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Special Purpose Spatial Light Modulators

San Diego State University Foundation

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I OBJECTIVES

Our objectives during this contract period (October 88 - March 89) were to improve the quality of the laser crystallized silicon films on PLZT using dual beam crystallization, to optimize the PLZT film growth conditions by magnetron sputtering, to study different GaAs growth conditions on sapphire and to measure various organic electro-optic modulator characteristics on materials provided by Celanese. These studies are important for the engineering of various special-purpose SLMs. In the following we summarize the results of our studies.

II SUMMARY OF RESULTS

1. Laser Crystallization of silicon on PLZT

During this grant period we have recrystallized silicon on PLZT and fabricated test transistors using dual beam recrystallization technique combined with anti-reflection stripes. Improved silicon film quality produced better transistor performance leading to a well controlled process for CMOS inverter fabrication. In particular, the mobility we obtained from the PMOS devices was twice as high as in previous fabrications. In addition, the buffer oxide thickness, which was affecting our yield due to metalization step coverage, has been reduced from $3.5\ \mu\text{m}$ down to $1.5\ \mu\text{m}$. By changing the fabrication sequence we were also able to decrease our minimum feature size from $25\ \mu\text{m}$ down to less than $5\ \mu\text{m}$. This will enable us in the future to implement circuits with higher complexity within the unit cells of our SLMs. Below we provide a more detailed description of our progress.

Recrystallized films using Ar^+ beam exhibit residual stress that is induced during the laser crystallization process. The cause of this induced stress in the material is the coupled effect of the mismatch of the coefficients of thermal expansion between the polysilicon and the underlying silicon dioxide, and the large thermal gradients that are present across the poly-Si/ SiO_2 interface during the recrystallization process. The use of the two beam technique to perform the laser recrystallization takes advantage of the absorption characteristics of polysilicon and the underlying SiO_2 at the two different wavelengths of the two lasers. At the Ar^+ laser wavelength of $514.5\ \text{nm}$ the polysilicon film is strongly absorbing, whereas the SiO_2 is transparent; at $10.6\ \mu$ the polysilicon absorbs weakly at room temperature ($\sim 1\ \text{cm}^{-1}$) whereas the SiO_2 layer beneath absorbs strongly ($\sim 2 \times 10^3\ \text{cm}^{-1}$). The use of the two lasers in unison thus provides an independent source of local heating for both of the layers. This independent control plays an important role in relieving some of the stress which arises from the temperature gradient across the poly Si/ SiO_2 interface. Therefore, we have modified our experimental set-up by combining a CO_2 beam with an Ar^+ beam. To obtain a suitable lateral temperature profile anti reflection (AR) stripes were used. This way, crystallization starts in the regions between the stripes and progresses towards the regions under the AR stripes,

confining all the grain boundaries and dislocations in these areas. By designing the subsequent masks for device and circuit fabrication properly with respect to AR stripe geometry, one can avoid these grain boundaries and dislocations.

The recrystallized films were characterized using Raman microprobe spectroscopy. Raman scattering is the inelastic scattering of light by optical phonons in a crystal. The Raman spectra can give us informations about the nature and the magnitude of the stress in the film. This is due to the fact that under strain there is a change in the spring constants which characterize the phonon dispersion of the material. In addition, the width of the spectra gives us information about the long range order inside the material. For single crystal silicon (Fig.1) there is only one peak around 522 cm^{-1} . The peak has a Lorentzian line shape with a Full Width at Half Maximum (FWHM) of about 3 cm^{-1} . As it can be seen from Fig.2 dual beam laser recrystallized film has exactly the same FWHM as that for bulk Si, which means that the recrystallized film as good as single crystal silicon was obtained. The fact that there is a shift in the location of the peak indicates that we still have some strain in the film. The reason for this is mostly due to the very thick ($1.5\text{ }\mu\text{m}$) polysilicon layer. In this fabrication we increased our polysilicon layer thickness from $0.7\text{ }\mu\text{m}$ to $1.5\text{ }\mu\text{m}$ in order to fabricate better phototransistors. The strain can be decreased by reducing the polysilicon thickness. However, noting that silicon on sapphire has the same amount of stress, it is possible to fabricate good devices in this thick polysilicon layers, even though this small amount of stress remains. Indeed, as it can be seen in Fig.3 the I-V characteristics of the PMOS and NMOS devices fabricated in this material are quite good. Especially, the mobility of PMOS devices was increased from $45\text{ cm}^2/\text{Vs}$ to $90\text{ cm}^2/\text{Vs}$. The threshold voltages and breakdown voltages of NMOS and PMOS devices were symmetrical, allowing for symmetric CMOS inverter design.

Another improvement in our process was to decrease the minimum feature size from $25\text{ }\mu\text{m}$ down to less than $5\text{ }\mu\text{m}$. This was achieved by exchanging the sequence of ion implantation of the dopants for the source and drain regions of the MOSFETs with the laser recrystallization step to eliminate the lateral diffusion of these dopants during laser crystallization. With this new sequence, however, the ion implanted impurities are activated during the gate oxide growth rather than by laser heat. This improved process will help us to reduce the dimensions of our devices to current VLSI technology dimensions.

One of the limitations of our previous process for Si/PLZT device fabrication was the low yield. We have determined the step coverage problem associated with the $3.5\text{ }\mu\text{m}$ thick buffer oxide layer (for the connection of the silicon devices and the PLZT modulator electrodes) as one of the major causes for the low yield. We therefore, concentrated our attention in finding ways of reducing the thickness of this thermal buffer layer that protects PLZT from heat damage during the crystallization process. We found that the dual beam crystallization allows a larger energy window for the crystallization process, enabling us to reduce the dwell time and to use thinner thermal

buffer layer. Accordingly, we can now use a 1-1.5 μ m buffer layer thickness, reducing dramatically the step coverage problem. Another benefit derived from dual beam recrystallization is the better repeatability. We have now developed a CMOS SPICE parameter set in agreement with our measured data, with which we can design various circuits and simulate their behavior.

We will now concentrate our efforts towards the implementation of various devices.

