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AMORPHOUS SILICON ACTIVE MATRIX SUBSTRATES FOR LIQUID CRYSTAL TV SETS

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1 INTRODUCTION

With progress of electronic technology, miniaturization of equipment and devices, enhancement of their performance and systematization have made a remarkable progress, and equipment playing roles of man-machine interface are given more and more importance everyday. In particular, display equipment play a central role in man-machine interface operations as they appeal to visual sense that can get more informations than any other human senses. The liquid crystal display equipment is a non luminiscent equipment having the following features in contrast with lightemitting type equipment as CRT's.

(1) As they are operable with low-power consumption, they can be driven with cells.
(2) As low-voltage operation is possible, miniaturization of drive circuit is possible.
(3) Display equipment can be thin in equipment depth and light in weight.
(4) As they are non luminescent elements, they causes little fatigue to viewer's eyes.
viewer's eyes.

By the reasons mentioned above, liquid crystal display equipment are rapidly growing at present compared with other thin display equipment, in particular for personal display equipment. Now, an enlargement of amount of information to be displayed, that is, giving them colors and enlargement of the display surface are expected.

In simple matrix liquid crystal display equipment, when number of scanning lines is increased, there emerges a problem of losing constrast, decrease of visual angles, and rising of drive voltage. In order to solve this problem, a development of active matrix liquid crystal display equipment is being promoted. This new equipment solves the problem by cutting crosstalk between each picture elements, by inserting thin film diode and thin film transistor into each picture element.

Fuji Electric has thought that it would be effective to use amorphous silicon (hereinafter abbreviated as a-Si) for active matrix substrate driving liquid crystal television and promoted its development. The developed active maxtrix substrates is thin film diode (hereinafter called TFD) substrate connecting scanning lines with each picture element through diode ring and thin film transistor (hereinafter referred to as TFT) substrate transmitting scanning signals and data signals to picture element through transistor formed to each picture element.

Up to now, for liquid crystal drive, TFT matrix has been the main stream of studies, however, since it was known that a good constrast can be obtained by devising a better drive signal system, interest in TFD matrix is increasing every day.

2 TFD SUBSTRATES

2.1 Structure

Fig. 1 shows a structure of unit picture element of the developed TFD substrate, in which (a) is a plan, while (b), a section of A-A'. Picture element is connected to scanning lines through reverse parallel-connected diode ring connected with two series-connected diodes. Diode unit has a structure that a-Si layer having pin junction is sandwiched metal films. When it is placed under irradiation, it prevents generation of photoelectromotive force and inhibits output current when voltage is low, and it is necessary to have a

