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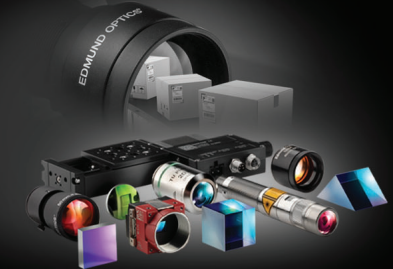
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Preferred orientations in MgO films deposited on amorphous substrates

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Reflection high-energy electron diffraction patterns show that the crystal orientation of MgO films deposited on amorphous substrates at 30 °C at normal vapor incidence varies with film thickness. Films in the thickness range of 50 Å to less than 1000 Å have a random orientation. As the film thickness is increased a $\langle 111 \rangle$ preferred orientation develops. The $\langle 111 \rangle$ preferred orientation remains unchanged upon annealing in vacuum at a temperature in the range from 400 to 550 °C for 1 h. The origin of these orientations is discussed.

Preferred orientations (or fiber textures) in films with NaCl structure on amorphous substrates have been the subject of several theoretical and experimental investigations.¹ Schulz² found that films of LiF and NaCl deposited on amorphous substrates at room temperature at normal incidence possessed a crystal orientation which varied with film thickness. For both LiF and NaCl, films thinner than ~100 Å showed some degree of $\langle 100 \rangle$ orientation, and as the film thickness was in-

creased, the orientation changed first to completely random and then to $\langle 111 \rangle$ for LiF and $\langle 110 \rangle$ for NaCl. Recently, Aboelfotoh^{3,4} also found that the crystal orientation of MgO (NaCl structure) films deposited on amorphous substrates at an oblique angle varied with film thickness. Films of thickness in the range from ~100 Å to ~500 Å showed a random orientation while those thicker than 500 Å showed a tilted $\langle 111 \rangle$ orientation. This letter describes further observation made on preferred orientations in MgO films on amorphous substrates and discusses their origin.

The films were deposited on glass substrates kept at 30 °C at a rate of 1–3 Å/sec with an electron gun.⁴ The films were then annealed in vacuum at a temperature in the range 400–550 °C for 1 h. The substrates were first outgassed by heating in vacuum to 300 °C, then allowed to cool to 30 °C. During deposition the pressure was maintained at $\sim 1 \times 10^{-5}$ Torr. The thickness of the films and the deposition rate were monitored by a quartz crystal located close to the substrate. The thickness range studied was from less than 50 Å to 4×10^4 Å. The films were examined by grazing-incidence reflection high-energy electron diffraction.

The diffraction patterns obtained for films of various thicknesses deposited at normal incidence are shown in Fig. 1. The patterns given by films thicker than 1000 Å are symmetrical with respect to the substrate

