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13. ABSTRACT *(Maximum 200 words)*

A particularly simple four-domain(4-D) twisted nematic(TN) liquid crystal display(LCD) device is proposed, which is composed of two left handed TN and two right handed TN subpixels. One of each pair of same handedness subpixels is rotated 180 with respect to the other, resulting in four domains that mutually compensate one other optically to provide a wide angle of viewing with no gray scale inversion. The detailed fabrication process is presented for a double SiO_x oblique evaporation technique used to realize this 4-D TN LCD. A reverse rubbed polyimide fabrication process has also been successfully used and will be presented in the full length article. We present here the first complete viewing angle and contrast ratio data for a simple and successful 4-D TN LCD cell.

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A simple four-domain twisted nematic liquid crystal display

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Abstract

A particularly simple four-domain(4-D) twisted nematic(TN) liquid crystal display(LCD) device is proposed, which is composed of two left handed TN and two right handed TN subpixels. One of each pair of same handedness subpixels is rotated 180^0 with respect to the other, resulting in four domains that mutually compensate one other optically to provide a wide angle of viewing with no gray scale inversion. The detailed fabrication process is presented for a double SiO_X oblique evaporation technique used to realize this 4-D TN LCD. A reverse rubbed polyimide fabrication process has also been successfully used and will be presented in the full length article. We present here the first complete viewing angle and contrast ratio data for a simple and successful 4-D TN LCD cell.

I. Introduction

It is well known that single domain TN cells, which are now most commonly employed in flat panel LCDs, have a narrow and non-uniform viewing angle characteristic[1]. Furthermore, the electro-optic(EO) characteristics of conventional TN-LCDs are strongly dependent on viewing angle, a serious inconvenience for good gray-scale operation, which is a prerequisite to developing a full color display. These drawbacks originate from the fact that the optic axis in the mid-plane of the cell is uniformly tilted in one direction. Because the nematic liquid crystal is highly birefringent, different viewing directions give substantially different degrees of birefringence, resulting in optical transmission behavior depending strongly on the viewing direction.

To overcome this shortcoming of conventional TN LCDs, two major approaches have been proposed, namely, negative retardation film compensated [2,3] and multi-domain LCDs[4-12]. The latter includes amorphous TN LCDs[13,14,15]. The negative retardation film compensation technique can only improve the gray scale characteristic in one viewing plane; namely, one of the planes containing the cell normal that is 45 degrees from the polarizer directions. The gray scale inversion problem still exists and sometimes becomes even worse in other viewing planes. On the other hand, although the amorphous multi-domain TN LCD has its own merits, i.e., a wide viewing angle and no rubbing , the disclinations at reverse tilt domain boundaries due to zero pretilt angle seriously degrade its performance [15]. The multi-domain technique was proposed in the late 80's. The main idea is to divide each pixel into subpixels in which the molecular configurations and optical responses are different. In this way, properly designed domains will mutually compensate in the contrast angular dependence to give a wide angle of viewing and improved gray scale characteristics.

Many techniques have been developed to achieve multi-domain TN(MDTN) structures. In the Tannma et. al. patent[4], each pixel was divided into two domains, where the rubbing directions are opposite to each other. H. Takano[5] as well as A. Lien[6] also developed a two domain TN device based on the effect of the fringe field produced by the edges of the pixel electrode. Yang[7] as well as Takatori[8] published a multiple rubbing method to fabricate a 2-D TN cell in which the rubbing directions of one or both substrates of the different domains of a pixel are opposite to each other. Koike et. al.[9] used a multiple alignment layer method to develop a 2-D TN cell based on different pretilt angles induced by the different alignment layers. In the complementary 2-D TN device developed by Takatori et al.[10-11], the top substrate has a low pretilt angle while the bottom one has a high pretilt angle. This device has alternating reverse tilted stripes. Two domain TN techniques have been reviewed in reference[12].