2. Magnetron Sputtering of PLZT on Sapphire

Our objective in studying the magnetron sputtering of PLZT on sapphire is to be able to integrate PLZT light modulators with silicon circuits on sapphire for smart SLMs. During this grant period our goal was to determine the necessary conditions for successful deposition of PLZT with our magnetron sputtering equipment.

We made two substantial improvement to our sputtering system that enable us to deposit high quality, uniform PLZT films with good repeatability. One of the major improvements made, is the ability to operate the system at much lower pressures (5 mTorr or less). The plasma can now also be maintained stable over long periods of 12 hours or more. The second improvement is an accurately controlled radiative heater that can heat the sapphire substrate up to 650 °C. Both these improvements enable us now to repeatably deposit "clean" PLZT films.

We have studied the deposited films with Rutherford Backscattering. First, we measured the spectra associated with a 9/65/35 bulk PLZT and matched to it our computer simulated results for the same concentration (see Fig. 4). Based on this result we can now calculate the desired spectra for the deposited film thickness. We also measure the actual spectra of the deposited films and adjust the growth parameters to fit the simulated data. Although, we have not been able to reach exactly the desired composition our measured results indicate that we are getting closer. For example, the backscattering spectra of films deposited during independent runs under similar conditions reveal same compositions as shown in Fig.5. This result is important in our final goal of depositing 9/65/35 PLZT.

We have also studied the composition of the grown films as functions of RF power and the substrate temperature. We found that the RF power does not affect significantly the composition, although it effects the deposition rates. However, the substrate temperature affects the composition significantly. For example, the lead deficiency in the grown films increases with increasing substrate temperature. This result corresponds to similar results obtained by researchers working on deposition of PLT/PZT. However, we find that the optical quality of the films also improves with the substrate temperature. We now are depositing PLZT at 550 °C using the second gun in our system to compensate for the lead deficiency.

3. Study of Different GaAs Growth Conditions on Sapphire

The objective of this study was to investigate the possibility of depositing GaAs on sapphire. Since device quality silicon can be grown epitaxially on sapphire, the deposition of GaAs on sapphire will enable the integration of photonic III-V devices with highly integrated silicon circuits.

During this grant period our focus was to investigate different growth conditions for GaAs on sapphire with molecular beam epitaxy. We have grown GaAs on sapphire, on silicon on sapphire and on InAlAs on sapphire at different growth temperatures. The Raman Spectroscopy of our grown samples have revealed the following results. First, the quality of the GaAs grown directly on sapphire improves with higher temperature. This is evident from the Raman spectra of the films grown at 600 °C and 650°C as shown in Fig.6. We observe a much lower FWHM at 650 °C demonstrating better crystallinity (Fig. 6b). The results are further improved when a thin InAlAs film is first deposited as a buffer layer as evidenced by Fig.7. We also note a second peak at 280 nm corresponding to the background doping concentration of the film. The best results were obtained however, for GaAs films deposited on a very thin film of silicon on sapphire. The silicon film thickness was about 300Å and the superior GaAs film quality is evidenced by Fig.8. In all cases the orientation of the deposited GaAs film was $\langle 111 \rangle$ as expected.

In the future we will further our studies using the GaAs/Si/sapphire approach and attempt to build MQW layers on GaAs deposited on Si.

4. Study of Organic Light Modulators based on Liquid Crystal Composites

Our objective was to characterize organic materials provided by Celanese Co. for spatial light modulation. Materials requiring both lowest switching energy and half-wave voltage are required for smart spatial light modulators.

We have deposited surface interdigitated aluminum electrodes on liquid crystal composite (LCC) material and observed their electrooptic modulation characteristics with transverse geometries. For depositing the Al electrodes we used an acetone-less processing which improved the electrode adhesion onto the spun films of LCC. We have verified the quadratic electro-optic response of the films and measured a half-wave voltage in the range of 300V with a dynamic range of 20:1 for the tested geometries. Two transmittance characteristics are shown in Fig.8. The photomicrographs of the modulators at the "ON" and "OFF" state are shown in Fig. 9a and 9b.

Since the required voltage is quite high for silicon devices, we are now focusing our efforts to place this LCC material within a fabry-perot resonator to reduce the half-wave voltage to more acceptable levels for silicon devices. We are also attempting to increase the optical interaction length by studying different deep electrode geometries.

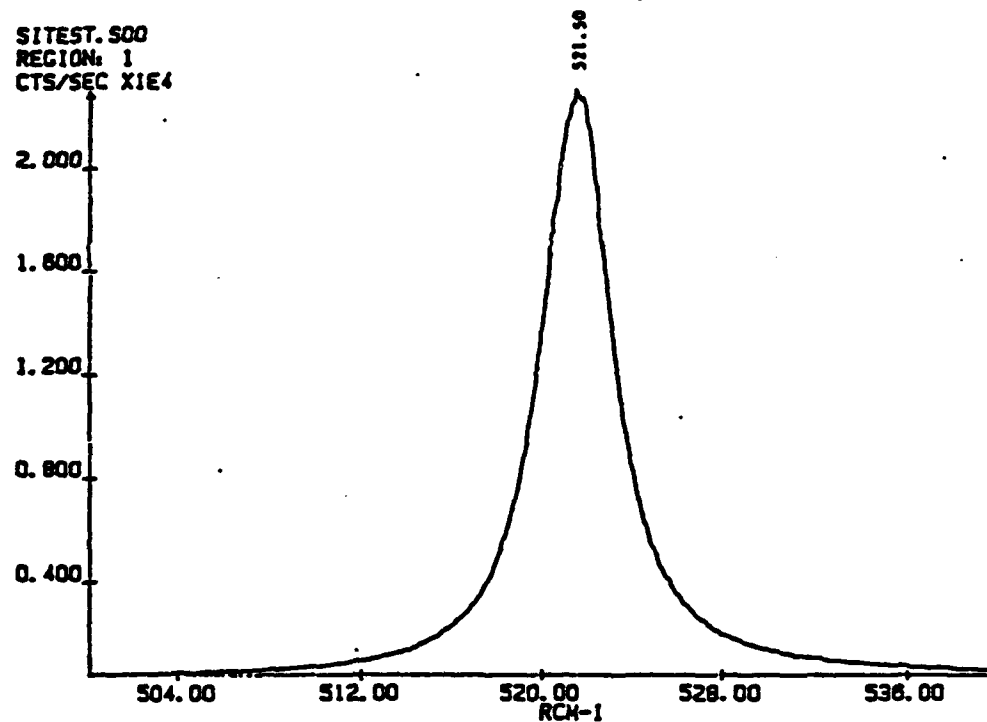


Fig.1 Raman Spectra of single crystal silicon.