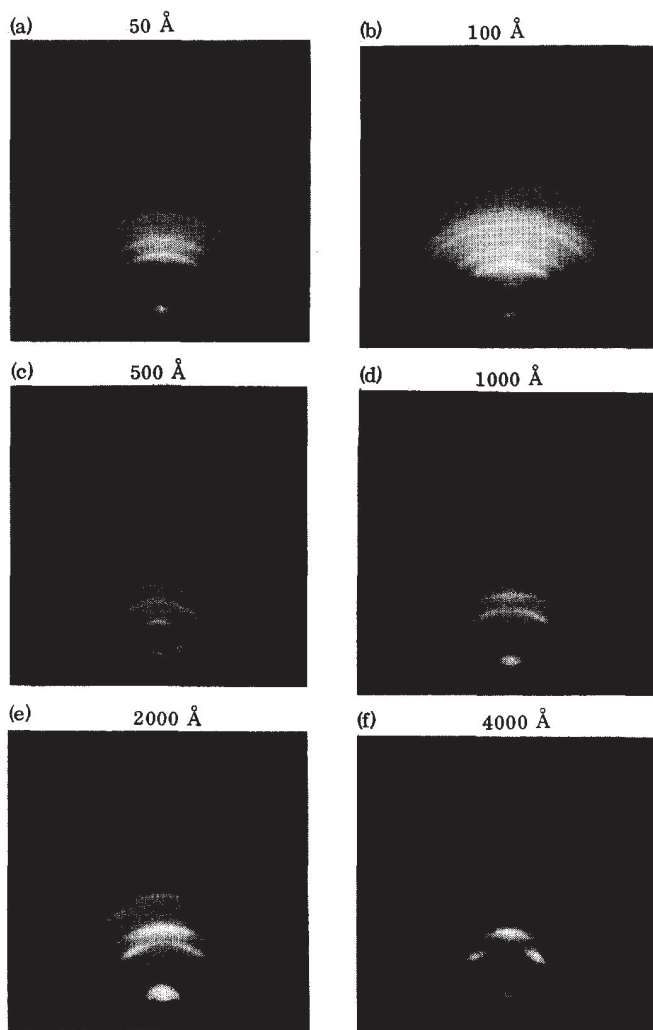


FIG. 1. Reflection electron diffraction patterns from MgO films deposited on glass substrates at 30 °C at normal incidence.

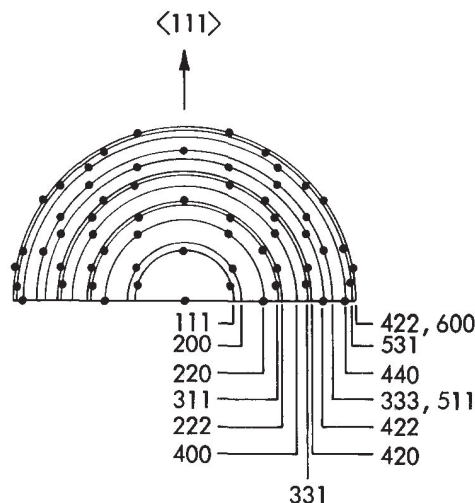


FIG. 2. Schematic representation of the diffraction pattern from $\langle 111 \rangle$ preferred orientation.

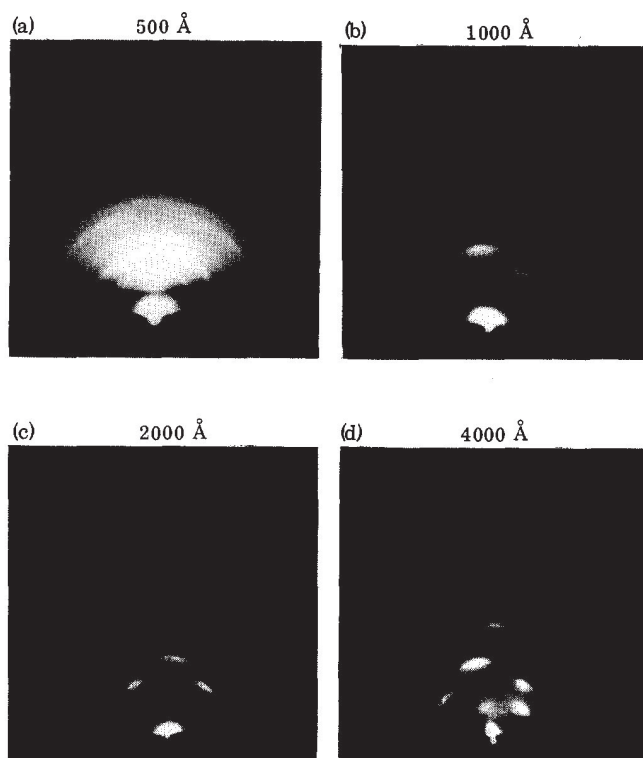


FIG. 3. Reflection electron diffraction patterns from MgO films deposited on glass substrates at 30 °C. The angle of incidence of the vapor beam varies continuously from $\sim 6^\circ$ to 20° during film deposition (see text).

normal, and this symmetry does not depend on the azimuth of incidence of the electron beam. Figure 2 shows a schematic diagram of positions of diffraction spots when the $\langle 111 \rangle$ axis of crystallites in MgO films is normal to the substrate surface. A comparison of the strong but diffuse spots in Fig. 1(f) with Fig. 2 shows that the surface structure of evaporated MgO films has a $\langle 111 \rangle$ preferred orientation. The direction of the $\langle 111 \rangle$ axis is dispersed within about 15° around the substrate normal. The present results and those previously reported⁴ thus show that the same preferred orientation develops at normal and oblique vapor incidence. Films thinner than 1000 Å, on the other hand, show a random orientation (Fig. 1).