Fig. 1 Structure of TFD substrate

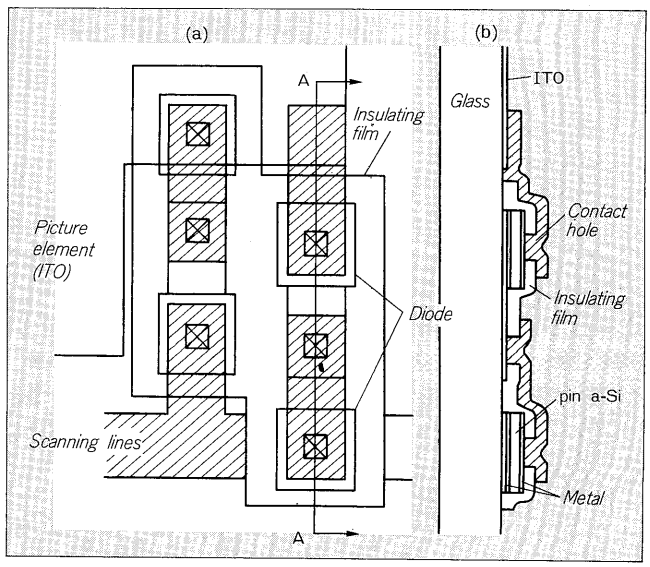


Fig. 2 Current/Voltage characteristics of diode ring

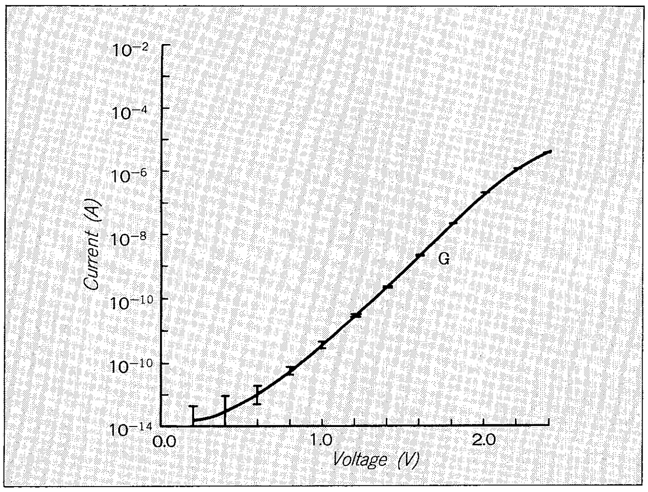
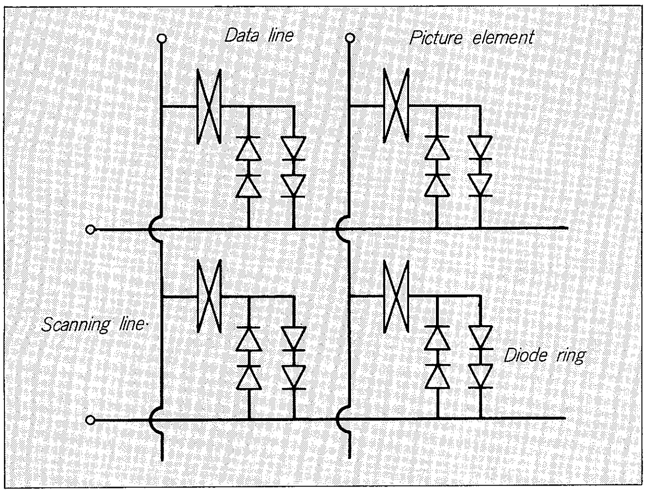


Fig. 3 TFD system liquid crystal display equipment equivalent circuit



metal film thickness of more than 1,000Å in order that it may be provided with a good switching characteristic. We have designed and manufactured on trial various types of TFD substrates, and for example, for a case of a substrate whose picture size is 3.5 inches, substrates for 85,800 picture elements (220 x 390) are being developed.

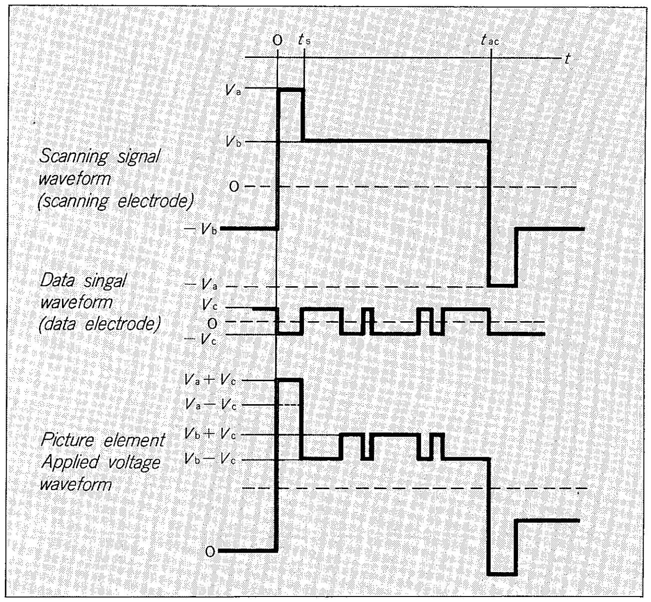
2.2 Electrical characteristics

Symbol G of *Fig. 2* shows current/voltage characteristics of a diode ring. It shows symmetrical output current as for positive and negative applied voltage. In the high voltage region, current is limited by the DC resistance and in the low voltage region, current fluctuation in the display surface is somewhat larger, but with the voltage of less than 0.5V, the current value is controlled to be less than 10^{-11} A, so that this does not raise any problem for its practical use.