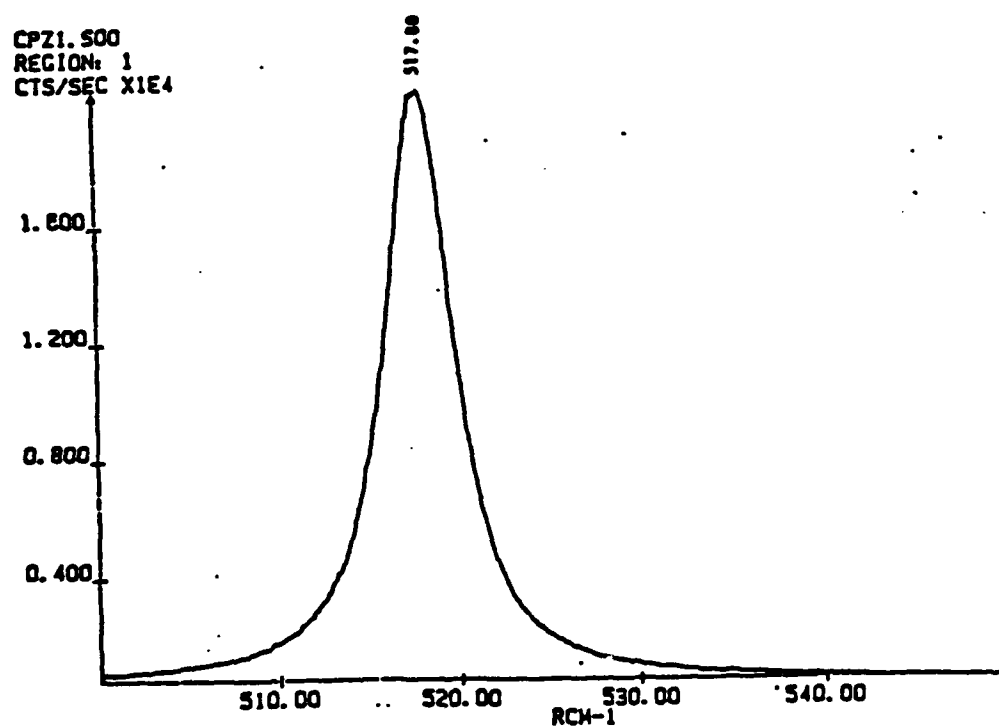
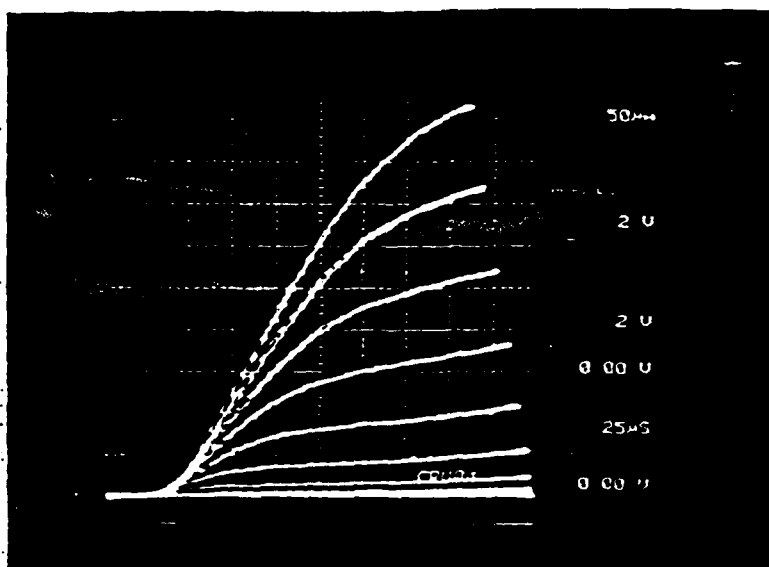


Fig.2 Raman Spectra of recrystallized silicon using dual beam.

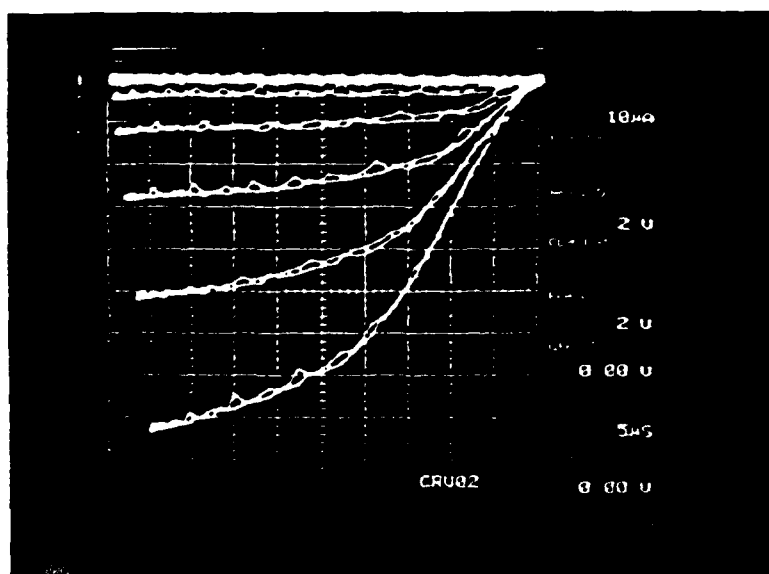


NMOS

$$V_{th} = 2 \text{ V}$$

$$V_{br} = 30 \text{ V}$$

$$\mu = 300 \text{ cm}^2/\text{Vs}$$



PMOS

$$V_{th} = -2 \text{ V}$$

$$V_{br} = 30 \text{ V}$$

$$\mu = 100 \text{ cm}^2/\text{Vs}$$

Fig. 3 The I-V characteristics of the fabricated transistors.

