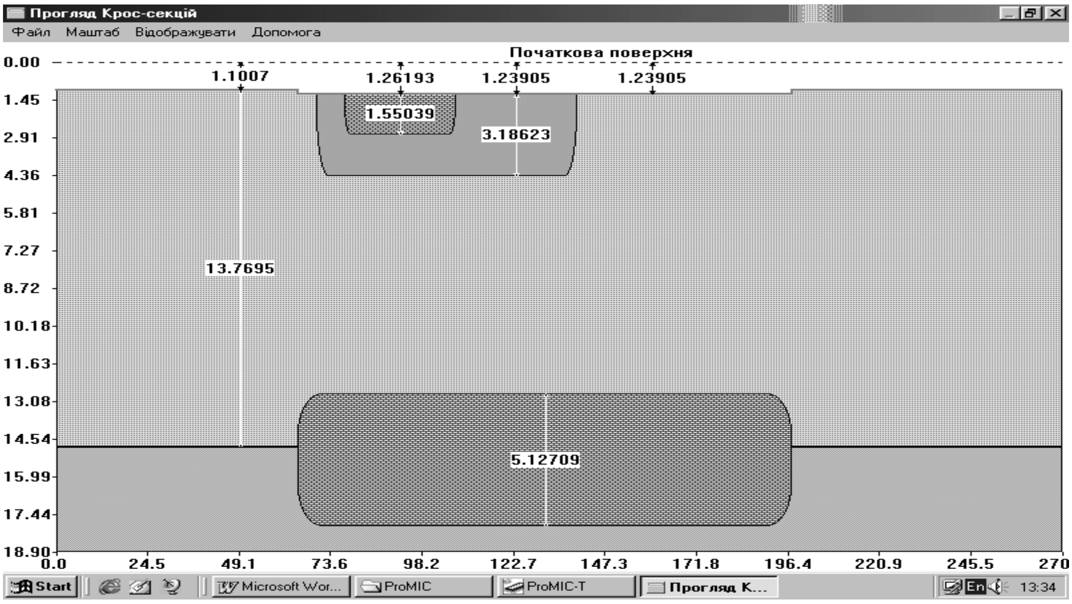

Рис. 5. Характеристики рельєфу напівпровідникової структури виробу К1021ХА5

ням концентрації домішки швидкість окислення кремнію значно зростає), то, відповідно, кремнію в даній області буде витравлено більше, ніж в інших напівпровідникових областях.

Аналогічна картина спостерігається і при виготовленні виробу L1488 (рис. 4).

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METHOD OF PARAMETER CONTROL OF DIELECTRIC LAYER PHASE THICKNESS ON SI CRYSTAL SURFACE

Conditions for the formation of light wave reflection amplitude spectra minima by the three-layer system of interfaces of the type: vacuum – oxide plane-parallel layer (resonator) – bulk crystal in the phonon region are investigated.

Analytic expressions connecting the frequency that corresponds to the minimum of reflection contour with the parameters of dielectric films and resonant excitation of bulk TO-phonon are obtained.

1. INTRODUCTION

There is a great deal of interest in the investigation of semiconductor surface oxidation, and following development of testing methods for the layer parameters of intrinsic oxides such as for *ZnO–ZnSe,* SiO_2*–Si* and so on. Reflection spectroscopy in the region of optical phonon excita tion is conveniently to use to these effects[1]. Comparing to other collective excitations of crystal, as excitons, for example, optical phonons are less critical to the damping factor value[2] and are realized by the transverse nature of light as well as by simultaneous performance of both - the laws of conservation of energy and momentum during the lattice absorption of phonon. Therefore, during that it is possible to convert the photon only to transverse optical TO – phonon. Hence, the complex permittivity in the region of TO – phonon excitation spectrum is[3]

$$\tilde{\varepsilon}(\omega) = \varepsilon_\infty + \frac{(\varepsilon_0 - \varepsilon_\infty)\omega_{TO}^2}{(\omega_{TO}^2 - \omega^2 - j\omega\gamma)} = \varepsilon_1 + i\varepsilon_2 \quad (1)$$

where ε_0 – static and ε_∞ – dynamic permittivities of the crystal, ω_{TO} – resonance phonon frequency, γ – damping factor.

This paper proposes a way of solving the problem. As it is known[4] if there is a non-dispersive layer on the crystal surface then the spectral position of out-line minimum is determined as by the parameters of collective excitation as by phase thickness of the surface layer. The phase shift together with the shift on a boundary of substrate – layer is 2π what opens the possibility to establish the dependence of ω_m upon the layer parameters.