2.3 Liquid crystal drive simulation

Fig. 3 shows an equivalent circuit of liquid crystal display equipment using TFD substrate. Liquid crystal is

Fig. 4 TFD System liquid crystal display equipment drive waveform



sealed between picture element connected to scanning lines through diode ring and stripe-form data electrode on the opposite substrate.

Fig. 4 shows drive waveform. Selection voltage (V_a) is applied to scanning electrode within selection time (t_s) and, holding voltage (V_b) is added to non-selection time (another scanning lines). ± V_c voltage corresponding to black or white indication (in case of monochromatic TV) is applied to data electrode to which data signals are given. Also, to picture element, a signal voltage consisting of "scanning signal-data signal" reversed at each frame (t_{ac}) is applied. In this drive waveform, by receiving an influence from the data signal voltage applied to other picture elements during non-selection time, non-selection voltage of the picture element will fluctuate. By this fluctuation, there will be a possibility of producing a phenomena of reducing displayed contrast due to fluctuation of the impressed effective voltage of the liquid crystal (crosstalk). Therefore, we made an investigation on this matter.

The current (I)/voltage (V) characteristics of the diode can be expressed by the following formula:

$$I = \frac{(V - I \cdot R_s)}{R_{sh}} + I_0 \cdot \exp \frac{e\,(V - I \cdot R_s)}{nkT} \quad \ldots\ldots (1)$$

whereas,

I : Current
V : Voltage
R_s : Series resistance
R_{sh} : Shunt resistance
I_o : Diode saturation current
n : Diode factor
k : Boltzmann constant
T : Absolute temperature
e : electron charge

Supposing picture element signal write-in voltage to be

E_s ($=V_a \pm V_c$), picutre element signal holding voltage E_h ($=V_b \pm V_c$), the voltage to be applied to both ends of liquid crystal E_{LC} can be obtained as:

$$\frac{dE_{LC}}{dt} = \frac{E_s}{(C_1+C_d)\cdot R_d} - \left(\frac{1}{R_1}+\frac{1}{R_d}\right)\left(\frac{E_{LC}}{C_1+C_d}\right) \quad ..(2)$$

Then, in the selection time ($0 \leqq t < t_s$),

$$E_{LC} = \left[\frac{R_1}{R_1+R_d}\cdot\left\{1-\exp(-\alpha t)\right\}+\frac{C_1}{C_1+C_d}\exp(-\alpha t)\right]\cdot E_s \quad \ldots\ldots\ldots\ldots\ldots (3)$$

in the non-selection time ($t_s \leqq t < t_{ac}$),

$$E_{LC} = \left[\frac{R_1}{R_1+R_d}\cdot\left\{1-\exp(-\alpha t\right\}+\frac{C_1}{C_1+C_d}\cdot\exp(-\alpha t)\right]\cdot E_s+\left[\frac{R_1}{R_1+R_d}\cdot\left\{1-\exp(-\alpha(t-t_s))\right\}+\frac{C_1}{C_1+C_d}\exp\left\{-\alpha(t-t_s)\right\}\right]\cdot(E_h-E_s) \quad \ldots\ldots\ldots (4)$$

can be oftained.

Thus, the effective voltage E_{rms} applied to liquid crystal is:

$$E_{rms} = \left[\frac{1}{t_{ac}}\cdot\int(E_{LC})^2\,dt\right]^{1/2} \quad \ldots\ldots\ldots\ldots (5)$$

whereas, $\alpha=(1/R_1+1/R_d)/(C_1+C_d)$, in which, C_1 is the capacity of liquid crystal; R_1, resistance of liquid crystal; C_d, diode capacity; and R_d, diode equivalent resistance ($=V/I$).

Fig. 5 shows an example of change of liquid crystal end voltage E_{LC} in function of time. It shows the change by using the parameters of n=3.5, $R_{sh}=10^{12}\,\Omega$, $R_s=10^6\,\Omega$, C_d=0.1pF, $R_1=10^{11}\,\Omega$, C_1=0.7pF, and E_s is changed up to 2.5-6V with E_h=2V condition. With this graph, it is easily seen that the charge of liquid crystal end is well held up to order of several tens of ms.