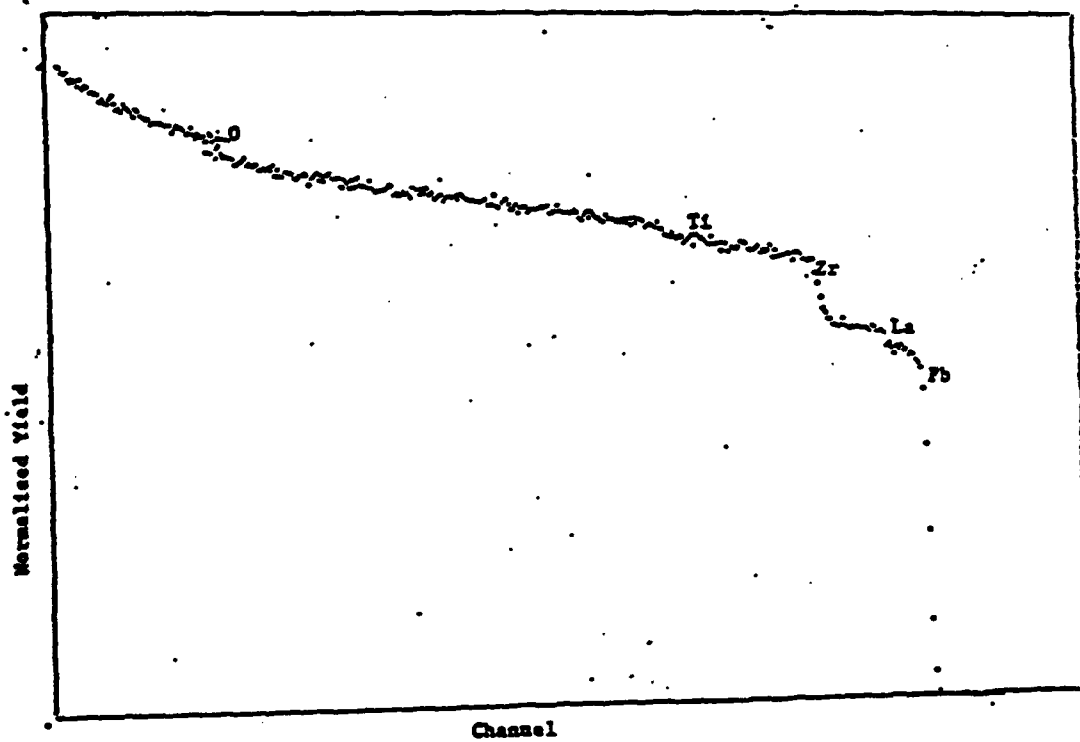
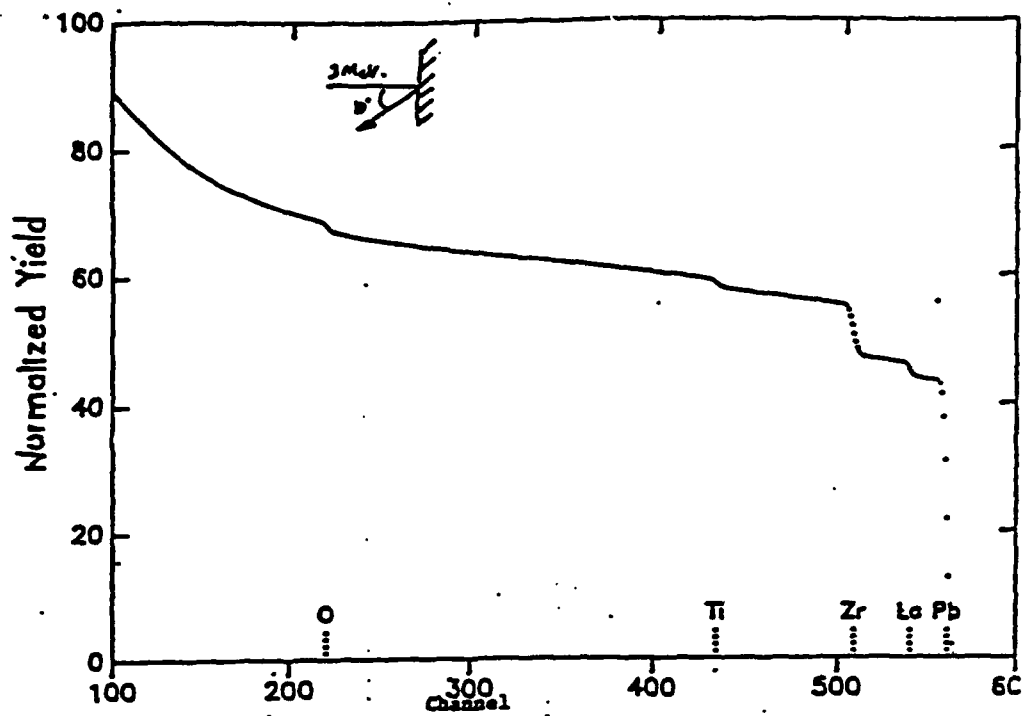


Fig.4:(a) RBS spectra simulated for 9/65/35 bulk PLZT
 (b) RBS spectra measured for 9/65/35/ bulk PLZT