Recent analytical simulation of the EO performance of MDTN cells shows that optimum viewing characteristics are obtained in a four domain TN LCD structure[16]. A technique suggested by S. Kobayashi's[15] group is to pattern photopolymer alignment layers with linearly polarized UV light. This has same problem as the amorphous TN cell. The reverse tilt domain defects can't be controlled. There are currently no complete viewing angle experimental data available for 4-D TN LCD's fabricated by any method.

In this paper , we report a particularly simple 4-D TN structure. This structure was realized by both double SiOx oblique evaporation and doubly rubbed polyimide. We confine our attention here to the former. The LC director configuration in each of four subpixels was electro-optically analyzed. We believe this is the first viewing angle and gray scale data for a 4-D TN LCD cell.

II. Structure of our 4-domain TN display

The structure of our 4-domain TN cell is shown in Fig.1(a). The arrows and dashed arrows in each subpixel indicates the pretilt directions for the top and bottom plates respectively. In this configuration, we have two left handed and two right handed TN subpixels. There is a two fold symmetry axes normal to and in the center of the pixel. From the pretilt direction of each subpixel, one can easily infer the LC molecular orientation(and, hence, optic axis orientation) in the mid-plane of the cell. This is indicated in Fig.1(b). Note that the nematic director(optic axis) in the mid-plane of the four subpixels points to each of the four corners of the pixel. This causes the subpixels to mutually compensate optically, providing good viewing angle characteristics.

For comparison, another 4-domain TN structure[15] is shown in Fig.1(c) and the director orientations at the mid-plane of the cell are illustrated in Fig.1(d). From the symmetry point of view, our 4-domain structure is different. The 4-domain TN cell of Ref.[15] has four same handedness pixels and belongs to the $\{C_4\}$ symmetry group, whereas our 4-domain TN structure has two left handed and two right handed subpixels and belongs to the $\{D_2\}$ symmetry group. However, the director orientation at the mid-plane of the subpixels shows the same configuration in both structures. It is not surprising that both structures give similar optical compensation effects.

III. Techniques

Our 4-domain TN structure can be realized by a two step SiO_X oblique evaporation process whose flow chart is shown in Fig.2. A clean indium tin oxide(ITO) coated glass substrate was first coated with an evaporated SiO_X alignment layer. Then, a photolithography process was used to form an equal width striped mask. The photoresist we used was Shipley S1400-31. After the photolithography process, the substrate was rotated by 180^0 and the second SiO_X evaporation was carried out. Finally, the photoresist used as a mask was removed by acetone. The evaporation angle was $85°$ from the plate normal. The thickness of the SiO_X layer was approximately 150A. Our 4D TN cell can be fabricated by assembling the two substrates in the same way as a conventional TN cell using two identical plates fabricated by the method described above. For the EO performance and viewing angle measurement, 6μm test cells were prepared and filled with NLC(zli-4792 or E7) purchased from Merck company. Due to the high pretilt angle($\sim 25^0$) generated by the evaporated SiOx layer, 6μm cells were used, instead of 5μm in order to satisfy the first minimum condition given by the Gooch and Terry equation[17] . The subpixel size was varied from 600μmx600μm to 24μmx24μm.

VI. Results and Discussions

The confirmation of the director configuration of our 4-domain TN structure shown in Fig.1(a)(b) was taken to be the top priority. Fig.4 shows the conoscopic image of each subpixel of our test cell when 5V was applied. The distorted cross pattern can be seen. When the cell voltage was removed, the cross pattern of each domain moves in the direction of the dashed arrows in Fig.1(b). This experimental result directly confirms the director configuration at the mid-plane of our 4-domain TN cell in Fig.1(a). An othoscopic image of the cell is given in Fig.4. The cell was constructed in the normal white e mode and field off state. The subpixel size is 100μm and the disclinations at the boundary of each subpixel can be easily seen. If a certain voltage is added to the cell, the brightness of each subpixel will alternate as the viewing direction is varied azimuthally.

Fig.5 shows iso-contrast measurements of the 4-D TN cell. The cell was in the normal white e mode and the on state at 6V. The polar angle dependence of the transmission, in eight gray levels, of our test cell along vertical viewing direction is indicated in Fig.6. These experimental results match with that of a computer simulation quite well[15], although our 4-D TN cell structure is different from that of Ref[15]. The viewing angle characteristics of a TN cell is mainly determined by the director configuration at the cell mid-plane. Therefore, the identical director configuration at the mid-plane of the two 4-D TN cells makes these results quite naturally understood.