Films were also prepared by holding the substrate at an angle to the vapor beam normal and then rotating the substrate holder about an axis which is laterally displaced with respect to the vapor beam normal during film deposition. This resulted in a continuous variation in the angle of incidence of the vapor beam from $\sim 6^\circ$ to 20° during film deposition. The patterns obtained for these films are shown in Fig. 3. These patterns are found to be symmetrical relative to the substrate normal when the electron beam is parallel to the plane of incidence of the vapor beam [for example, Fig. 3(c)] and asymmetrical when the electron beam is perpendicular to the plane of incidence of the vapor beam [for example, Fig. 3(d)]. This indicates that the $\langle 111 \rangle$ axis is tilted away from the substrate normal. Figure 4 shows the patterns obtained from films deposited at 30 °C and then annealed in vacuum at 400 and 500 °C for

1 h. These patterns show that the $\langle 111 \rangle$ orientation developed at 30 °C remains unchanged upon annealing, thus suggesting that the $\langle 111 \rangle$ deposition texture is energetically stable.

At a pressure of 10^{-5} Torr during film deposition the number of residual gas molecules striking the substrate surface is comparable to that of the vapor molecules. Because of the small surface area of the vapor source compared to the walls of the evaporation system which are at room temperature, the residual gas molecules can be assumed to be in thermal equilibrium with the walls. They have, therefore, a much lower temperature than the vapor molecules. The vapor molecules can then lose some of their energy by transferring it to the adsorbed gas molecules. The lifetime of the vapor molecules on the substrate surface is, therefore, increased and that of the residual gas molecules is decreased. Thus, the interfacial interaction between the deposit molecules or ions and the substrate can be assumed to be quite strong.

As a result of the strong interfacial interaction between the deposit molecules or ions and substrate (in this case, a low interfacial energy predominates over the surface free energy), the mobility of the deposit molecules or ions on the substrate surface is decreased, the nucleation frequency is, therefore, increased and, due to the random arrangement of the substrate ions, no preferred orientation is developed. The fact that the crystals nucleate in random orientation (Fig. 1) indicates that the interfacial energy between the crystal and substrate is independent of crystal orientation. On

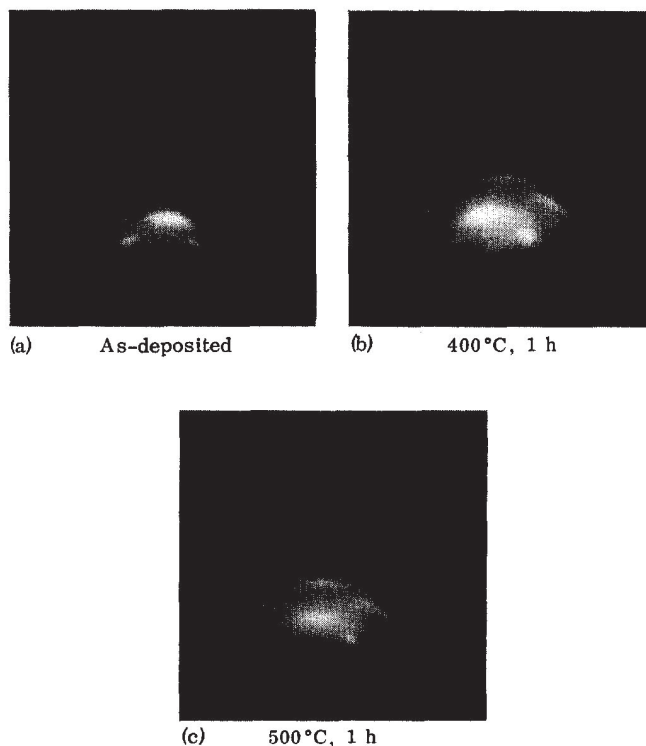


FIG. 4. Reflection electron diffraction patterns from 2000-Å-thick MgO film deposited on glass substrates at 30 °C (a) and then annealed in vacuum at 400 °C (b) and 500 °C (c) for 1 h.

the other hand, if the interfacial interaction is weak (here, the surface free energy predominates over the interfacial energy), a $\langle 100 \rangle$ orientation would be preferred since this orientation best minimizes the surface free energy. This orientation has not, however, been observed in MgO on glass substrates. The appearance of some degree of $\langle 100 \rangle$ orientation in LiF and NaCl² on glass substrates thus indicates that the interfacial interaction of LiF and NaCl is not as strong as that of MgO on glass substrates.