Fig. 6 shows the relationship between selection voltage E_s having liquid crystal resistance as parameter and liquid crystal effective voltage E rms. The figure shows that there is a tendeny that when the liquid crystal resistance becomes smaller, the effective voltage is lowered, and crosstalk width (width shown by shade lines) also increases. In case of liquid crystal whose OFF voltage is 2.0V, and ON voltage, 2.5V, we will know that $R_1 > 5\times10^{10}\,\Omega$ would be necessary. The crosstalk width depends greatly on the reciprocal relation between diode capacity (C_d) and liquid crystal capacity (C_1).

Fig. 7 shows the relationship between diode capacity and crosstalk width, parameter being C_1=0.7pF and V_c =

Fig. 5 Change of liquid crystal applied voltage in function of time in case selection voltage (E_s) is changed.

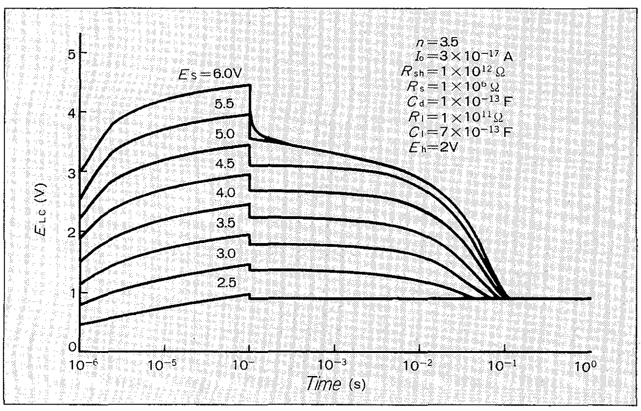


Fig. 6 Relationship between selection voltage (E_s) and liquid crystal effective voltage (E_{rms}) when liquid crystal resistance (R_1) I_s changed.

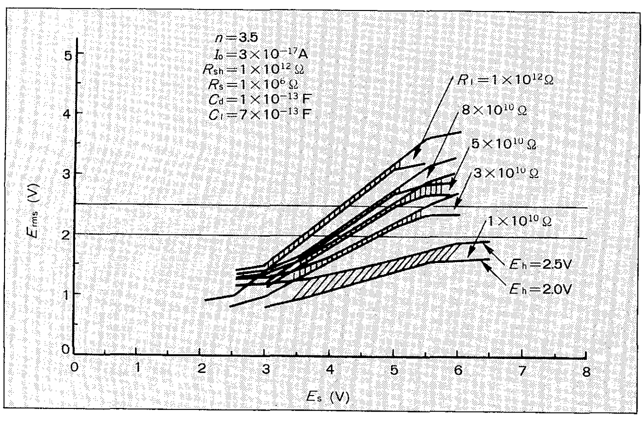


Fig. 7 Relationship between diode capacity and crosstalk width

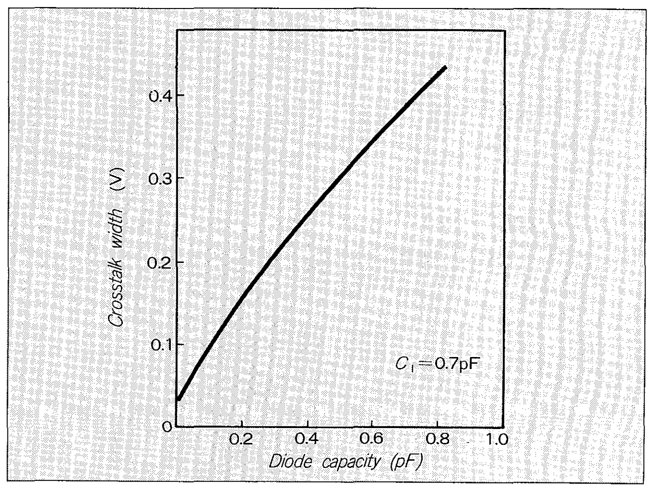
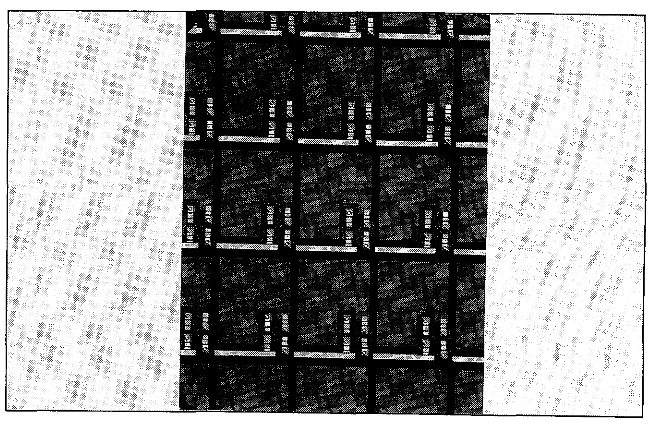