Our 4-D TN display can also be realized by a reverse rubbing technique[10-11], which will be suitable for mass production in the display industry. This part of the work, including the optical simulation of our 4-D TN cell as well as the stability of this 4-D structure and the effect of disclinations on contrast, will be published in a full length article[18].

V. Conclusions

A new 4-domain TN cell structure was proposed, which has D_2 symmetry. This structure is composed of two left-handed TN and two right-handed TN subpixels. A two-fold axis lies normal to and at the center of a pixel, giving it D_2 symmetry rather than the C_4 symmetry of the cell of Ref[15]. The molecular direction at the mid-plane of each subpixel points to each of the four pixel corners. This causes the four subpixels to optically compensate each other, giving a symmetric viewing angle and wide gray scale inversion free zone. Our 4-domain structure is very simple and can be realized by many techniques including the double SiOx oblique evaporation technique. For the first time, we provided complete experimental data on the viewing angle characteristics of 4-domain TN LCDs.

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Figure Captions

Fig.1 (a) Structure of a simple 4-domain TN cell. The dashed and solid arrows indicate the LC molecular tilt directions at the top and bottom plates respectively.

(b) Director configuration at the mid-plane of the 4-D TN cell

(c) Structure of the 4-domain TN cell of Ref.[15].

(d)Director configuration at the mid-plane of the 4-domain TN cell of Ref[15]

Fig.2 Flow chart of the double oblique SiO_x evaporation process

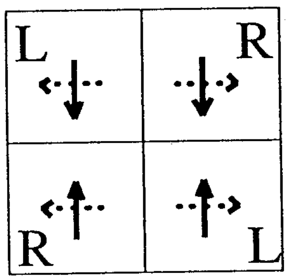
Fig.3 Conoscopic images of the four subpixels. 5V is applied to the cell.

Compare with the configuration of the cell corresponding to Fig.1(a).

Fig.4 Orthoscopic photomicrograph of a 4-D TN LCD cell prepared by the double SiO_x oblique evaporation at the normal white e mode and off field state.

Fig.5 Viewing angle characteristics for our 4-D TN test cell at the normal white e mode. The on state voltage is 6V.

Fig.6 Vertical viewing angle dependence of transmission in 8 gray scales at the normal white e mode for our 4-D TN test cell.



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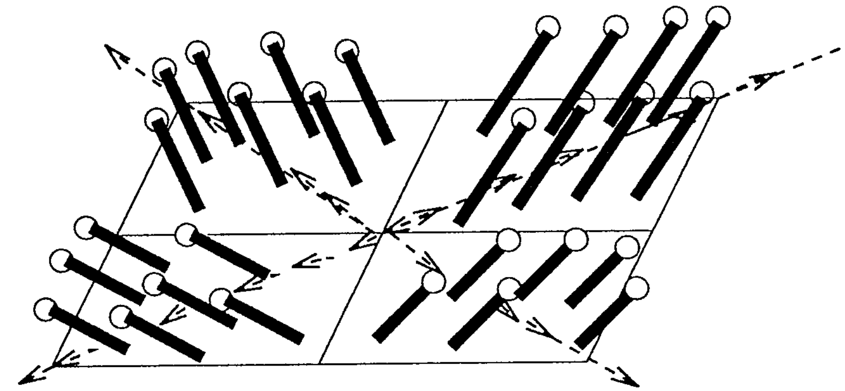

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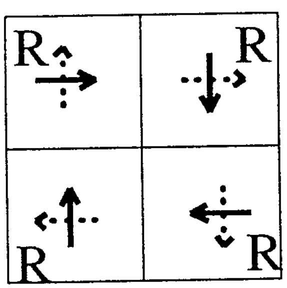

