Diffractive Liquid Crystal Displays

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Abstract

An overview of author activity in the area diffractive LCDs are given. The formation of colour spectrum DL CDs is made by switchable phase diffraction gratings created in a LC layer due to using of comb-like electrodes. The offered DLCDs functionate without polarizes, have high contrast and spectral of pure colours, broad viewing ngles. The existing production equipment can be adapted to manufacturing of DLCD without considerable alterations.

Keywords : LC, diffraction gratings, spectra, colours.

1. Introduction

Up to now two main systems of color selection are known and widely used in LCD technology. In the first one color selection is implemented by matrix color filters (MCF). In the second one birefringence layers are involved which are performed from photopolymers. Both systems have essential drawbacks.

The main drawback of the known systems is the large passing light losses which are stipulated by:

- utilizing the two polarizes , that make more than 50 % of losses;
- dividing a pixel onto three subpixels, (the losses reach 66,6 %);
- light absorption in the bulk of the filters (only for the first one of the mentioned systems), that gives 30-40 % of losses.

With due regard for all substantial losses the real light transmittance is of 6-10 % for the first system and 15-20 % for the second one.

Both systems have very poor observation angles.

Another drawback is the high cost price of the product. It is stipulated by usage of expensive polarizes and by large costs at manufacturing. According to some sources, costs of manufacturing of the MCF reach up to 70-80 % of the whole colour display unit price. The considerable contribution to the high cost price of LCD introduce the costs of liquid crystal material, which should obey high requirements, and of display design which meets rigid requirements to high accuracy of keeping LC gap at constant value through the whole LC screen, homogeneity of LC orientation etc.

2. The Offered System of Colour Selection

The offered system of colour selection is based on principles of white light diffraction when dispersing the white light into its constituent wavelengths is implemented by electrically switchable phase grating. Such phase grating can be realized by utilizing fringing electric fields from transparent interdigitated electrodes penetrating a thin layer of any aligned LC material. The dielectric coupling of LC will tend to align LC molecule axes along the field lines of fringing electric field. Such way an anisotropic phase grating in LC media is formed with a period limited by only the lithographic process possibility used to fabricate the interdigitated electrodes . We named this display as "Diffractive LC display (DLCD)".

Manuscript received February 12, 2003; accepted for publication March 17, 2003.
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3. Design of Pixel and Operation Principle

The pixel of DLCD includes (Fig. 1)[1,2]:

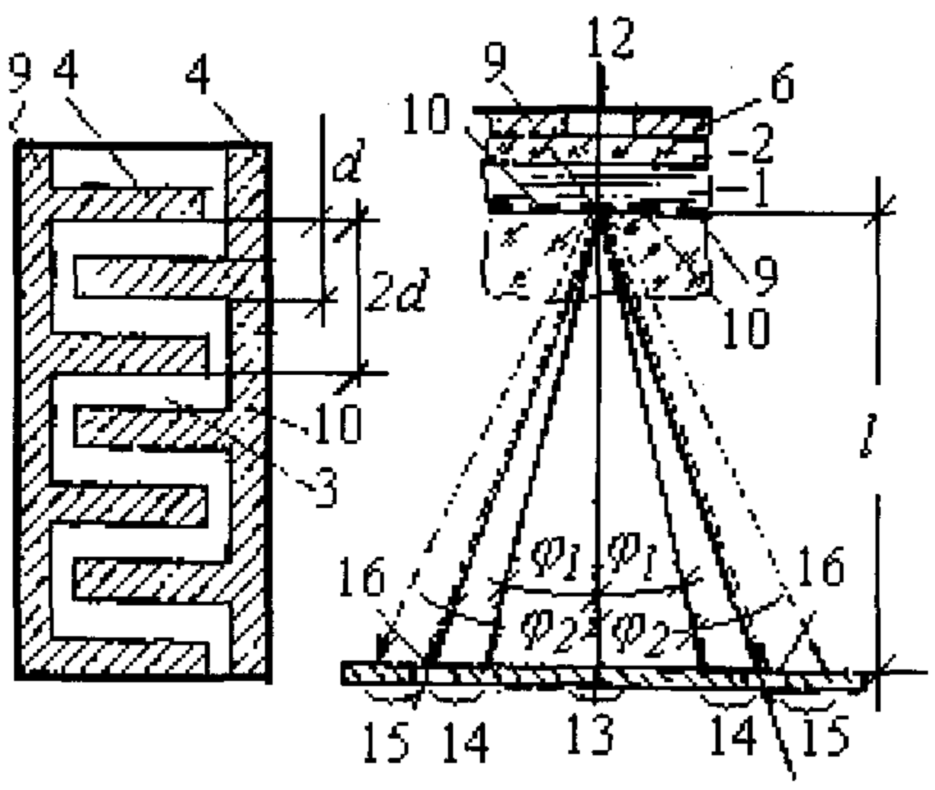

Fig. 1. Design of electrodes(a) and cell (b).

- LC layer (1), which is sandwiched between substrates (2);
- two transparent ITO electrodes (9, 10); one of them (input along the propagated light) is solid, the other has an interdigitated pattern. It consists of the two equal in size half parts with the period **Fig. 2** Formation scheme of two colours of **2*d** twice larger than the period of the net interdigitated electrode system equal to **d**.
- input (6) and output (7) opaque masks with slots (12, 16) respectively;

In a initial state all LC molecules have some homogeneous orientation, for example, planar. The rays of white light passing through the slots of the input mask, travel through the homogeneous LC layer and are absorbed by the output mask Under applying voltage across the solid electrode on one glass plate and one of the half part of the interdigitated electrode system on the other glass plate, the deformed hybrid texture of anisotropic LC media is formed and creates a phase grating with periodicity of **2*d** equaled to the period of the half part of the interdigital electrode system. Now diffraction effect is possible, and if the source light is polychromatic one, it is split into a spectrum of wavelengths with the angular position of the spectral bands given by the formula:

$$\sin\phi = \pm m\lambda/2d,$$

where ϕ is the diffraction angle (the angle of the

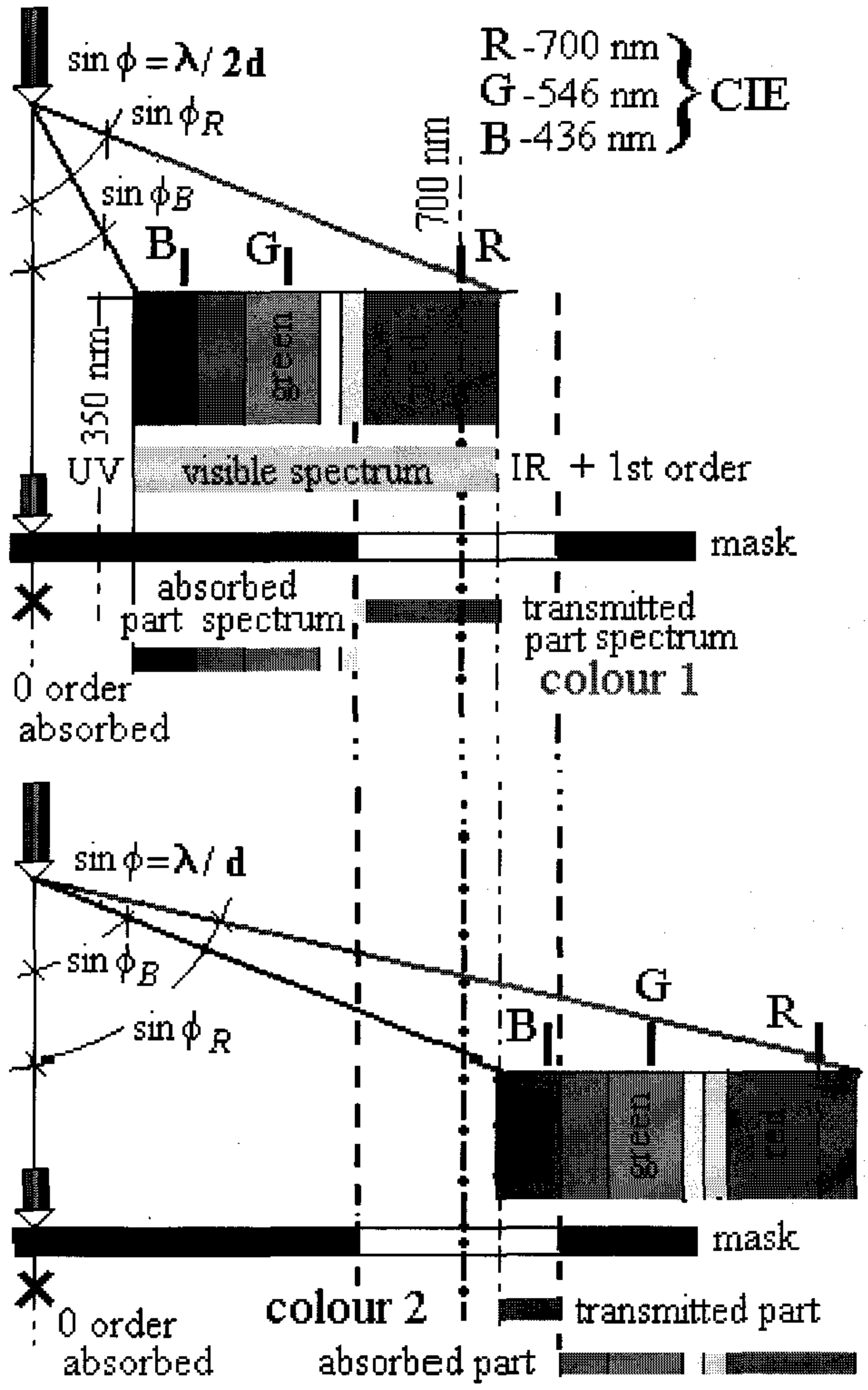

Fig. 2. Formation scheme of two colours.

maximum light intensity of wavelength λ), **2d** is the grating period, m=0,1,2.3… is the diffraction order. Mutual arrangement of the input and output mask slots and diffracted spectral bands is presented in scale of visible light wavelength in Figure 2. It is seen that at the formed grating period of **2d**, the conditions for passing the long-wave part of the visible light spectrum through the output mask slots are created (COLOUR 1 -**R**).

If the voltage applied between the solid electrode on one substrate and the connected half parts of the interdigitated electrode system on the counter substrate, the phase grating with period of **d** is created. Now conditions for a light transmission with a wavelength twice smaller, than in the previous case(COLOUR 2 - **B**) are created.

Thus, changing the period of LC phase grating by electrical switching it is possible to get three optically distinguishable states: DARK state, the COLOR 1 (**R**), the COLOR 2 (**B**). So, there is every possibility to manufacture two color display units. Later updating provide an opportunity of getting 3 or 4 colours. The distribution of light intensity among the diffracted spectra of switchable diffraction gratings depends upon the amplitude value of driving voltage. Some examples of redistribution of the light power intensity for the different orders can be seen in Fig. 3, 4.