Fig. 8 TFD Substrate (enlarged photo)



0.4V. It is obvious from this figure that by designing diode capacity, that is, diode dimensions to be the smaller, the better it will be the improvement of the crosstalk width. As the result of the simulation mentioned above, it was found out that by working out the composition of diodes, it is possible to drive a large-picture liquid crystal display equipment as large as some 1,000 scanning lines.

[3] TFT SUBSTRATE

3.1 Structure

Fig. 9 shows an enlarged photograph of TFT substrate. The pitch between each picture element is 0.24mm in longer side and 0.18mm, in shorter side direction. *Fig. 10* shows the sectional structure of a-Si transistor. It is a reverse stagger type, providing a gate electrode to a-Si film having drain electrode and source electrode through Si-N film which is an insulating layer. The gate electrode connected to scanning lines is formed by a metal film and it acts also as a light screening layer. Gate insulating layer SiN, intrinsic a-Si layer, n-type a-Si layer will undergo patterning after continuous forming by plasma CVD. Further, a metal film is formed and drain patterning so as to be connected to data lines and source electrode patterning will be made so as to be connected to each picture element electrode. The channel width to length ratio is 8. On this a-Si transistor, SiN film insulating layer was formed and a metal film for screening light was formed also to cover the channel unit and part of source and drain electrodes.

3.2 Characteristics

Fig. 11 shows the relationship between a-Si transistor

Fig. 9 TFT substrate (enlarged photo)

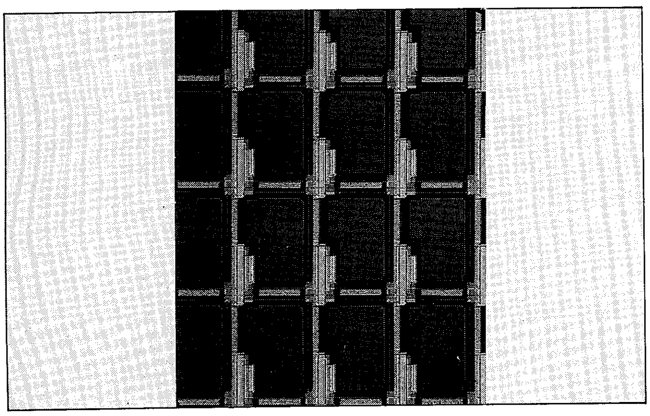


Fig. 10 Sectional structure of a-Si transistor

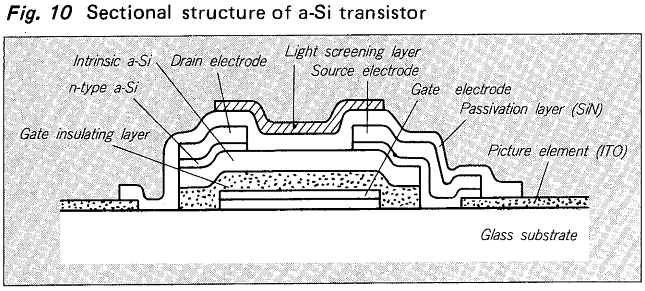
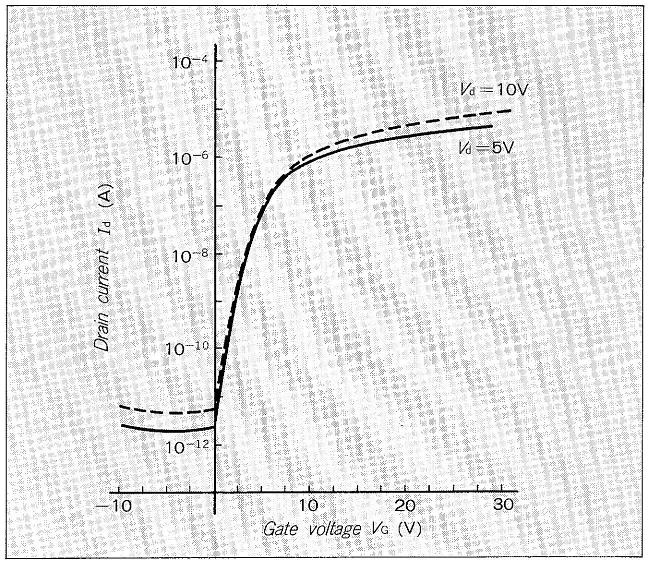


