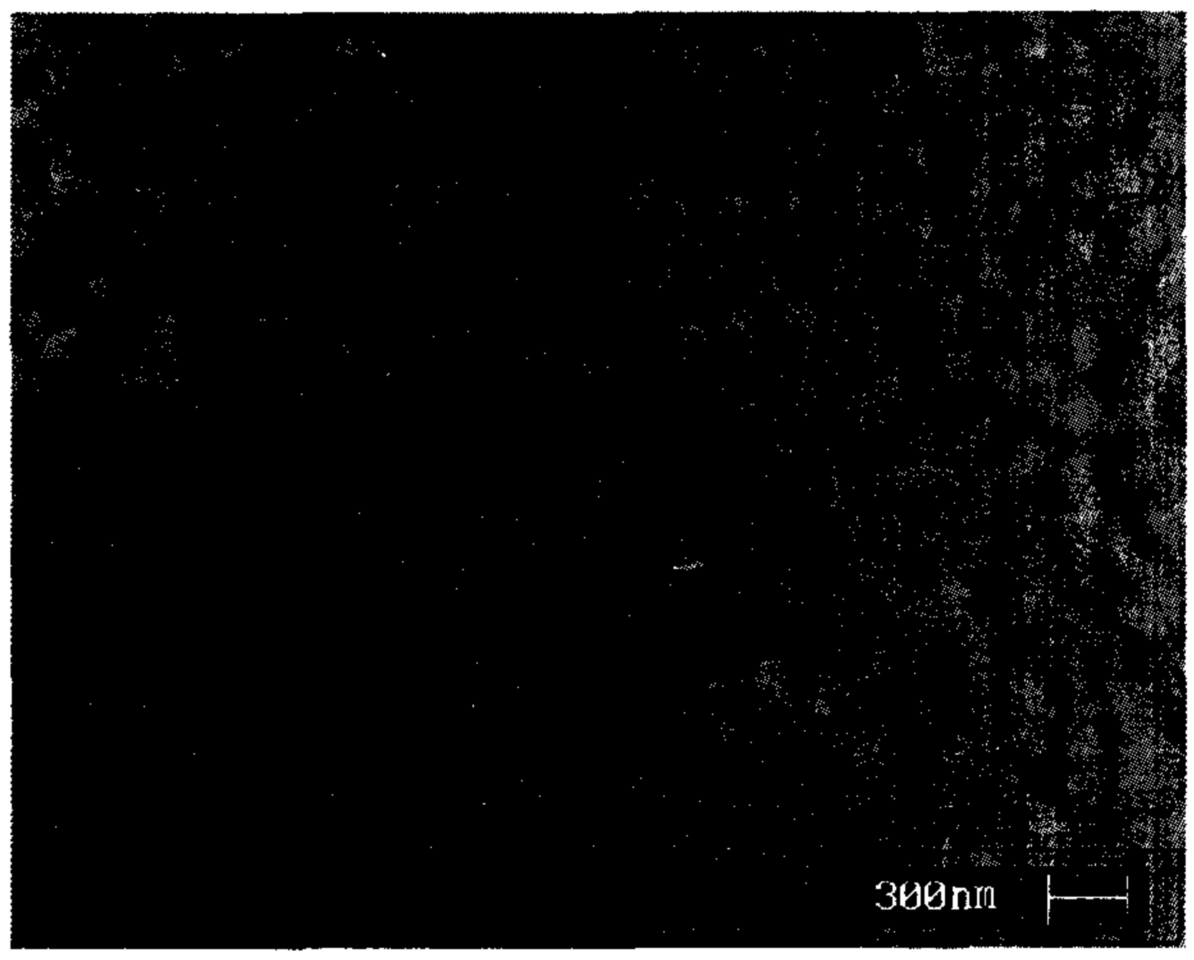

Figure 2 : SEM micrograph on the MgO film deposited by e-beam evapor ation.

$$\rho = k'\left[\frac{n^2-1}{n^2+1}\right]$$

where k' is the dielectric constant for MgO (=9.078). The calculated density of this film is ~2.61 gm/cm³ that which is ~72% of the bulk crystalline value of 3.65 gm/cm³.

On the other hand, density gradient along the film thickness could be controlled by choosing the suitable deposition parameters (substrate temperature, oxygen partial pressure and deposition rate). It was possible to decrease the film inhomogeneities and improve the film density. Refractive indices of the film were determined and shown in Fig.4. The $n(\lambda)$ for the high strain point glass substrate as determined from SE measurements are also shown in the figure. The optical constants are found to be consistent with good quality films reported in the literature.

