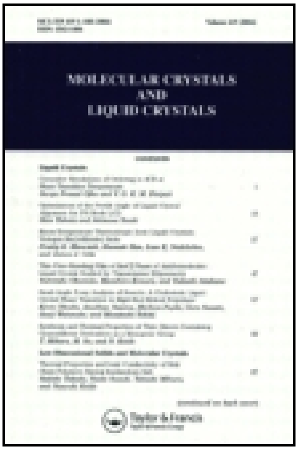

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

LC Vision: the New Application to Silicon Surface Defects Testing

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Version of record first published: 24 Sep 2006

To cite this article: M. G. Tomilin, S. Yu. Kerpeleva & E. I. Terukov (2001): LC Vision: the New Application to Silicon Surface Defects Testing, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 368:1, 1-8

To link to this article: http://dx.doi.org/10.1080/10587250108029924

Mol. Cryst. and Liq. Cryst., 2001, Vol. 368, pp. 1-8
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LC Vision: the New Application to Silicon Surface Defects Testing

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The thin layers of oriented NLC applied on the surface under investigation as a free film can visualize through a polarizing microscope structural inhomogeneities and microrelief defects. On this basis a nondestructive method to study substrates quality has been developed. The results of defect detection on different silicon surfaces are discussed for the first time.

Keywords: silicon surface; structural defects; substrate testing

INTRODUCTION

The investigation of silicon surfaces defects is an important problem LCD's substrates manufacturing. We studied the capability of a new method for TFT-LCD's substrates testing using nematic liquid crystals (NLC) recently developed [1]. The technique also may be applied for testing microelectromechanical elements and solar cells.

The history of NLC technique use dates back from 1916 when nematics applied on the surface of some minerals were found to orientate themselves spontaneously towards fixed crystallographic directions [2]. In 1970 P. G. de Gennes future Nobel prizeman established that the number of directions of easy orientation is related to the symmetry of a substrate. Ten years later N. Tichomirova and A. Ginsberg investigated surface symmetry properties of some crystals: NaCl, KBr, LiF, GASH, etc. [3]. However the main attention in that pure scientific experiments was drawn more to the NLC molecules behavior on the surface rather than to the surface quality analysis.

The first technical applications were proposed for solid surface topographical studies by applying electrical field on NLC layer [4, 5]. In 1985 we proposed to use the NLC films for nondestructive testing of optical materials under no-field conditions. This technique was called LC vision. The basic theory of LC vision was developed two years later [6]. During last ten years the NLC technique was efficiently used in material science: mineralogy, crystallography, metallography and also in medicine [7,8].

In original part of the paper the main attention would be devoted to the new field of LC vision application for silicon substrate defects detecting. The experiments were limited by structural defects detecting in *a*-Si:H layers.

2.THE PRINCIPLE OF NLC TECHNIQUE

Here we discuss the application of NLC for visualizing through a polarizing microscope the images of microrelief or structure defects on the silicon surfaces. The recording of these regions becomes possible if the NLC deformed structure is illuminated in transmissive or reflective modes and observed through optical microscope with crossed polarizes and appearing figure is compared to the background structure. The principle scheme of the NLC is shown on Fig.1.

The light intensity over NLC layer I(x,y) modulated by deformed NLC structure is described by equation:

$$I(x,y) = I_0 Sin^2[\,\delta(x,y)/2] \qquad (1)$$

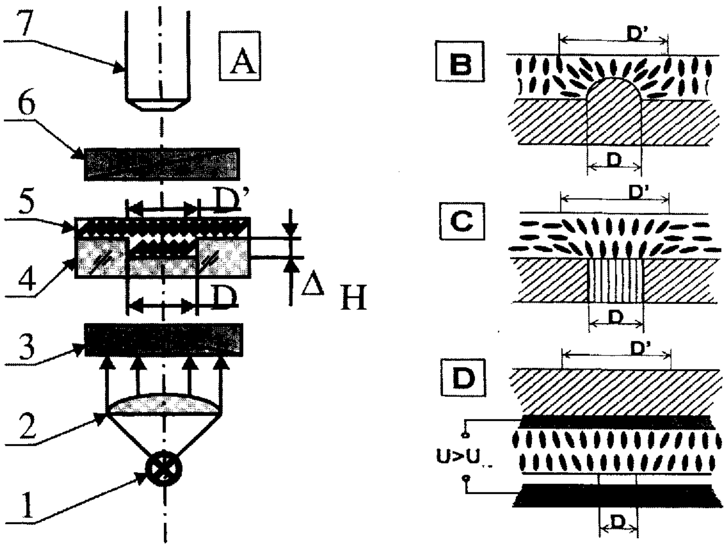


Fig.1 Scheme for visualizing defects on optical surfaces and patterns of NLC deformation in vicinity of the most typical defects: 1-radiation source; 2-condenser lens; 3-polarizer; 4-sample; 5-NLC layer; 6-analyzer; 7-microscope. D-size of defect; D'-size of its image in NLC layer. A,B-microrelief defects; C-structural defect; D- electrical or magnetic field distribution.

The phase delay δ(x,y) caused by the NLC birefringence is equal to:

$$\delta(x,y)= {2\pi}/{\lambda}\left[-n_0 \cdot H + \int_0^H n(x,y,z)dz\right] \qquad \textbf{(2)}$$

where H is the thickness of NLC film; n (x,y) is the film reflective index in deformed zone; n_0 is the refractive index of a non-deformed layer. If the orientation field has no twist deformation then only orientation bending occurs, hence:

$$n\,(x,y,z) = [n_e^{-2} Sin^2\varphi(x,y,z) + n_0^{-2} Cos^2\varphi(x,y,z)]^{-1/2} \tag{3}$$

Here φ(x, y, z) is the deflection angle of the long axis of the molecules with the respect to the surface normal; n_o, n_e are the refractive indices of NLC layer for ordinary and extraordinary polarization. The usual value of NLC optical anisotropy is equal to 0,2 but in extreme cases it may be up to 0,4. It permits to use very thin layers to obtain sufficient value of phase delay.

The recording process is simple, obvious and informative. Rotating polarizer and analyzer may optimize the observation. The main and virtually the sole operation is to put a uniform NLC layer a fraction of a micrometer thick on the substrate surface. Such a layer can be applied using a rotating table or even a simple paintbrush. The beating of the NLC to the temperature of transition to isotropic phase makes the film more uniform. The resolution of the NLC layer depends on its thickness and may be about 2000 lines/mm. The wetting conditions may be changed by special dopants. The reliable results in visualizing the defects on the surface are obtained by repeatable applying and removing the NLC layers and observing the stable defects images. The NLC layer may be easily removed by a solution of alcohol or acetone.

The NLC film distorts the real images of the surface defects because of its elasticity. To retrieve the information about the real size of the defects when only the size of their images is known a theory was developed. The theory was used to describe in analytic form the defect's image formation process and its relation to NLC film parameters.

Another problem of LC vision theory is the sensitivity of the NLC technique. It is apparent that such sensitivity depends on the experimental conditions, physical nature of defect origins and the sort of LC layer.

On the first stage the phase delay that appears during the radiation transport through the NLC layer was theoretically considered. It was regarded as function of the surface interaction energy fluctuations because of surface defects. But now

in doing so we have to take into accounts the average interaction energy. In this case the sensitivity S is given by derivative:

$$S = d\Phi/dE, \tag{4}$$

where E is the fluctuation of interaction energy. But for final sensitivity determination the methods of information theory of optical image are to be applied. They permit to take into account the thermal LC-noise as well as that of surface itself, the regular surface pattern spectrum and recording device transfer function. This approach promise to give the limits of both sensitivity and resolution of NLC technique in visualizing the defects [9].

3. RESULTS

The silicon substrates are widely used in solar cells, microelectronic and micromechanic elements. The visualizing of structural defects permits to select defects free materials and substrates for improving their parameters and durability.

The LC vision is compared with other inspection technique such as chemical etching (destructive method), X-ray testing for detection internal volume defects, electronic microscopy and NLC testing with applying electric field for detection only surface defects. The common disadvantage of these methods is the unsuitableness for large size silicon substrates (D = 400 mm) testing that must be produced for nearest future application. LC vision is the best way for direct observation of structural defects distribution on the large size surfaces using only light microscope technique.