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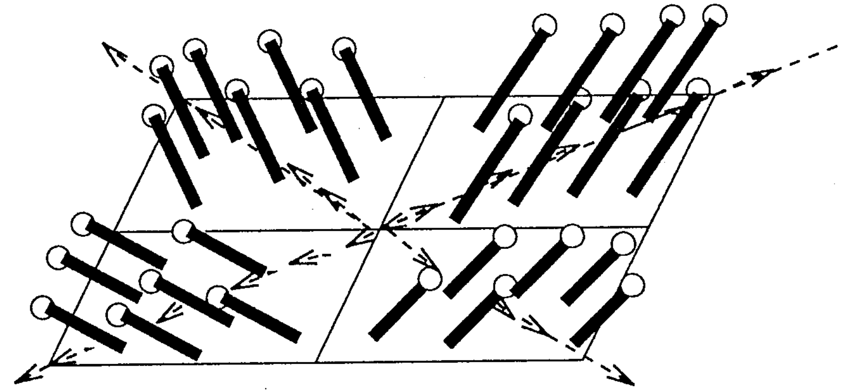

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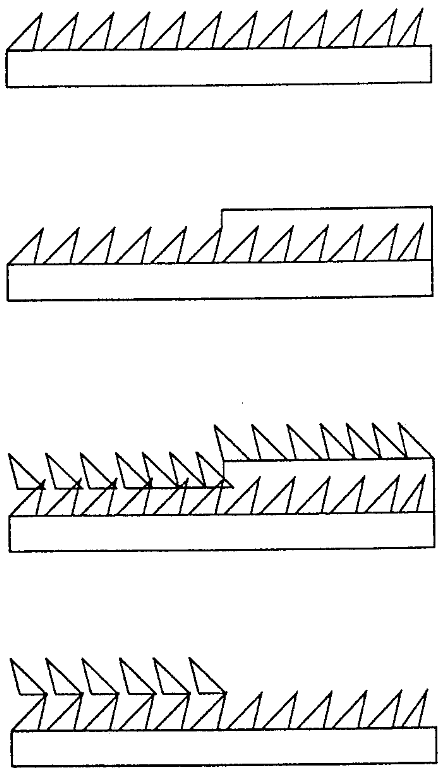
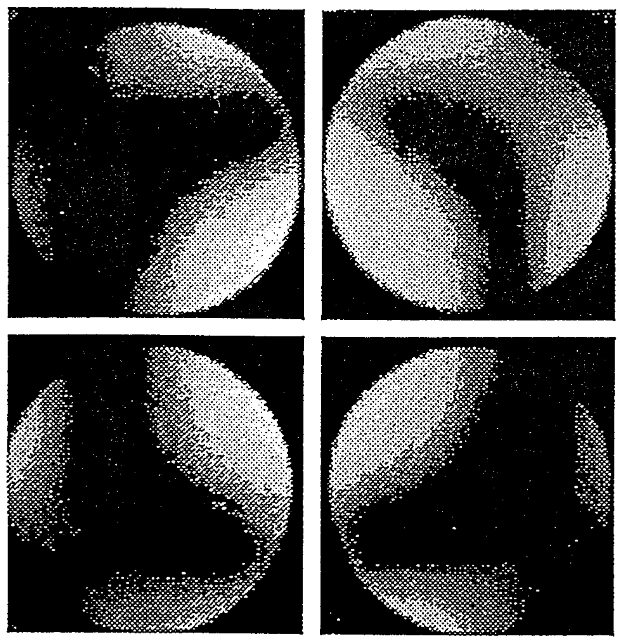