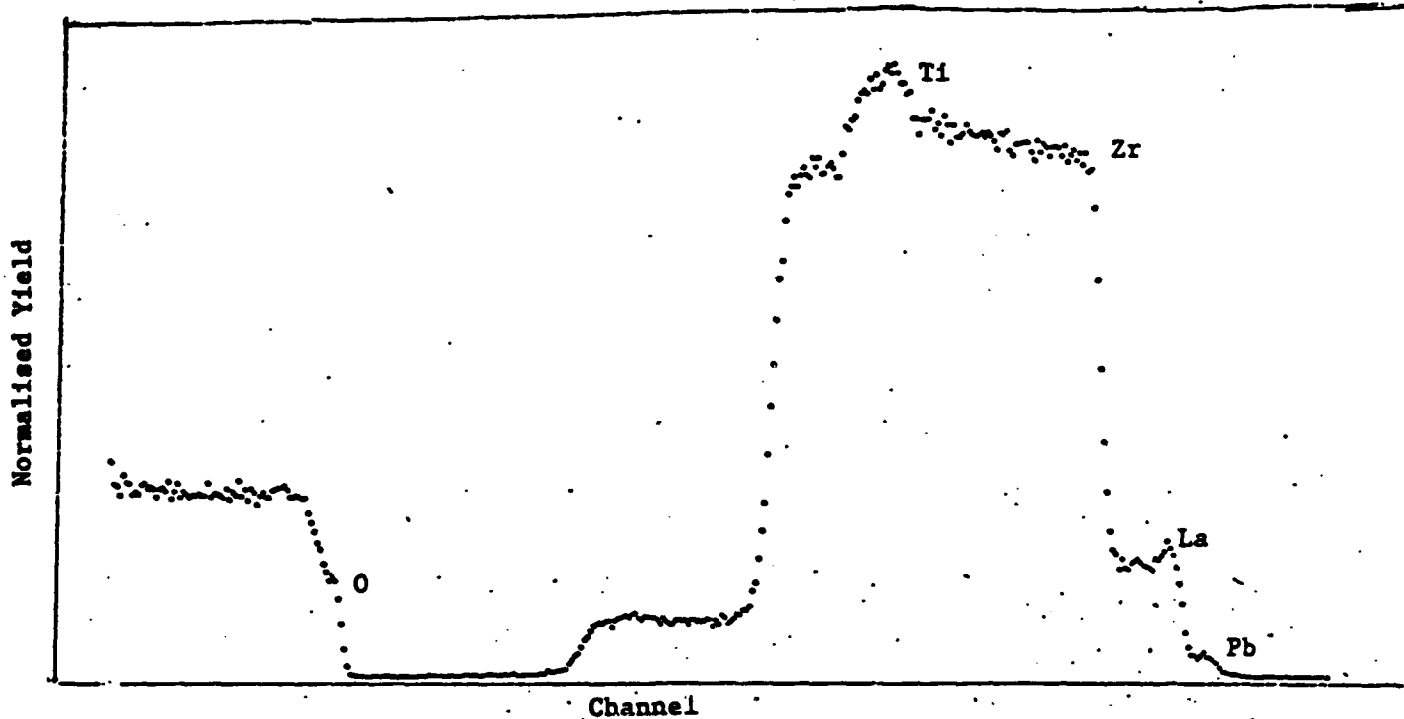


Fig-5a RBS spectra for thin film PLZT deposited @300W R.F, 580 °C

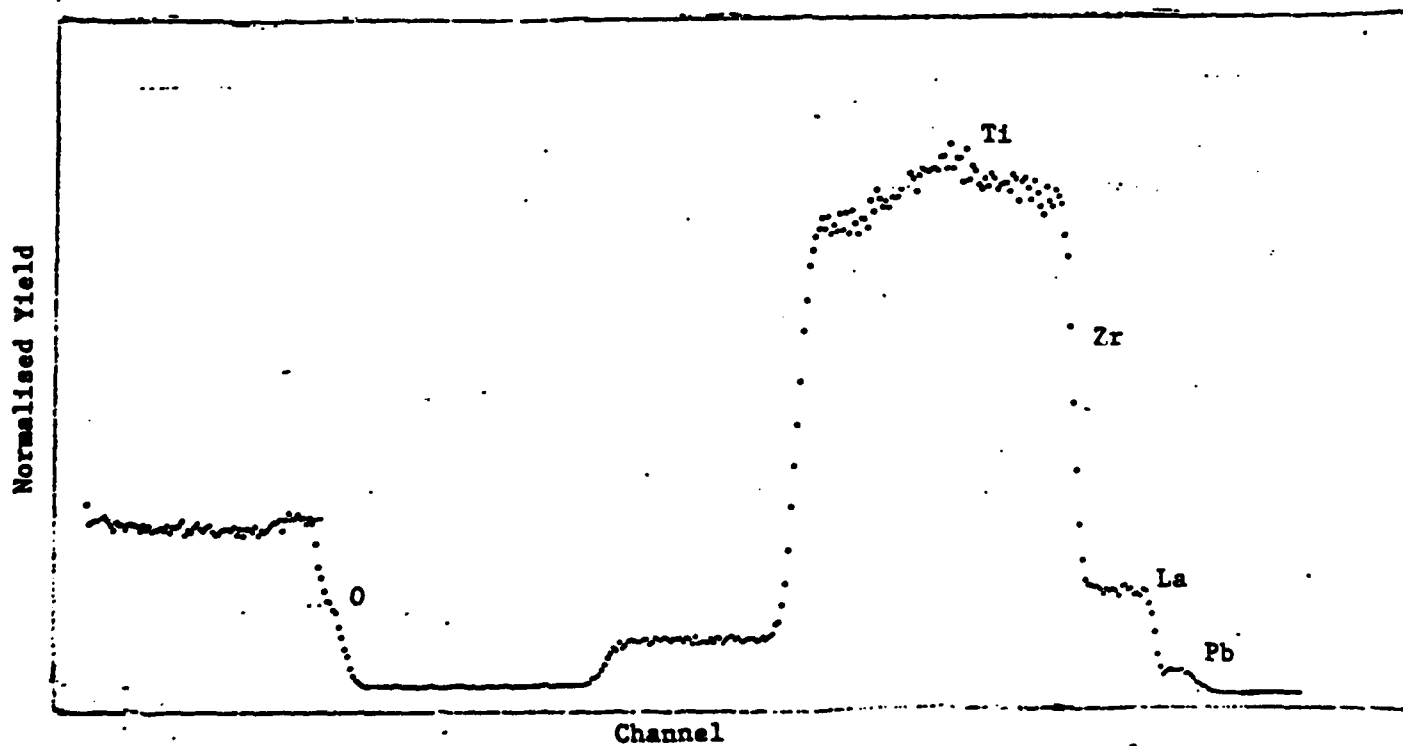


Fig-5b RBS spectra for thin film PLZT deposited @350W, 580 °C