The example of examining the *a*-Si:H film surface deposited by magnetron sputtering on p-type Si substrate is shown on Fig. 2. LC vision gives the opportunity to visualize the regions of structural inhomogeneities caused by structural defects on the substrate itself. The same type of defect is observed on the opposite side of the substrate without *a*-Si:H film. It illustrates the influence of substrate morphology on *a*-Si:H film structural inhomogeneity.

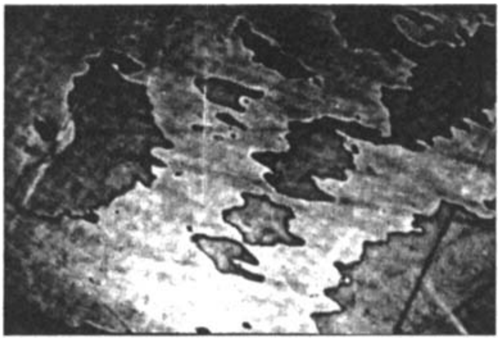
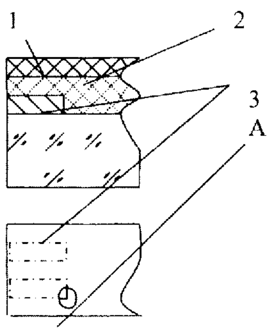


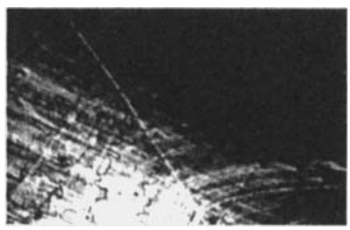
Fig. 2. The structural defects in *a*-Si:H visualized with NLC. Magnetron sputtering, magnification 300^X, MBBA, t°=18°C.

The same effect of the substrate structure influence is illustrated on Fig. 3. The configuration of Cr electrodes evaporated on the glass substrate is observed through *a*-Si:H film.



Geometry of experiment.
1 – NLC; 2 – *a* – Si:H film;
3 – Cr - electrode.

A



Electrodes configuration visualized by NLC on the surface of *a*–Si:H film deposited by glow discharge. Magnification 300^X, MBBA, t°=18°C.

Fig. 4 demonstrates the microcrystalline Si inclusions in *a*-Si:H film induced by the structural defect on vitrous glass substrate.

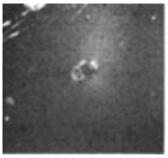


Fig. 4. The inclusions in a-Si:H detecting by NLC. Magnertron sputtering, magnification 300^X, MBBA, t°=18°C

The similar situation is shown on Fig.5. The local centers of crystallization in a-Si:H layers visualized by NLC technique may be caused by Er clusters. In this case structural defects in a-Si:H depends not on substrate but on a-Si:H film homogeneity itself.

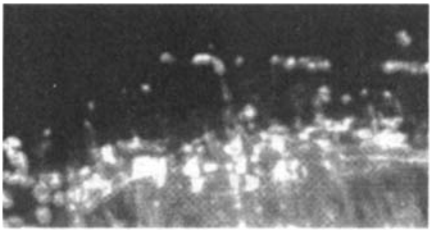


Fig. 5. Centers of crystallization in a – Si:H, caused by clusters of erbium. Magnertron sputtering, magnification 300^X, MBBA, t°=18°C.

4. CONCLUSION

LC vision was adapted for the first time for testing *a*-Si:H layers on different substrates. The experiments revealed high efficiency of LC vision in detecting structural inhomogeneities on the surfaces of *a*-Si:H layers.

Most of structural defects on the surface of *a*-Si:H films were caused by the substrate defects. It shows the important role of substrate surface quality in the technological process of silicon substrate manufacturing. LC vision also may be applied to the substrate surfaces quality testing and to investigation of other silicon materials modifications.

LC vision seems to be a fruitful testing technique for different countries Silicon Valleys.

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