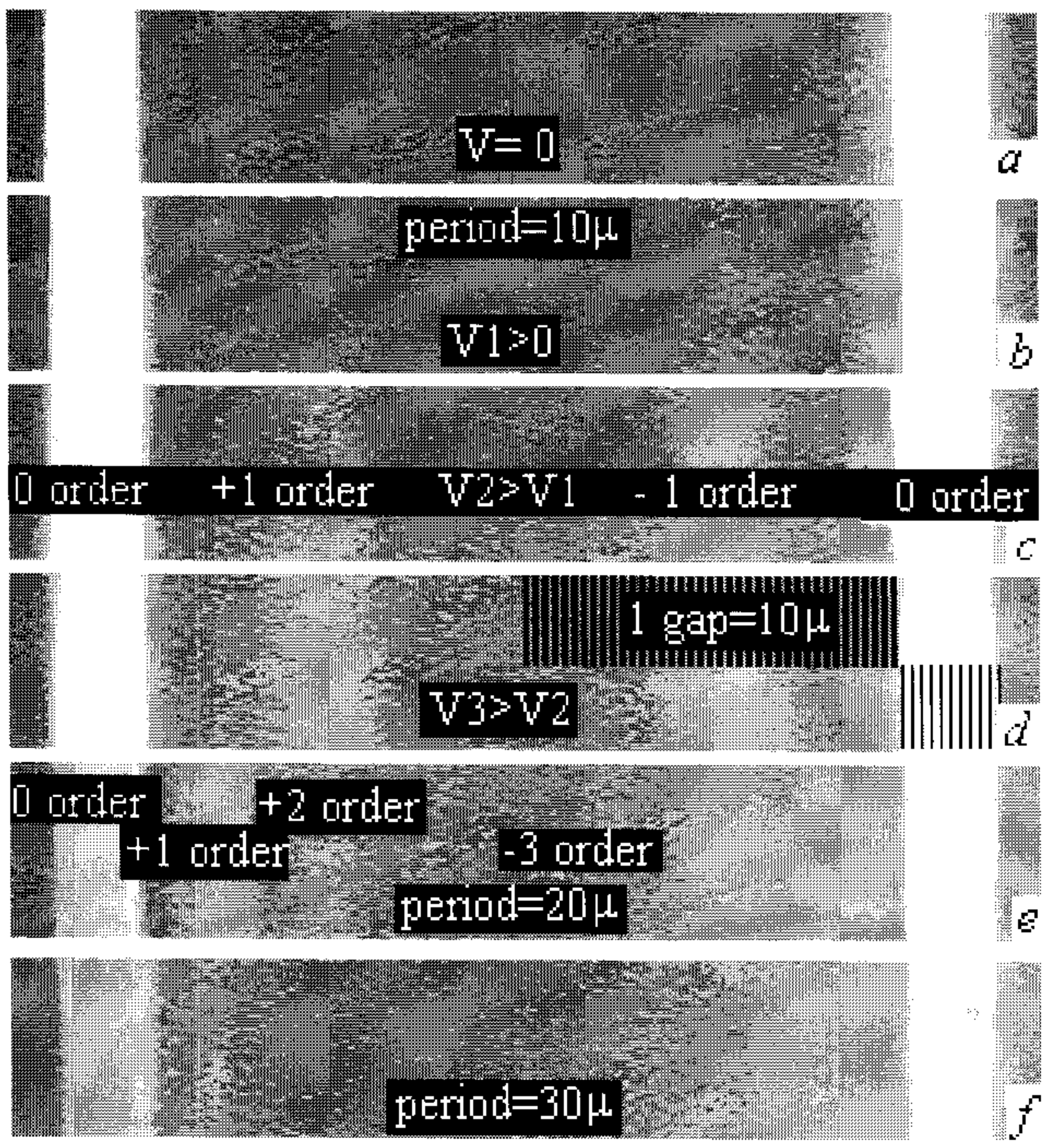

Fig. 3. Light redistribution between diffraction orders under applied voltage for grating periods 10 µm (a-d), 20 µm (a, e) and 30 µm (a, f).