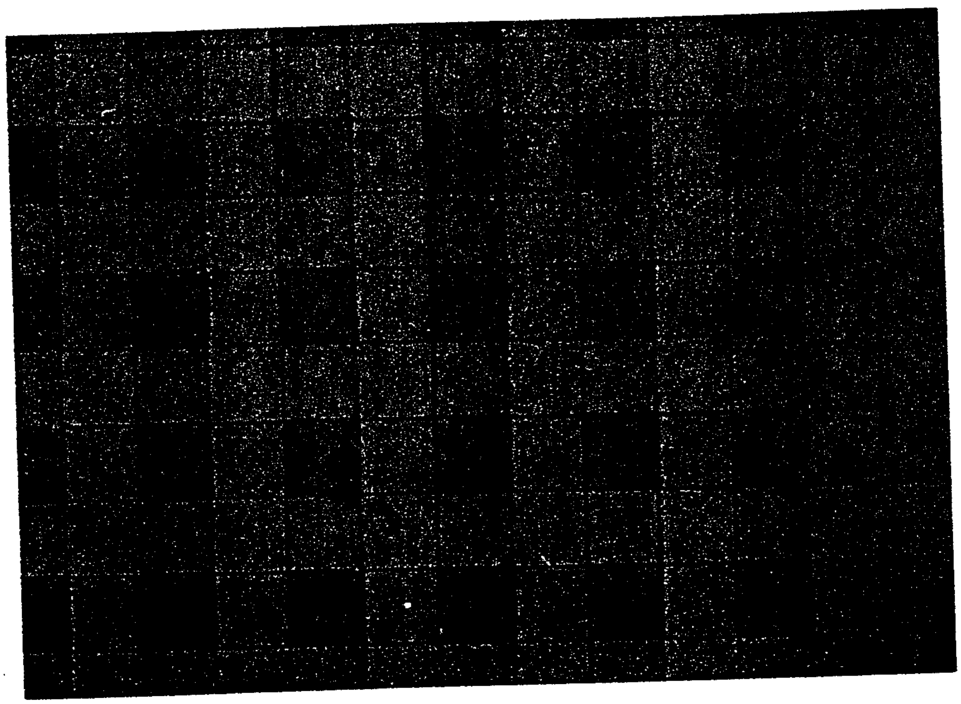
First SiOx oblique evaporation

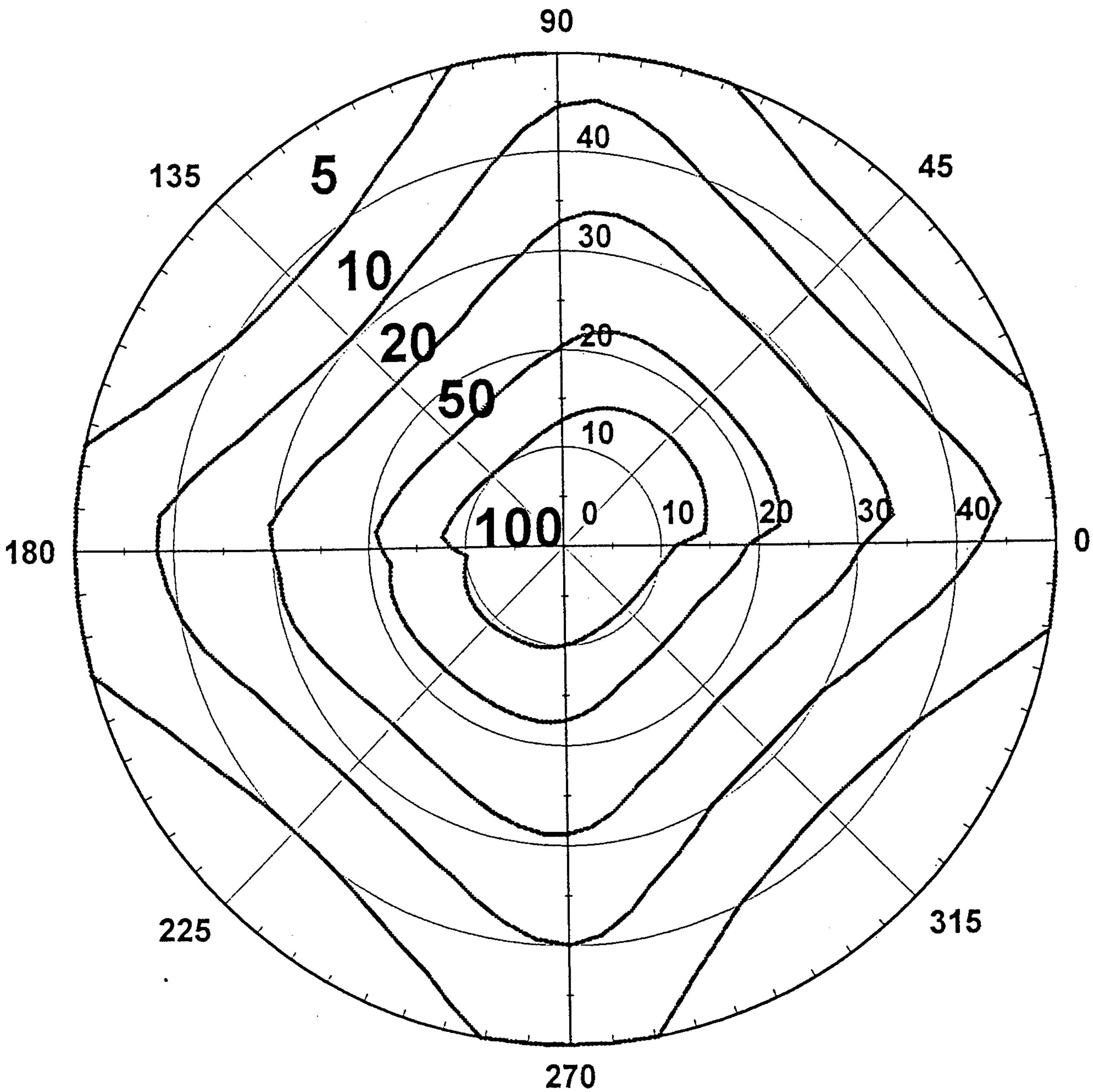
Photolithography process

Second SiOx Oblique evaporation

