

The Spin-Coating Process Mechanism Related to Polymer Solution Properties

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Coating the substrate with an amorphous polymer layer is a very common process in the manufacturing of integrated circuits, but the fundamental spin-coating mechanism has not yet been precisely determined. This study examines the influence of the macromolecular characteristics on the spin-coating process both experimentally and from a phenomenological point of view. It is concluded that the weight-average molecular weight of the spun-on solution is a pertinent parameter, and that chain entanglements in polymer solutions may be considered as the basic phenomenon responsible for the formation of the solid polymer layer.

INTRODUCTION

The spin-coating process is extensively used, particularly in microelectronics, for coating planar or pseudoplanar surfaces. Spin coating has long been accepted as the best coating method for obtaining a thin (0.2–2 μm), uniform, adherent, homogeneous film over the wafer. It is accomplished by flooding the substrate with a polymer solution and rotating it at a constant speed (1000–8000 rpm) until the solvent has evaporated. For a given polymer solution and a given piece of equipment, the thickness of the film depends on the rotating speed. Figure 1 gives an example of a spinning curve showing the final polymer layer thickness, t , as a function of rotating speed, ω .

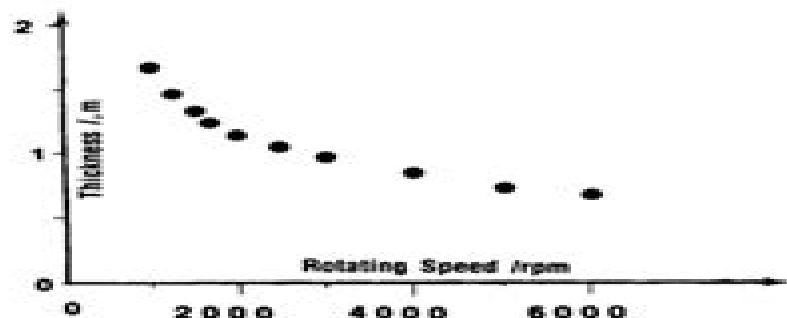


Fig. 1. Spinning curve showing polymer layer thickness, t , as a function of rotating speed, ω . PMMA 2041, 9% in chlorobenzene, bake 10 min at 160°C in a belt oven.

It already has been noted elsewhere (1–5) that $\log(t)$ versus $\log(\omega)$ is always linear:

$$t = K\omega^\alpha$$

and that α is found to vary from 0.4 to 0.7. The theoretical value of 0.67 is foreseen in the work of Washo (1), based on the following three assumptions: the solution is a newtonian fluid, the volumetric flow rate is constant, and there is no evaporation of solvent during spinning.

But it is reasonable to assume with Chen (2), Mayerhofer (3), and Lai (4) that some evaporation of the solvent (cellosolve acetate, butyl acetate, chlorobenzene, etc.) occurs during the spinning process, simultaneously with the flow of the solution on and off the wafer, although current solvents are not highly volatile fluids. Considering the investigation of the solvent-evaporation effect presented by Chen (2), the film layer begins to form during rotation. Therefore, it is necessary to include, in the hydrodynamic equations, the effect of heat transfer in addition to momentum transfer (fluid flow) and mass transfer (solvent evaporation). A quantitative correlation is found for film thickness, t , as a function of evaporation rate, E ; latent heat of evaporation, λ ; heat capacity of the evaporating solvent, C_p ; initial newtonian shear viscosity of the solution, μ ; and angular velocity, ω :

$$t = K_0 \cdot \mu^{0.36} \cdot \omega^{-0.50} [E \cdot \lambda / C_p]^{-0.60}$$

where K_0 is a proportional constant for solvent solutions.

According to Chen's formula, the thickness of the film is not a direct function of either the

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