4. Lighting Problem

All said above is valid for the case in which the light source and the receiving screen are effectively at an infinite distance from the diffraction sheet (Fraunhofer diffraction) that implies a parallel beams of wave-trains in use. For real displays, in which the light source and the receiving screen are both at a finite distance from the diffraction sheet, the real beams of wave-trains are divergent and convergent ones (Fresnel diffraction). Therefore it is necessary to enter into the display additional optical elements that reduce divergence (or convergence) of beams (condenser) and form spectral band images at a small distance from the diffraction sheet.

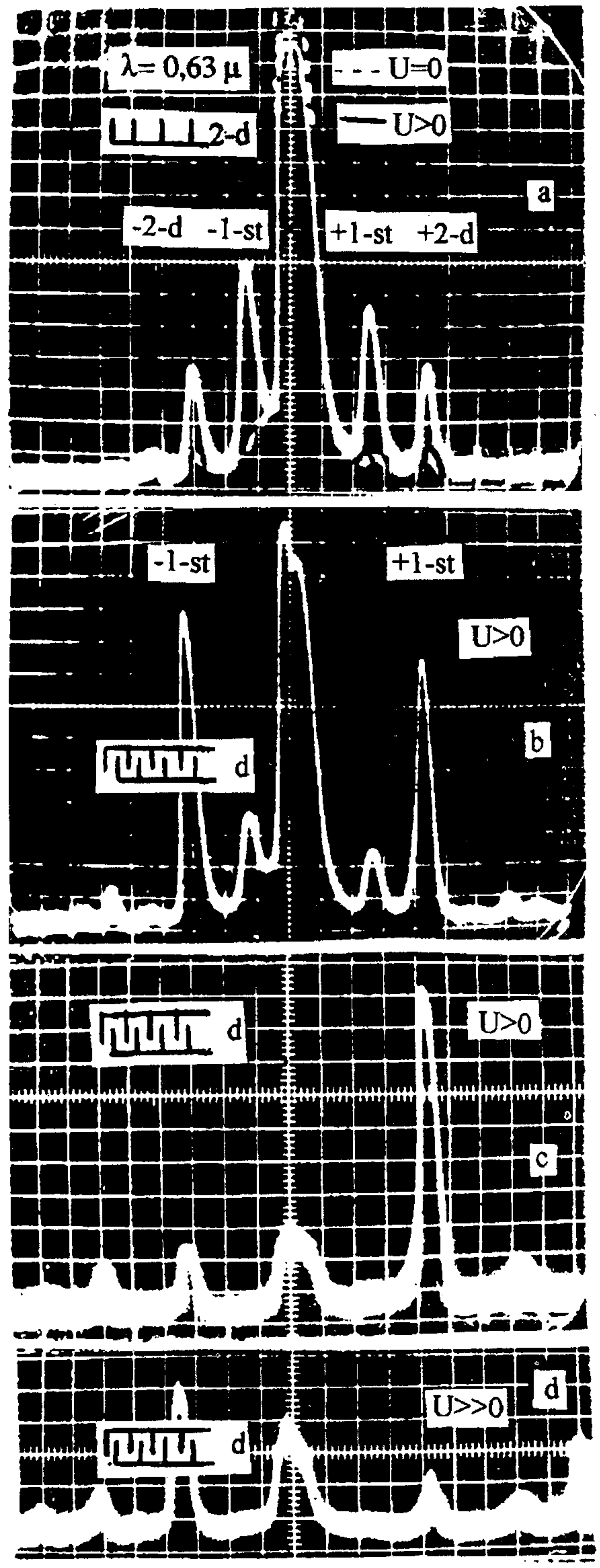

Fig. 4. Intensity restritibution between different orders for grating periods **d** and **2*d.**

The design of a substantial pixel is given in Fig. 5.

Here input mask slots generate a narrow linear beam arranged in focal point of the cylindrical raster - condenser. The condenser form a pseudo-parallel beam lighting the pixel area. In outcome in the focal plane of the linear cylindrical lens the map of the diffraction spectrum will be formed.