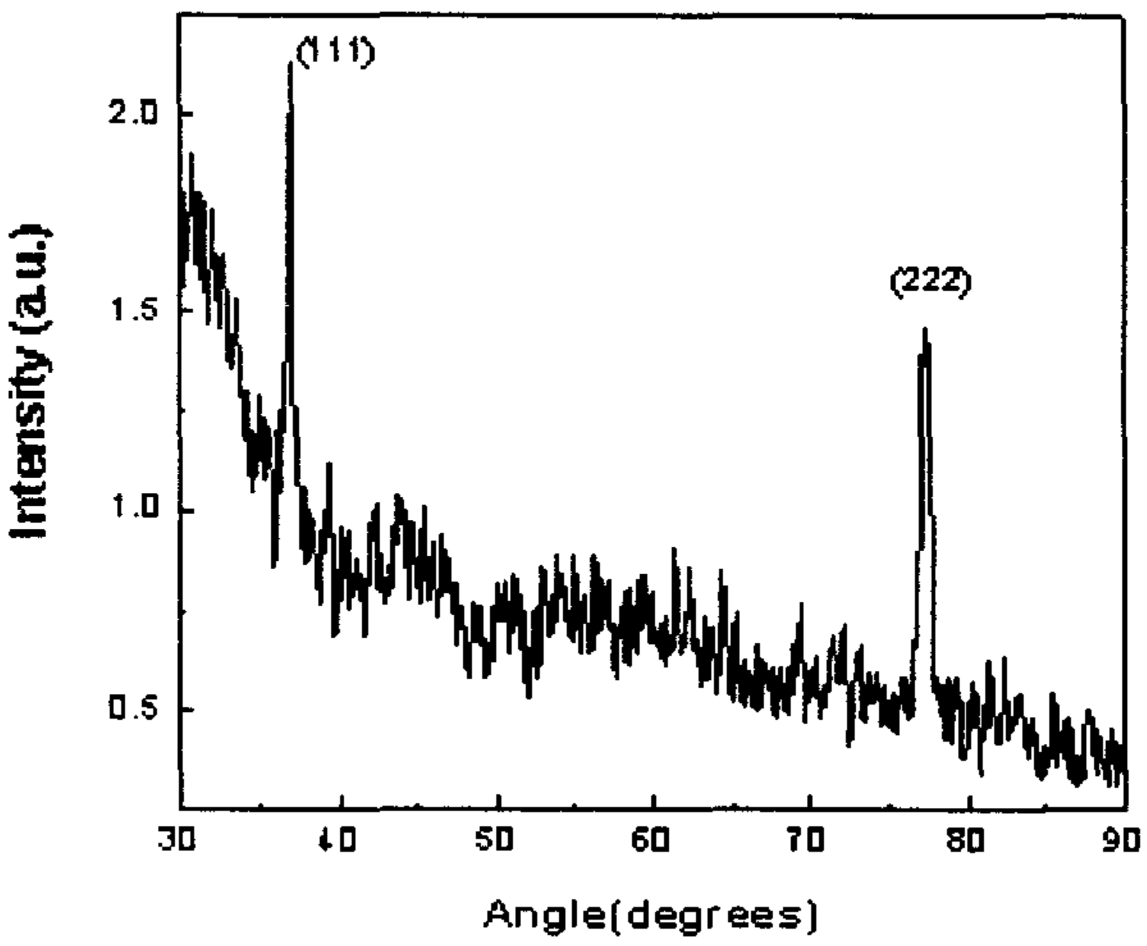

Figure 1: X-ray diffraction pattern of the MgO film deposited on high strain point glass (NPX-7). Film thickness is ~600 nm.