With increasing film thickness, a $\langle 111 \rangle$ orientation develops with an axis normal to the substrate surface at normal vapor incidence and tilted away from the substrate normal at oblique vapor incidence. If the tilted $\langle 111 \rangle$ orientation originates from the preferential growth of those crystals out of the random initial deposit in azimuths such that the $\{100\}$ faces are more or less facing the vapor beam,⁵ the orientation would then be expected to be $\langle 100 \rangle$ at normal vapor incidence. Furthermore, if the orientation is due only to differences in the growth rates of planes of dense atomic packing,⁶ the orientation axis would be expected to be normal to the

substrate surface independent of the angle of incidence of the vapor beam. This is not, however, what has been observed experimentally, the fact that the $\langle 111 \rangle$ axis tilts away from the substrate normal and toward the vapor beam at oblique vapor incidence suggests that the $\langle 111 \rangle$ orientation is influenced by the supply of vapor ions or molecules. The $\langle 111 \rangle$ growth orientation may then originate from the growth competition between differently oriented crystals due to differences in the number of ions or molecules condensing on them, i.e., the orientation is due to the angular dependence of the condensation coefficient as suggested by Bauer.¹

¹E. Bauer, in *Single Crystal Films*, edited by M. H.

Francombe and H. Sato (Pergamon, London, 1964), p. 43.

²L.G. Schulz, *J. Chem. Phys.* 17, 1153 (1949).

³M.O. Aboelfotoh, *Bull. Am. Phys. Soc.* 18, 495 (1973).

⁴M.O. Aboelfotoh, *J. Vac. Sci. Technol.* 10, 621 (1973).

⁵D.M. Evans and H. Wilman, *Acta Crystallogr.* 5, 731 (1952).

⁶W.M.H. Sachtler, G. Dorgelo, and W. Van Der Knapp, *J. Chem. Phys.* 51, 491 (1954).

Alignment and wetting properties of nematic liquids

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Contrary to recent claims, no correlation of useful predicting power exists between the tendency of a nematic liquid to align transverse to a solid surface and the difference between the surface free energies of the nematic liquid and of the substrate. Observations that lead to this conclusion are reported for systems in which (i) the composition but not the surface tension of the nematic liquid, (ii) the adsorbed layer and hence the surface free energy of the substrate, and (iii) the temperature is varied.

It has been known¹⁻⁴ for some time that some nematic liquid crystals, in particular *p*-methoxy-benzylidene-*p*-*n*-butylaniline (MBBA) align with their optic axes perpendicular to solid surfaces upon which a molecular layer containing hydrocarbon chains had been adsorbed. It has also been known⁵ that such surfaces have low surface free energies characteristic of pure hydrocarbons. Recently, these observations have been generalized^{6,7} to claim that the alignment properties of a solid-to-nematic interface and the wetting properties of the interface are correlated. It is the purpose of this letter to present experimental evidence that no such correlation of useful predicting power exists.

In the absence of external electric or magnetic fields, the orientation of the optic axis of a thin layer of nematic liquid is determined by forces acting in the vicinity of the solid-liquid interface since the boundary conditions are propagated into the bulk by the well-known⁸ elastic forces in the nematic liquid. There are numerous interactions (on a molecular scale or slightly longer range) that lead to a lowering of the energy of the

nematic liquid in the vicinity of the interface by orienting the molecular axes,⁹ but only one of these mechanisms, namely the effect of surface topology,¹⁰ is presently understood in detail. The question is whether it is *useful* to consider the sum total of these interactions, as they are demonstrated in the wetting properties, and without regard to their directionality, as a predictive indicator for the alignment tendency of a given solid-nematic interface.

The contact angle α of a liquid resting on a solid substrate is an experimentally easily accessible measure of the energetics at the interface¹¹; that is,

$$\gamma_S - \gamma_{SL} = \gamma_L \cos \alpha, \quad (1)$$

and

$$W_A \equiv \gamma_S + \gamma_L - \gamma_{SL} = \gamma_L (1 + \cos \alpha). \quad (2)$$

Here γ_S , γ_L , and γ_{SL} are the free energy per unit area of the solid and liquid surfaces and of solid-liquid interface, respectively, and W_A is the work of adhesion. Of these energy quantities γ_L is measured easily by in-