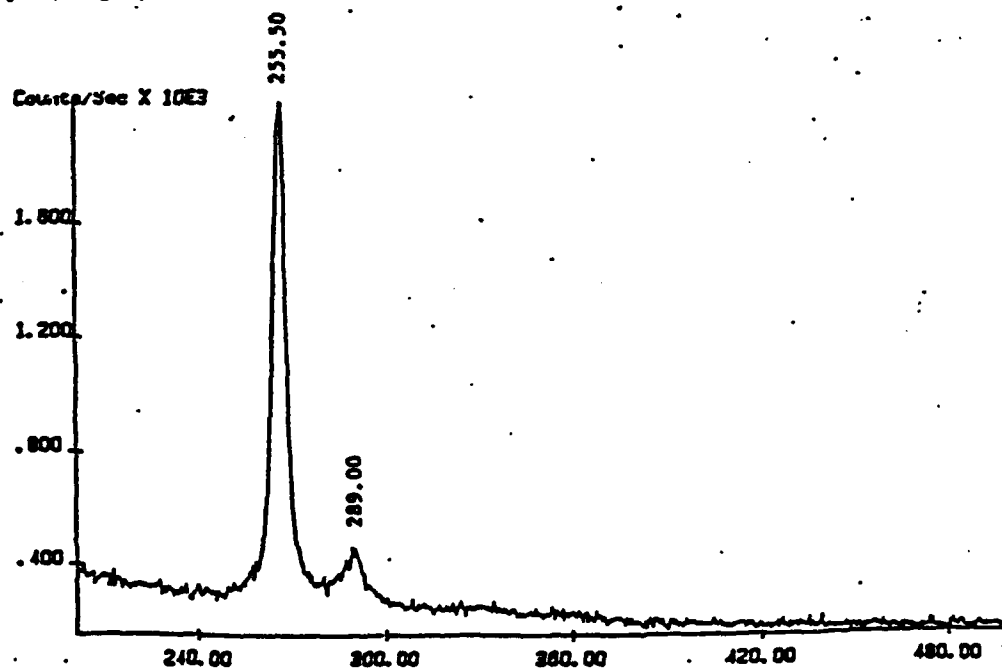
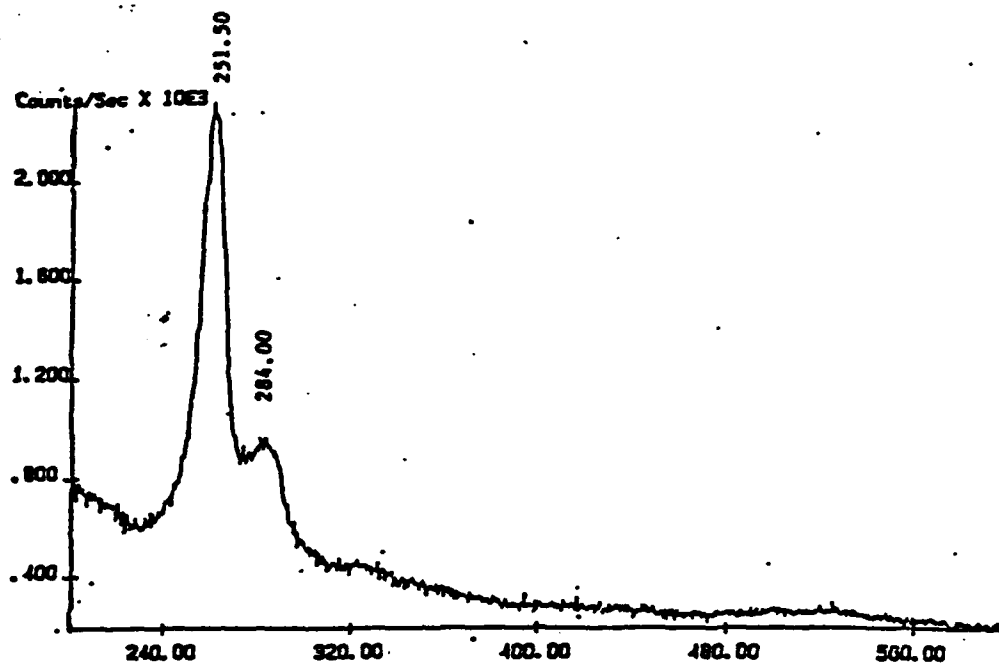


Fig-6:(a) Raman spectra of 111 oriented GaAs on sapphire deposited at 600 C.
 (b) Raman spectra of GaAs on sapphire deposited at 650°C.
 Note the improvement on the FWHM.