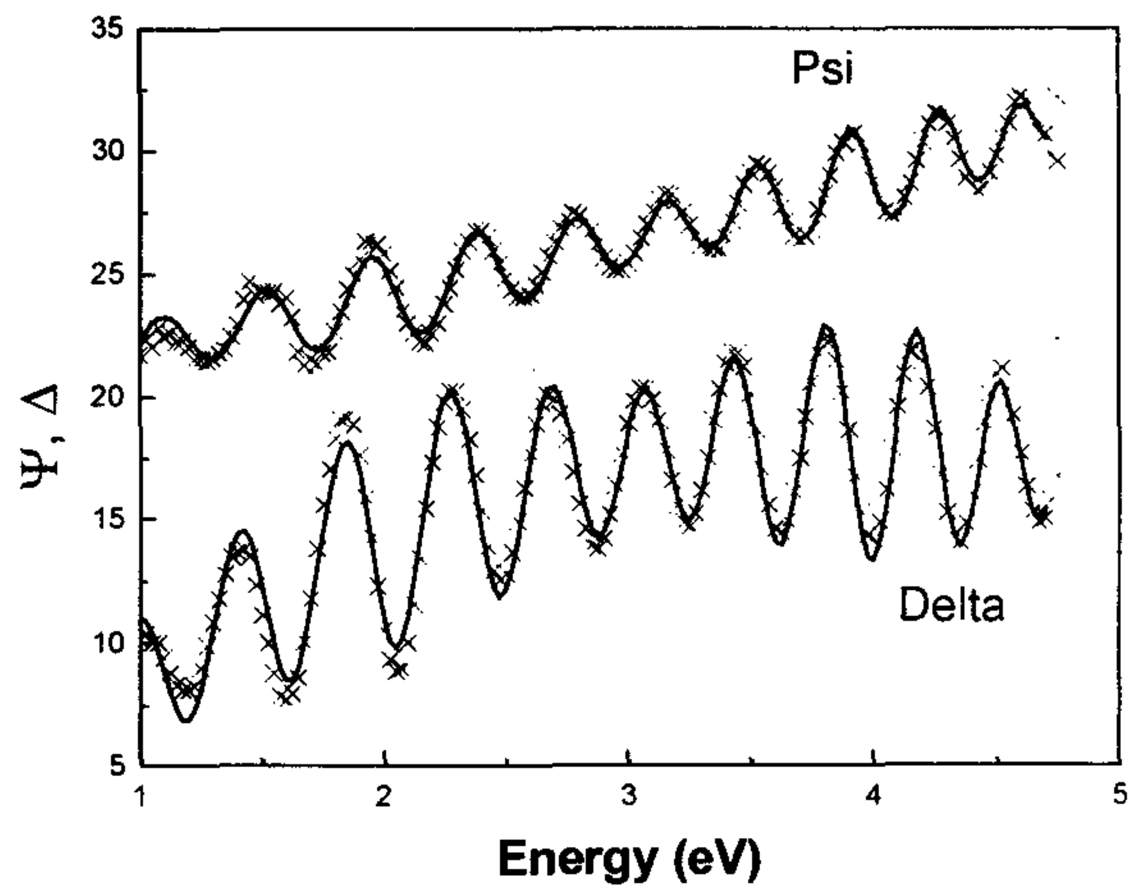

Figure 3: Measured ellipsometric angles ψ and Δ (crosses) along with fit (solid lines) using a multilayer model using effective medium approximations.