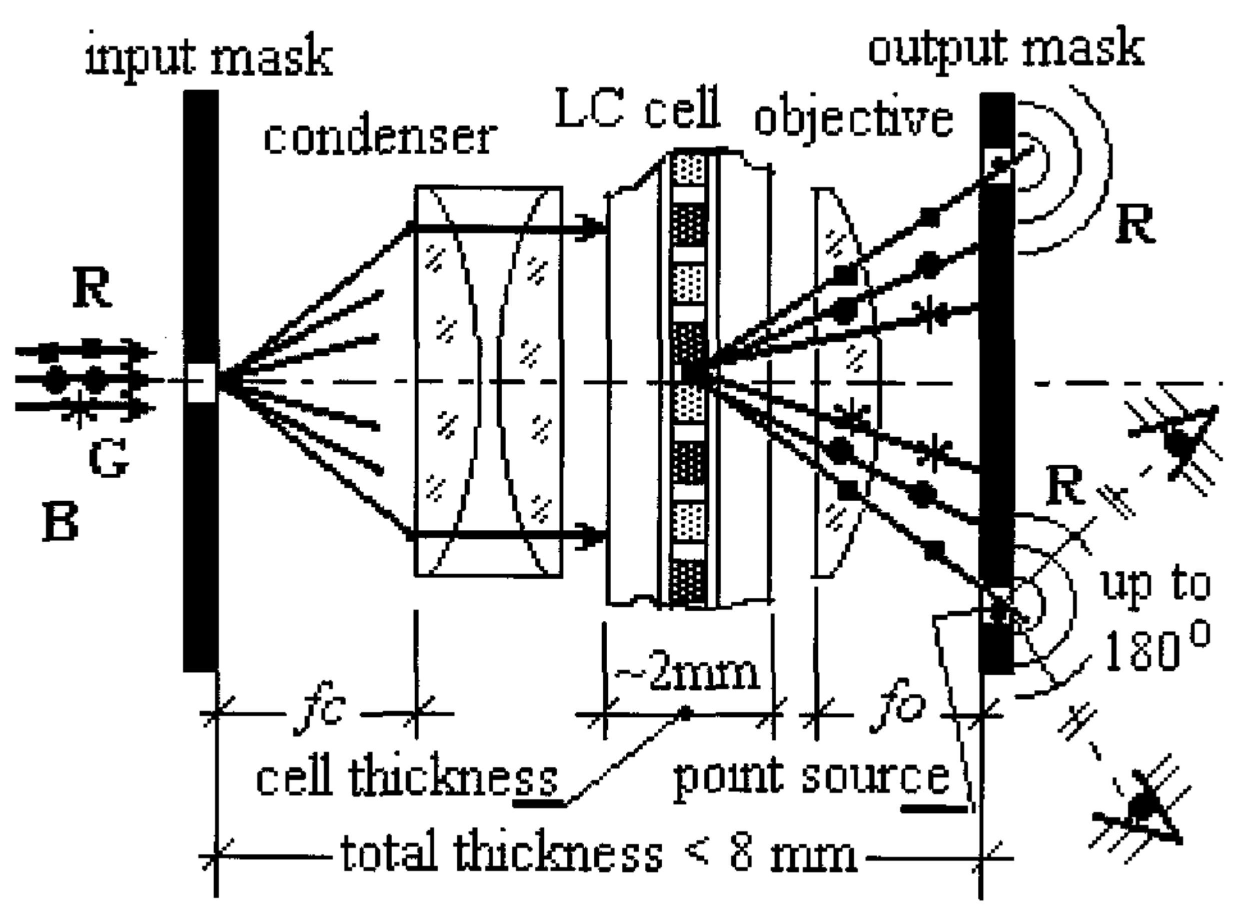

Fig. 5. Substantial pixel design.