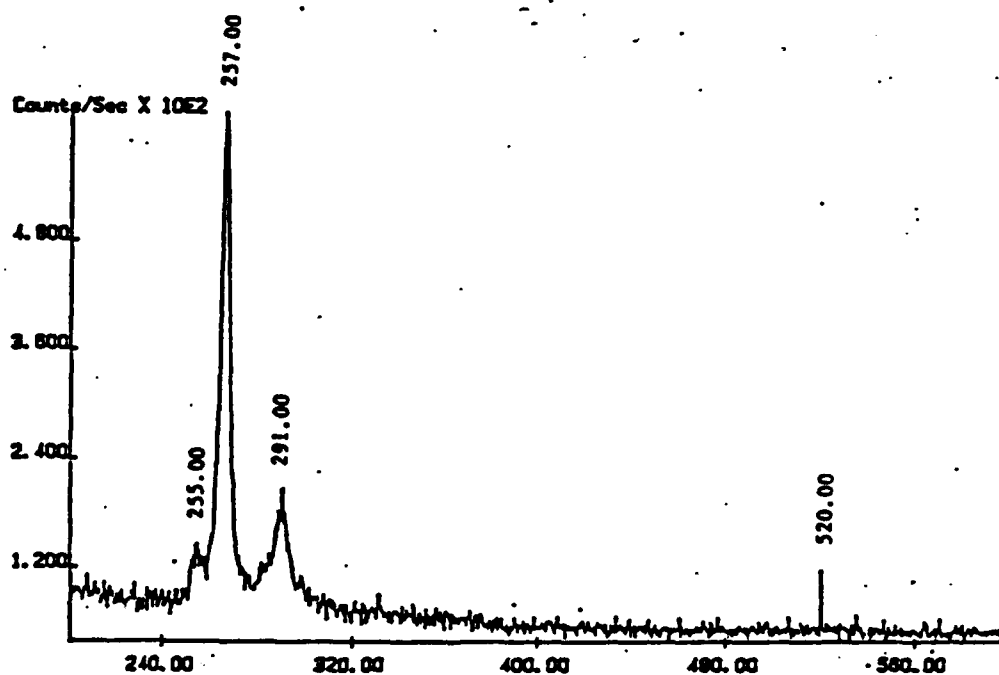
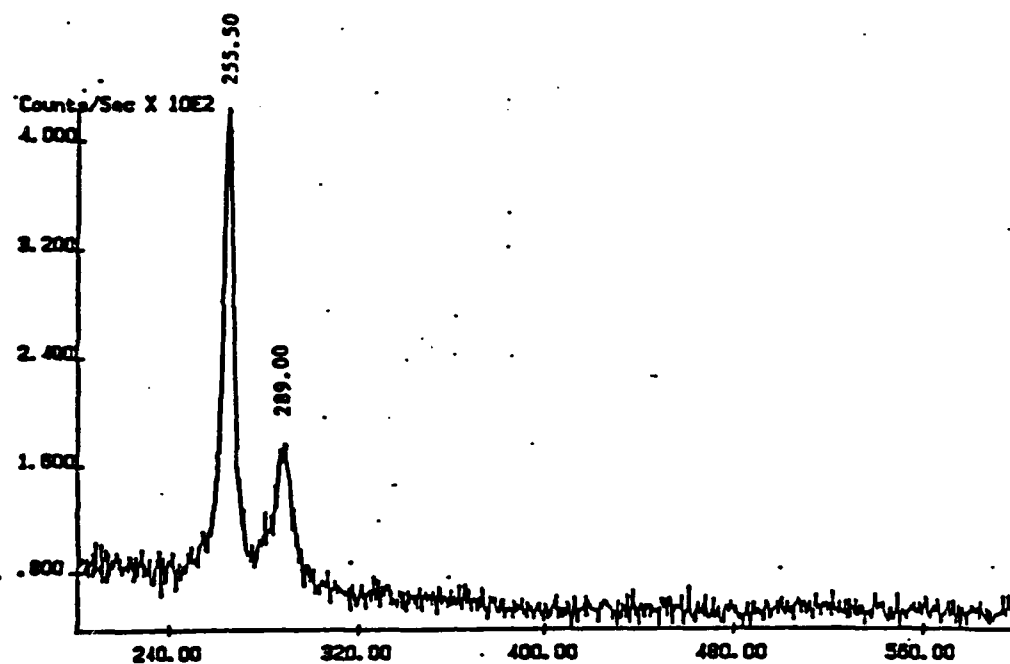


Fig.7:(a) Raman Spectra of GaAs grown InAlAs on Sapphire.
 Note the smaller FWHM and the second peak resulting from the depletion of carriers.
 (b) Raman spectra of GaAs grown on thin Si on Sapphire.
 One can observe both the transverse and longitudinal modes and the depletion caused by the pump beam.

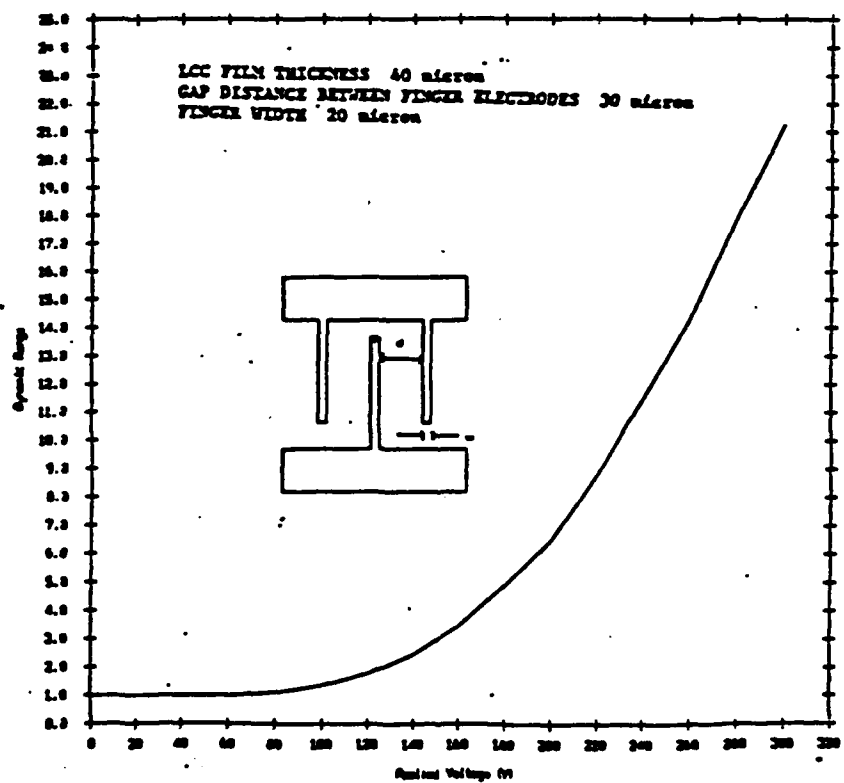
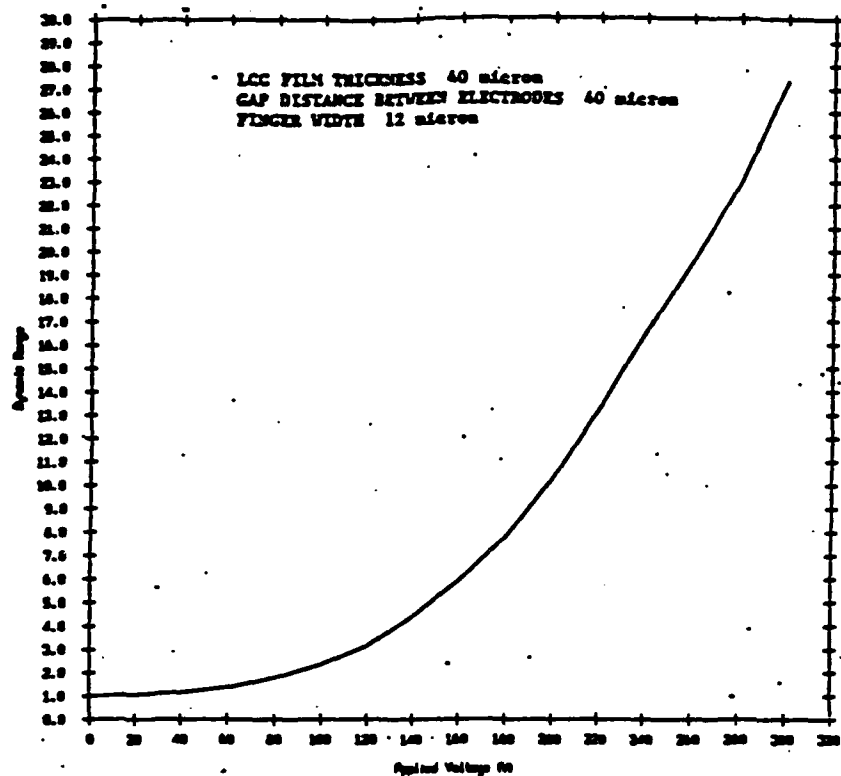