Remove photoresist







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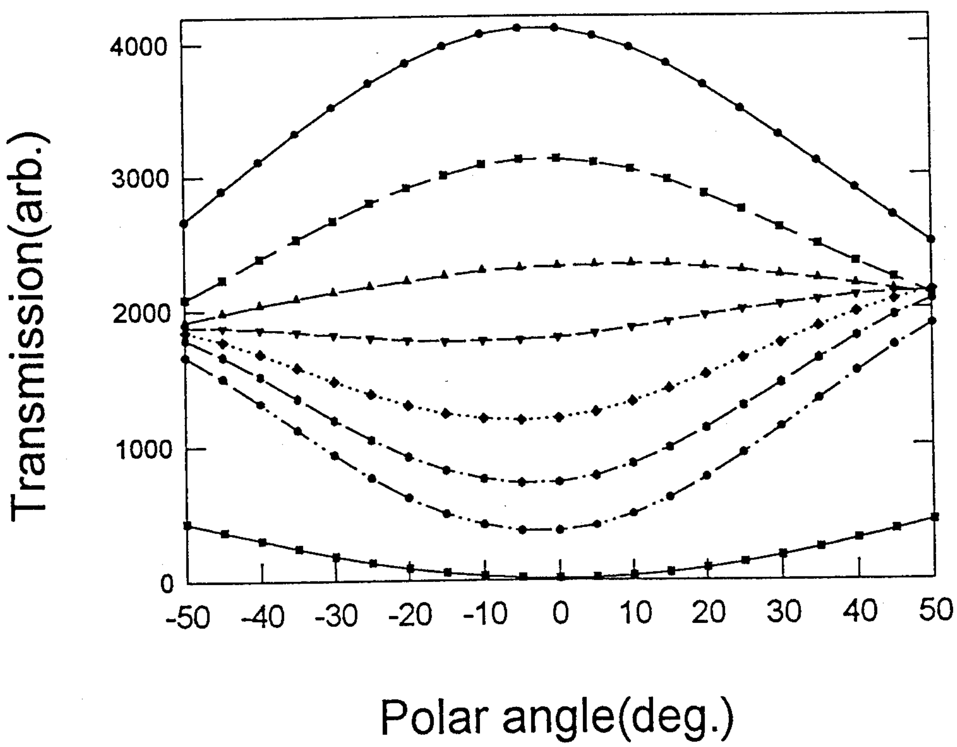

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