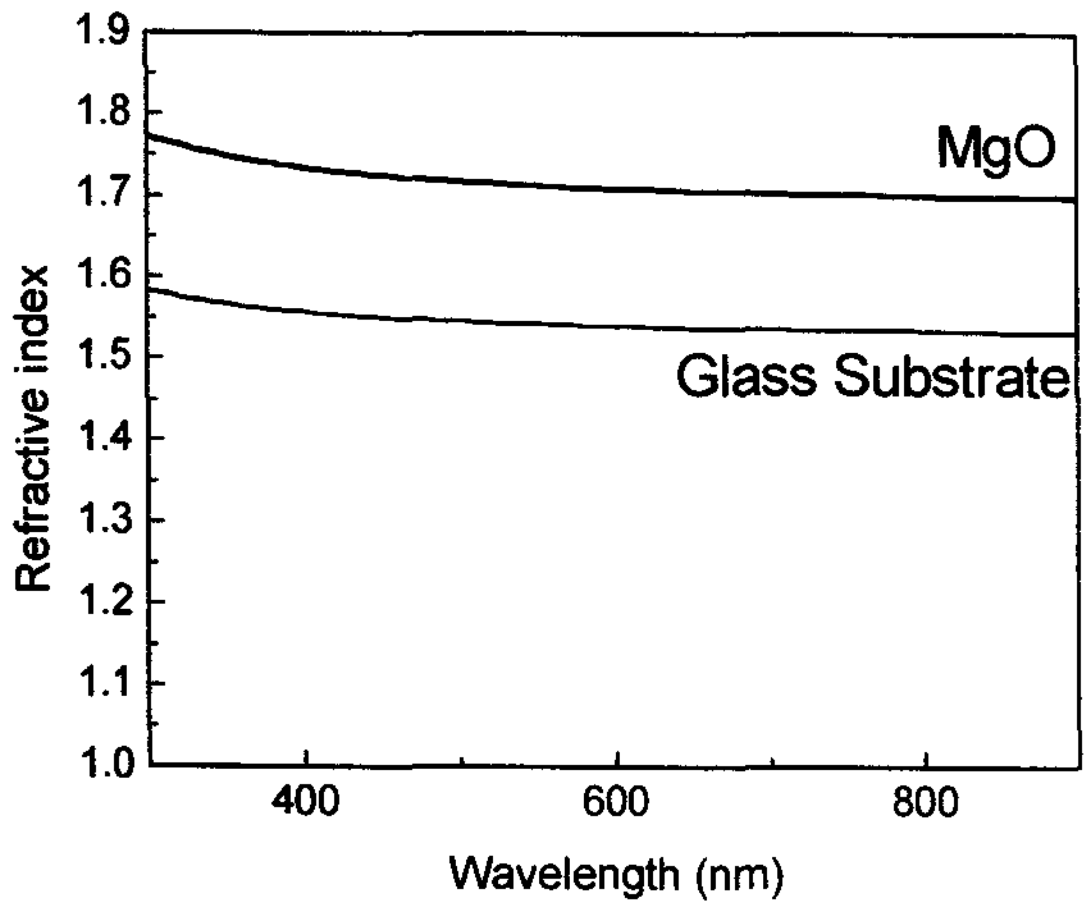

Figure 4: Real part of the refractive index (n) as a function of wavelength for e-beam evaporated MgO and glass (NPX-7) as determined from ellipsometric analysis.

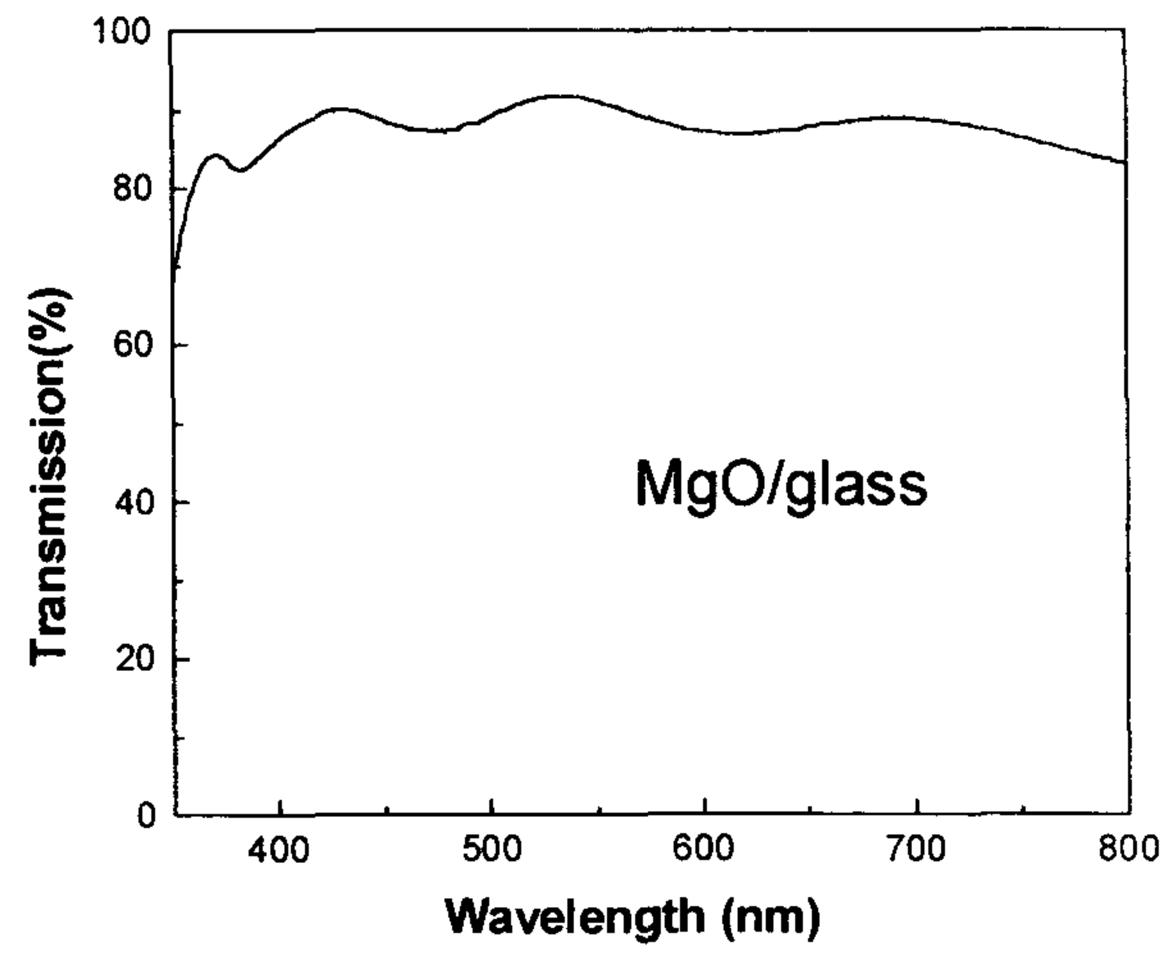

Figure 5: Transmission spectrum on a 600 nm thick MgO film deposited on glass by e-beam evaporation.