2. RESULTS AND DISCUSSION

The reflection complex amplitude $\tilde{r}_{13}$ from the plane parallel layer on the crystal surface for any arbitrary angle of incidence taking into account multi-beam interference is

$$\tilde{r}_{13} = \tilde{r}_{12} + \frac{\tilde{r}_{23}(1-\tilde{r}_{12}^2)exp(-i\delta_s)}{1-\tilde{r}_{21}\tilde{r}_{23}\,exp(-i\delta_s)}. \quad (2)$$

Here, 12 and 23 indices correspond to interfaces of vacuum – layer and layer – substrate, $\delta_s = \frac{4\pi n_s d_s}{\lambda}$ – is the wave phase shift in the layer with thickness d_S and refractive index n_s.

In (2) first term is conditioned by the wave reflection from external interface (reference beam), and second term is due to multireflection of the beam inside the layer (informative beam). These beams are coherent, they interfere and resulted interference pattern is determined by physical parameters of resonator reflection system. For the wave-lengths λ_m which correspond to reflection minimum the following condition should be valid

$$\frac{d\tilde{r}_{13}}{d\omega} = 0, \quad (3)$$

and according to (2) at the wave-lengths λ_m the condition of phase compensation is

$$\varphi_{23} + \delta_S = m\pi, \quad (4)$$

where m – is arbitrary whole number, φ_{23} – is wave phase shift at the reflection from the internal interface of substrate – layer.

It is easy to see that condition (4) is correct only in the region of out-line refection minimum by the following. According to (2) energetic reflection coefficient $R_{13}(\omega)$ is

$$R_{13} = \tilde{r}_{13}\tilde{r}_{13}^{*} = \frac{(\rho_{12}-\rho_{23})^2 + 4\rho_{12}\rho_{23}\sin^2\frac{\Delta}{2}}{1+\rho_{12}^2\rho_{23}^2 - 2\rho_{12}\rho_{23}\cos\Delta}, \Delta = \phi_{23} + \delta_s, \quad (5)$$

where $\tilde{r}_{ij} = \rho_{ij}\exp(i\phi_{ij})$. The expression (5) as a light frequency function has a unique extremum – minimum in the point of $\omega = \omega_m$ where the following conditions are satisfied

$$\frac{dR_{13}}{d\Delta} = 0 \qquad \text{and} \qquad \frac{d^2R_{13}}{d\Delta^2} > 0. \quad (6)$$

The condition (5) allows to establish the correlation between the parameters of ω_m, δ_S and n, χ – hat are optical refractive and absorption indices in the substrate bulk.

In fact, according to the definition of tangent of wave phase shift at reflection from the interface of layer – substrate

$$\tan\varphi_{23} = \frac{Im\,\tilde{r}_{23}}{Re\,\tilde{r}_{23}} = \frac{2\chi n_s}{\varepsilon_s - n^2 - \chi^2}, \quad (7)$$

where permittivity $\varepsilon_s = n_s{}^2(\chi_s = 0)$. Taking into account (4) the equation (7) become

$$\varepsilon_s^2 + \varepsilon_1^2 + \varepsilon_2^2 + \frac{2\varepsilon_s\varepsilon_1}{\tan^2\delta_s} = \frac{2\varepsilon_s}{\sin^2\delta_s}(\varepsilon_1^2 + \varepsilon_2^2)^{1/2}. \quad (8)$$

Its solution gives the answer on our issue[5,6]. Having found real and imagine parts in (1) and put them in (8) we have the following 4rd order equation relatively ω^2:

$$(2\varepsilon_S\varepsilon_\infty + (\varepsilon_S^2+\varepsilon_\infty^2)\tan^2\delta_S)^2 - \left(\frac{2\varepsilon_S\varepsilon_\infty}{\cos^2\delta_S}\right)^2 +$$

$$+\left[\frac{2(\varepsilon_\infty^2+\varepsilon_S\varepsilon_\infty)\tan^2\delta_S\Delta_{LT}^2(\omega_{TO}^2-\omega^2) + \varepsilon_\infty^2(\varepsilon_S^2+\varepsilon_\infty^2)\Delta_{LT}^2\tan^2\delta_S}{(\omega_{TO}^2-\omega^2)^2+\omega^2\gamma^2}\right]^2 -$$