The output mask slots skip light of a definite wavelength, and are practically point sources with the directional diagram close to circle. Therefore the value of contrast and spectral content of light in a broad band of angles does not depend on a viewing angle. Examples of the diffraction spectra are given in Fig. 6.

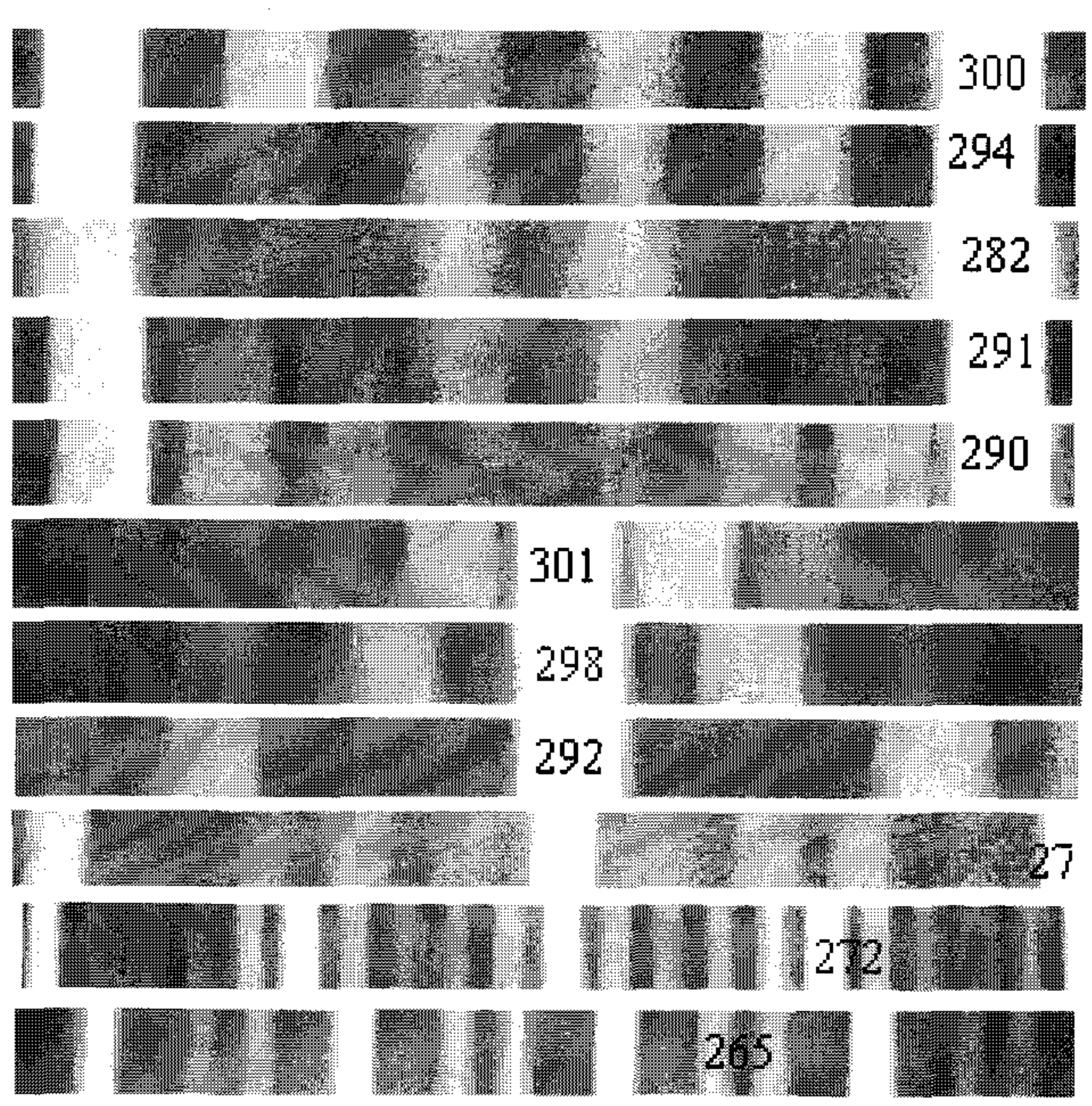

Fig. 6. Examples of the diffraction spectra for different periods and voltages(without any micro colour filters or photopolymers).