Fig. 11 TFT output characteristics



drain current (I_d) and gate voltage (V_G). The drain voltage (V_d) is 5V, 10V. In the negative gate voltage region down to −10V, with 10^{-10} A, the drain current does not depend on gate voltage, but in the positive region, the current value will steeply be increased, and when $V_G = 15V$, I_d will become 3μA. From $I_d - V_G$ relationship of the saturation characteristics, values of more or less 3.3V as the threshold voltage and more or less 0.5cm^2/V·s as mobility (μ) are obtained. In case the drain voltage is negative, the output current shows a value of V_G apparently increased by V_d, and when V_d is reversed in sign, I_d will not only reverse its positive/negative sign, but change also its absolute value.

[4] FEATURES AND APPLICATION OF a-SI ACTIVE MATRIX

Fuji Electric is at present promoting development of TFD substrates and TFT substrates at the same time. Here in this section, we like to discuss first the features of the two materials. The junctions that determine the characteristics of an element is pin-junction in TFD, and this structure is fundamentally the same as that of consumer use a-Si solar cells which are now being mass produced. Also large surface solar power cells as large as 1,200cm^2 (30cm x 40cm) are being developed at present. There is no problem in manufacturing TFDs by using large-surface substrates. In TFT, the SiN/a-Si surface plays an important role in determining characteristics, and further improvement would be necessary for having a stabilized manufacture with large-surface substrates.

One of the most important in manufacturing process is that there should be no defect whatsoever. In TFD system, as the scanning lines and data lines will come across being formed on the separate substrate through intermediary of liquid crystal, there is no possibility of causing line trouble except for scanning line interruption. Also, as interruption of scanning lines can easily be checked and eliminated, there would be only relatively minor troubles in the whole system. However, the difficulty is that, as 4 diodes are formed for one picutre element, even a trouble in a single diode would cause a defect in the whole system. On the other hand, in TFT, as its structure is that scanning lines cross data lines on the substrates through an intermediary of the insulating film, there is a risk of producing line troubles, besides the point trouble, so that the problem is to overcome the phenomena and the process bringing a solution to the problem is under development.

As for the drive voltage driving liquid crystal, for TFD, the liquid crystal drive is possible with a voltage less than 5V for the case two series diodes are used, and less than 6V when three series diodes are used, and adaptability with CMOSIC is very good. On the other hand, for TFT, for that, gate voltage of about 15V is necessary and a voltage a bit higher than the case of TFD is necessary for the drive.

As TFD is a two-terminal element, one has to run a risk of enlarging the crosstalk when one wishes to have a better contrast effect with this system of liquid crystal equipment, however, it is expected to that the problem be solved by making the diode area smaller and by making the ratio to the liquid crystal capacity larger. On the other hand, as TFT is a three-terminal element, there is little danger of getting crosstalk so that enhancement of the contrast is possible.

5 CONCLUSION

Fuji Electric has developed active matrix substrates composed of TFD and TFT and has proved that they could be used efficiently for liquid crystal display equipment. We are taking full advantage of our experience in our developing technique for large-area a-Si film forming and patterning technique that we have acquired with conventional a-Si solar cells, on basis of which, we like to manufacture and supply activie matrix substrates that fully satisfy the needs of our customers, thus contributing to the progress of man-machine interface system with liquid crystal display equipment.

We are going to promote our project aiming at improving ever the performance of active matrix substrates from now on including enlargement of their display surface.