Fig.8: Transmittance of organic LCC modulators in function of the applied voltage for geometries as indicated in the figures.

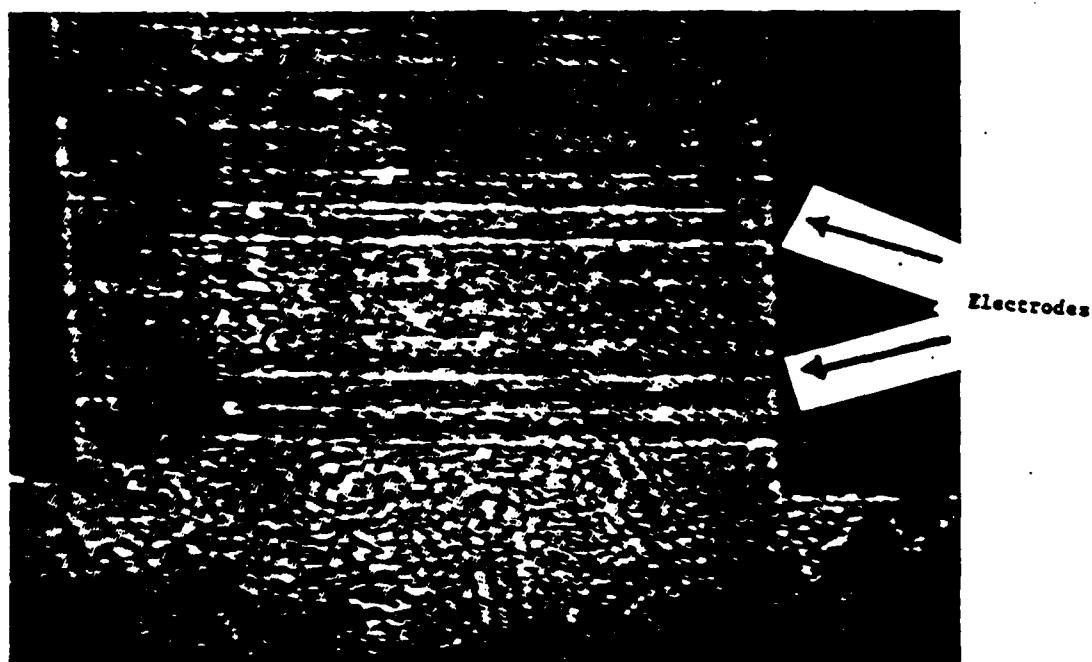
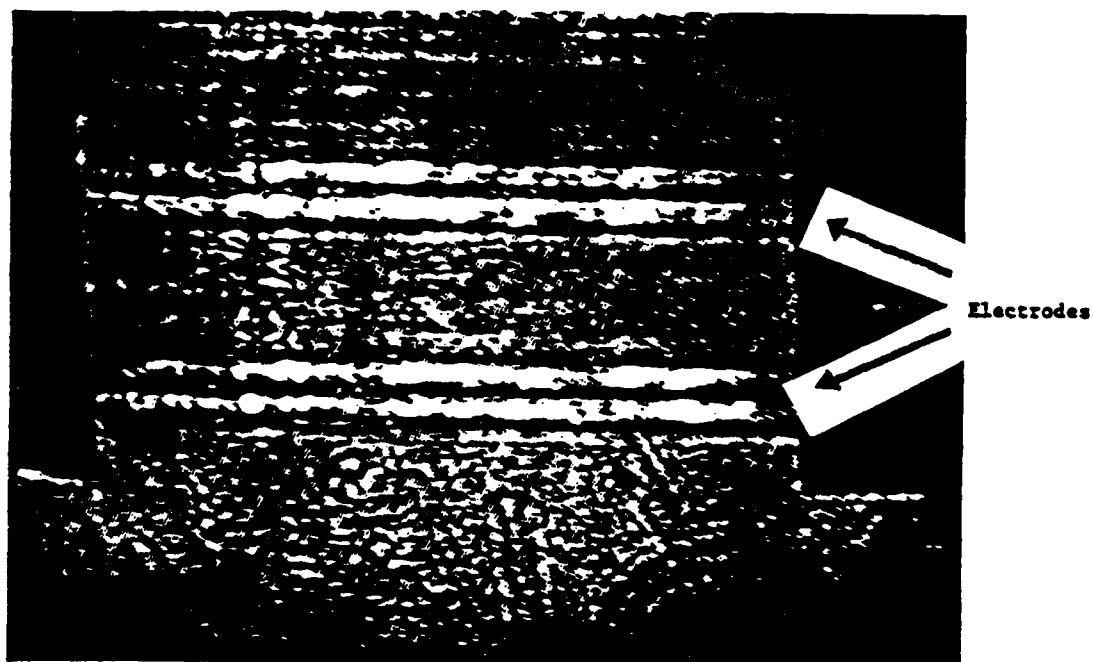


Fig.9:(a) Modulator at the ON state
(b) Modulator at the OFF state.

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