5. Main Advantages of The Offered DLCDs

5.1. High brightness of images for lack of polarizes and absorbent matrix colour filters. High and independent from viewing angles contrast.

5.2. Higher efficiency of use of light because the necessity of division of the pixel area on 3 subpixels (R,G,B) is absent. Different colours are transmitted through the same slot.

The resolution can be increased 3 times which is especially important for high- definition television.

5.3. Transmission voltage curve and spectral characteristics absolutely independent of :

- angle observation,
- variation in the LC layer thickness,
- temperature variation,
- time (no aging) and ambient light.

They are determined only constructively given parameters of the diffraction grating.

5.4. Super-high response. The LC layer thickness does not affect the grating formation and can be minimized to a technologically accessible low value up to 1 … 0.5 μm and less.

5.5. DLCDs allow to work with anyone (including very cheap and ferroelectric) LCs and does not show the high requirements to aligning layers.

5.6. Simple design and manufacturing procedure compatible with TFT and available technology. Inside the cell in contact with the LC there are no elements chemically reacting with LC, such as micro filters or protecting layers.

5.7. The cost price of manufacturing of diffractive displays is much lower due to absence expensive polarizers , micro filters and expenses their installation, due to exception of many expensive procedures .

5.8. DLCDs can be made on an existing production equipment with minor adaptations

6. The R&D Activity

The pioneer work on Diffractive Liquid Crystal Displays (DLCDs) had been made by the author in 1974, and it was that time that the author took out an USSR patent [1] on this subject for the first time. Since 1997, the research and development (R&D) activity on DLCDs has been carried at the author by privat way , without any other financial support.

During this activity, the main design and field-performance data of DLCDs were obtained and their relations to the properties of liquid crystal materials were established; the advantages and disadvantages of DLCDs were assessed, and attempt of fabricating an working DLCD prototype was made with available in Russia technological equipment. Some experimental observations were published and 5 Russian patents for different versions of DLCDs were taken out [4].

7. Conclusion

On the basis of the conducted R&D work, the following conclusions can be drawn:

7.1. The idea of selection of colours based on switchable diffraction grating formed in a liquid crystal layer is realizable. Owing to polarizes lack, the brightness of DLCD image can be increased not less than 50 % compared to well-known LCD. The image contrast is high and practically does not depend on viewing angles. There is no need in synthesis expensive dyes or photopolymers and expenditures to design them into DLCD device. Any range of colours can be obtained by adjusting the width of mask slots and their arrangement.

7.2. Even now DLCDs could be manufactured with the existing industrial equipment of minimal updating.

Mass manufacturing of DLCDs might be even cheaper than that of commercial ones due to:

- uselessness of color microfilters, polarizes, or photopolymer layers and expenditures on their setting in the production process;
- the possible utilization of any electrooptical effects (including such "ancient" as 90° TN, electric field controllable birefringence and cholesteric-nematic transition effects) for DLCD to operate; for these effects is no need of using very expensive LC materials;
- DLCDs do not make the exacting requirements to the precise uniformity of LC layer gap or to strict maintenance of anchoring angles . This is an additional factor to simplify the production and reduce its price.

Thus, DLCDs are the new type of colour LC displays of high consumer properties and of low cost in mass manufacturing. They can take a worthy place among remaining LCDs.

8. Acknowledgments

The author is very much obliged to Organizing Committee of IMID'03 for the kind granting of a tribune to read this paper and for the financial support.

References

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[4] Portfolio of patents on diffractive displays: Russian patents №2201611, №2202817, № 2196351 № 2196352, № 2196353