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DEVELOPMENT OF VLSI OPTICAL DATA LINK(U) WESTINGHOUSE
RESEARCH AND DEVELOPMENT CENTER PITTSBURGH PA
P G McMULLIN ET AL. 01 OCT 87 DAAL01-86-C-0023

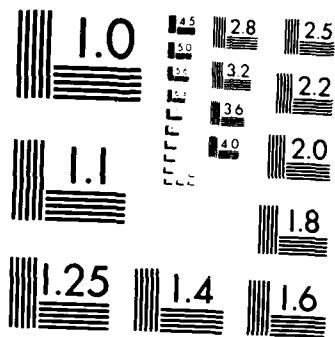
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**DEVELOPMENT OF VLSI
OPTICAL DATA LINK**

Quarterly Technical Status Report #3 for the period
March 1 to May 30, 1987

Contract No. DAAL01-86-C-0023
Department of the Army
Electronics Technology and Device Laboratory
Fort Monmouth, New Jersey 07703

P. G. McMullin
Crystal & Device Technology Research

R. L. Messham
Microeletronic Device Research

October 1, 1987

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This report covers a sequence of epitaxial growth runs on sapphire substrates. The gallium arsenide films resulting do not have as good a surface morphology as the films previously grown on silicon-on-sapphire substrates. However, the films are highly oriented with respect to the substrate and controllable to obtain 111 or 100 orientation. Further optimization of deposition on sapphire substrates will be continued while the main thrust of the program will be directed to the formation of devices fabricated in gallium arsenide layers deposited onto the silicon epilayer of SOS substrates for evaluation purposes.

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1. INTRODUCTION

The objective of the program is to provide optical interconnection capability for radiation-hard VLSI circuits based on SOS signal-processing components and GaAs optical components. The silicon and GaAs circuit components are to be fabricated on a common sapphire substrate. The GaAs devices will reside in GaAs epilayers deposited locally onto the substrate. Because the SOS substrate already has a silicon epilayer, the GaAs epilayer may be deposited directly onto the sapphire, or onto the existing silicon layer.

Preliminary results, described in the previous quarterly report, indicate that epitaxial deposition is more readily achieved for GaAs on the silicon layer than on the sapphire substrate. There are advantages, however, to direct deposition onto the sapphire. First, the sapphire substrate is crystallographically more perfect than the silicon layer. It is well known that the silicon layer in SOS material has a high density of twins and dislocations. A GaAs epilayer on a more perfect substrate could be expected to have better crystallinity. Second, since silicon is a dopant for GaAs, direct deposition onto sapphire should give a cleaner GaAs layer and eliminate any need for a passivation layer below the device active region. To obtain these advantages, good epilayers must be grown on sapphire substrates.

This quarterly report reviews the results of a series of runs on sapphire wafers and summarizes the outlook for direct deposition onto sapphire.

2. MOCVD CONDITIONS

A sequence of MOCVD runs was carried out using two-inch diameter sapphire wafers of $1\bar{1}02$ surface plane orientation. The wafers were purchased from Union Carbide as suitable substrates for SOS silicon epilayer deposition. The wafers have lapped backsides and front surfaces finished with a proprietary polishing method. They were prepared for GaAs deposition by thorough solvent cleaning.

Once placed in the MOCVD reactor, the sapphire wafers were heated to 300°C to drive off residual moisture. Most of the runs then involved a prebake in flowing hydrogen and arsine at 750°C for six minutes to further clean and precondition the surface. The substrates were then ramped to and stabilized at the growth temperature. The flow of trimethyl gallium (TMG) was switched on to initiate GaAs deposition. The GaAs layer target thickness was $1.5\ \mu\text{m}$. At the end of the deposition cycle, the TMG flow was stopped and the samples were cooled in flowing arsine.

In this run sequence the temperature of the epilayer deposition cycle was varied from 600 to 700°C . The growth rate was varied from standard ($1.4\ \text{nm/s}$) to slow ($0.3\ \text{nm/s}$). Samples were prepared in which the epilayer composition was changed from GaAs to GaAlAs with 30% or 70% AlAs. The surface preconditioning included exposure to trimethyl gallium and trimethyl aluminum for two-minute cycles immediately before beginning the GaAs deposition. Also, the three-step growth process described in Quarterly Status Reports #1 and #2 was tried yet again. The preliminary attempts using the low-temperature nucleation layer for sapphire substrates had all failed to yield epitaxial growth. In this sequence, a prolonged anneal was used after the low-temperature deposition to allow more time for recrystallization of the nucleation layer.

3. RESULTS AND DISCUSSION

The GaAs layers deposited on sapphire substrates were characterized by optical microscope inspection of the surface morphology. Most of the layers were grainy in appearance, with surface roughness much greater than observed for GaAs layers on the silicon epilayer. Many of the samples showed signs of faceting texture, indicating well-oriented material. Several samples were further characterized to determine the crystallographic structure.

