A CONTRIBUTION TO THE MEASUREMENT OF YOUNG'S MODULUS OF THIN FILMS

The paper describes a new method of measuring Young's modulus of thin films which takes advantage of length expansion anisotropy of suitably selected substrates. In the conclusion the results of measuring Au, Ag and Cr thin films in high vacuum on the singlecrystalline quartz substrate of AT cut are given.

The stress in thin film deposited on the substrate could be divided into two components. The first one - thermic component $\sigma_t$ - occurs at various coefficients of thin film length expansion $\alpha_f$ and substrate $\alpha_s$ and the temperature difference $\Delta T$ of the substrate during thin film condensation and during measuring of stress. The second component is the intrinsic stress $\sigma_i$ which appears as the consequence of thin film condensation mechanism. The resulting stress is given by the sum of both components:

(1) $\sigma = \sigma_i + \sigma_t$

where

(2) $\sigma_t = E_f (\alpha_f - \alpha_s) \Delta T$

$E_f$ is thin film Young's modulus the value of which generally differs from that given for the bulk material. From the physical point of view we usually are interested in the intrinsic stress determined from the relations (1) and (2). In most cases it is taken for granted that the length expansion coefficient equals to that of thin film as well as to that of bulk material.

The suggested method for determination of $E_f$ takes advantage of the results of thin film stress measurements at different $\Delta T$ on the substrates which have pronounced anisotropy of length expansion coefficients.

For the stresses measured in the direction of main axes of ellipsoid $\alpha_s$ which are at the same time the minimum and maximum measured stresses, the following system of equations is applied when the further-given presumptions are respected:

(3) $\sigma_1 = \sigma_i + E_f (\alpha_f - \alpha_{s1}) \Delta T$

(4) $\sigma_2 = \sigma_i + E_f (\alpha_f - \alpha_{s2}) \Delta T$

where $\alpha_{s1}$, $\alpha_{s2}$ are the coefficients of length expansion in the direction of main axes of ellipsoid $\alpha_s$. The condition for validity of the system is:
a) $\sigma_1$, $\sigma_2$, and $E_f$ must be isotropic. In most cases this can be reached when the flow of vapors is parallel to the normal of the substrate. For the thin films, when the substrate temperature is lower than that of epitaxy, only the uniaxial growth texture with random orientation in the plane of the substrate occurs at the most. The fulfillment of this condition can be verified by measuring $\sigma_1$, $\sigma_2$ at $\Delta T = 0$ or by structural analysis.

b) $\sigma_1$, $\sigma_2$ stresses must be smaller than the stresses corresponding to the given thin film thickness of the plastic deformation limit.

c) The formation condition of the layer must be such as to prevent the change of composition (e.g. oxidation) or thin film structure at high $\Delta T$.

We obtain Young's modulus by solving the system of equations (3) and the evaluation can be done graphically according to the relation

$\sigma_2 - \sigma_1 = E_f (\alpha_{S1} - \alpha_{S2}) \Delta T \tag{4}$

The suggested method was applied to the determination of $E_f$ of Au, Ag and Cr thin films evaporated at high vacuum ($p < 5 \times 10^{-6}$ torr) on variously hot substrates made from singlecrystalline quartz of AT cut which results in $\alpha_{S1} - \alpha_{S2} = 4.40 \times 10^{-6} K^{-1}$. The measuring results are plotted accordingly to the relation (4) in the graph in fig.1. For measurements of $\sigma_1$ and $\sigma_2$ the interferential method of determining the deflection of circular substrates /1/ was used as well as the photographic registration of Newton's rings. The measurement errors depend on the

![Graph](image-url)

Fig.1. The results of Young's modulus measurements of Au, Ag and Cr thin films plotted according to the relation (4).