$$-\left(\frac{2\varepsilon_S\varepsilon_\infty}{\cos^2\delta_S}\right)^2\frac{(\Delta_{LT}^2 + 2(\omega_{TO}^2-\omega^2)\Delta_{LT}}{(\omega_{TO}^2-\omega^2)^2+\omega^2\gamma^2} + 2(2\varepsilon_S\varepsilon_\infty + (\varepsilon_S^2+\varepsilon_\infty^2)\tan^2\delta_S) *$$

$$\frac{2(\varepsilon_\infty^2\tan^2\delta_S + 2\varepsilon_S\varepsilon_\infty)\Delta_{LT}(\omega_{TO}^2-\omega^2) + \varepsilon_\infty^2\Delta_{LT}^2\tan^2\delta_S}{(\omega_{TO}^2-\omega^2)^2+\omega^2\gamma^2} = 0. \quad (9)$$

For the sake of simplicity let us suppose that $\varepsilon_s = \varepsilon_\infty$ then Eq. 9 is summarized as following

$$\Omega^2 + \Omega\left(\frac{\Delta_\varepsilon\omega_{TO}^2}{\varepsilon_\infty} + \frac{\gamma^2}{\tan^2\delta_s}\right) + \left(\frac{\sin\delta_s}{2\varepsilon_\infty}\Delta_\varepsilon\omega_{TO}^2\right)^2 - \frac{4\varepsilon_\infty^2\cos^2\delta_s\omega_{TO}^2\gamma^2}{\sin^4\delta_s} = 0 \quad (10)$$

and has a solution

$$\omega_{min}^2 = \omega_{TO}^2 + \frac{1}{2}\left(\Omega + \sqrt{(\Omega^2 - \sin^2\delta_S \Delta_{LT}^2 + \omega_{TO}^2\gamma^2 \cot an^2\delta_S\,)}\right) \tag{11}$$

$$\Omega = \Delta_{LT} - \gamma^2 \cot an^2\delta_S, \quad \Delta_{LT} = \omega_{LO}^2 - \omega_{TO}^2, \; \Delta_\varepsilon = \varepsilon_0 - \varepsilon_\infty$$

If the condition $\gamma \langle\langle \omega_{TO}$ is satisfied, then Eq. 11 is reduced to

$$\Omega^2 + \Omega \frac{\Delta_\varepsilon \omega_{TO}^2}{\varepsilon_\infty} + \frac{\sin^2\delta_s}{4\varepsilon_\infty^2}\Delta_\varepsilon^2\omega_{TO}^2 = 0\,, \tag{12}$$

with solution

$$\omega_m^2 = \omega_{TO}^2\left[1 + \frac{\Delta_\varepsilon}{\varepsilon_\infty}\cos^2\frac{\delta_S}{2}\right]. \tag{13}$$

It follows from (13) that energetic minimum position of phonon reflection out-line oscillates periodically between the limit spectral positions of phonon resonance frequencies ω_{TO} and ω_{LO}. In limiting case when $\delta_S \to 0$ solution (13) coincides with well-known Saachs-Teller-Lyddane expression

$$\omega_{min}^2 = \omega_{TO}^2 \frac{\varepsilon_0}{\varepsilon_\infty} = \omega_{LO}^2\,, \tag{14}$$

that confirms the correctness of the proposed approach.
Let us see the dynamics of phase spectra variation. As it follows from

$$\frac{dR_{13}}{d\Delta} = 2\,Re\,\tilde{r}_{13}\left(\frac{d\,Re\,\tilde{r}_{13}}{d\Delta} + \tan\varphi_{13}\frac{d\,Im\,\tilde{r}_{13}}{d\Delta}\right) = 0\,, \tag{15}$$

if the godograph $\tilde{r}_{13}$ locus crosses the coordinate origin at the frequency of ω_{min} then the phase out-line changes its spectral shape as it peculiar to excitonic part of the spectrum[6]. If it envelopes the origin of coordinates then $\varphi_{13}(\omega)$ out-line has a “S” shape otherwise it has “N” shape.

CONCLUSIONS

The out-line minimum of phonon reflection wave from interfaces of vacuum – nondispersive layer – bulk with resonance dispersion of permittivity locates at the frequency of phase compensation. Spectral position of out-line minimum is determined by the layer phase thickness and parameters of resonant excitation in crystal. The frequency of out-line reflection minimum oscillates at the variation of layer phase thickness in limits of longitudinal-transverse splitting.

Phase $\phi_{13}(\omega)$ of reflection wave is multiple to π at the frequency of reflection curve minimum. The proposed approach is correct for arbitrary case of reflection for Hertzian waves by three layer structures.

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