It may be pointed out that an absorptive component ($k(\lambda)$) was not required to fit the experimental data indicating an excellent crystallinity of the films (X-ray diffraction pattern on the same film is shown in Fig. 1). Moreover, the film density estimated from SE data using Lorentz-Lorenz equation for optimized sample was found to be ~3.42 gm/cm^3.

Further, Fig. 5 shows the transmission spectrum of a ~600 nm thick MgO film on glass (NPX-7). A high value of transmission (~92%) in the visible region supports the excellent stoichiometry and crystalline properties of our MgO films deposited by electron beam evaporation at low substrate temperatures.

4. Conclusions

MgO films having good crystallinity with (111) orientation were obtained using e-beam evaporation of MgO in oxygen atmosphere. Spectroscopic ellipsometry was effectively utilized to obtain quantitative information on film density and structureal inhomogeneities along the film thickness. Films with high physical density and optical transmission suitable for incorporation in AC plasma display panels were obtained.

5. Acknowledgements

We gratefully acknowledge Mr. M.S. Kohli, Dr. Rahul Kapil and Mr. R.B. Gupta for many fruitful discussions. Financial support from DST, Government of India to carry out this work is gratefully acknowledged.

5. References

[1] T. Orade, T. Iemori, M. Osawa, N. Nakayama, and I. Morita. IEEE Trans. on Electron Devices, 23, 313 (1976).

[2] C. Son, J. Cho, and Jong-Wan Park, J. Vac. Sci. Technol. A17, 2619 (1999).

[3] G.V. Samsonov, The Oxide Hand Book; Chapter 2,5 (IFI Plenum Data Company, New York, 1982).

[4] S. Andoh, K. Murase, and S. Umeda, IEEE Trans. Electron Devices 23, 319 (1976).

[5] J.M. Zeng, H. Wang, S.X. Shang, Z. Wang, and M. Wang. J. Cryst. Growth 169, 474 (1996).

[6] J. Boo, S. Lee, K. Yu, W. Koh, and Y. Kim. Thin Solid Films 341, 63 (1999).

[7] P. Tiwari, S. Sharan, and J. Narayan, J. Appl. Phys 69, 8358 (1991).

[8] D.K. Fork, F.A. Ponce, J.C. Tramontana, and T.H. Geballe. Appl. Phys. Lett. 58, 2294 (1991).

[9] T. Ishiguro, Y. Hiroshima, and T. Inoue, Jpn. J. Appl. Phys., Part 1, 35, 3537 (1996).

[10] S. Amirhaghi, A. Archer, B. Taguiang, R. McMinn, P. Barnes, S. Tarling, and I.W. Boyd, Appl. Sur. Sci. 54, 205 (1992).

[11] S. Fujii, A. Tomozawa, F. Fujii, H. Torii, R. Takayawa, and T. Hirao, Appl. Phys. Lett. 65, 1463 (1994).

[12] S. Kim and S. Hishita, Thin Solid Films 281-82, 449 (1996).

[13] Y. Misaki and M. Mikawa, J. Vac. Sci. Technol. A15, 48 (1997).

[14] M. Tonouchi, Y. Sakaguchi, and T. Kobayashi, J. Appl. Phys. 62, 961 (1987).

[15] S. Yadavalli, M.H. Yang and C.P. Flynm, Phys.Rev.B 41, 7961 (1990).

[16] Fu X. R, Wu G. M, Song S.G, Song Z. T, Duo X.Z, and Lin C.L., Appl. Surf. Sci., 148, 223 (1999).

[17] B. Drevillon, Prog. Cryst. Growth. Charac. Mater. 27, 1 (1993).

[18] E.H. Choi, H.J. Oh, Y.G. Kim, J.J. Ko, J.Y. Lim, J.G. Kim, D.I. Kin, G. Cho, and S.O. Kang, Jpn. J. Appl. Phys. , Part I 37, 156, (1993).

[19] R. Kim, Y. Kim, and J.-W. Park, J. Mater. Sci. Eng. B36, 1469 (2001).