3.1 X-RAY TEXTURE CAMERA EVALUATION

Samples were submitted for x-ray texture camera analysis. In this procedure, the sample is placed at a 30 degree angle to the incident collimated x-ray beam. The sample is rotated about an axis perpendicular to the surface, and the film is wrapped around the sample inside a cylindrical holder to register the spots produced when the diffraction condition is satisfied. The resulting pattern is shown in Figure 1 for Sample M42. Many of the spots in the pattern originated from the sapphire substrate. These are identified by comparison with exposures made using bare sapphire samples. The extra spots are marked, and indexed, to determine the orientation of the surface GaAs layer. Some information can be obtained by inspection. An amorphous surface layer would give a diffuse scattering with no well-defined spots. This is obviously not the case for the sample of Figure 1. Fine-grain polycrystalline material, with random orientation of the grains, would give a pattern of streaks following well-defined paths on the film. This also is not evident for the sample shown. The strong spots, circled on the figure, are consistent with 111 orientation of the GaAs layer. The weak spots, indicated by small dots, are consistent with

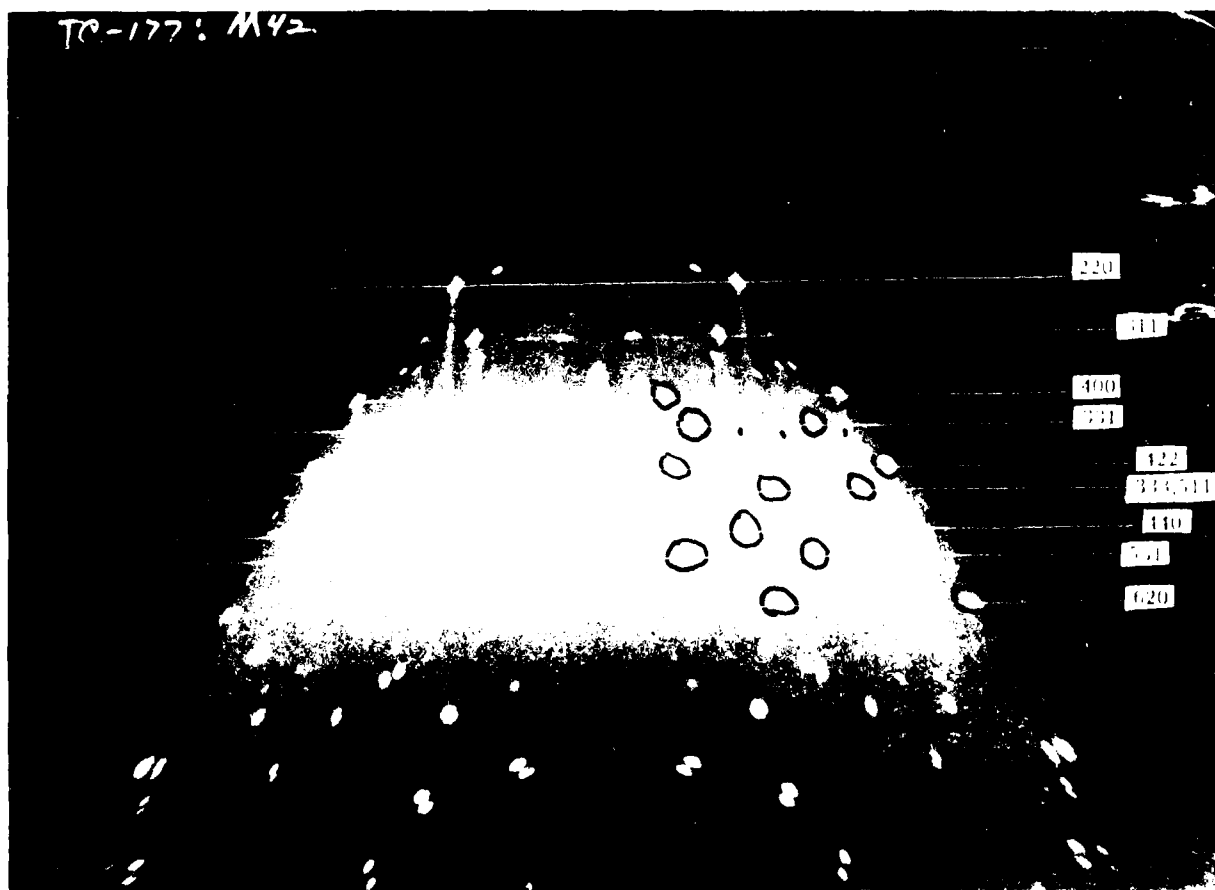


Figure 1. Diffraction pattern from x-ray texture camera characterization of Sample M42.

GaAs of 511 orientation, present as a moderate volume density of twinned material with respect to the predominant orientation.

For the sample of Figure 1, the standard run conditions described above were used, with a 650°C deposition temperature and a 30% AlAs composition for the layer. The x-ray texture camera results show that this sample is a reasonably good epilayer, with a high density of twins. In this respect, the GaAs layer resembles the silicon layer of SOS, in which the twin density is very high near the interface with the substrate. Further characterization of this sample by cross-section TEM will be necessary to determine the distribution of twins within the volume of the layer.

3.2 UV SCATTERING HAZE EVALUATION

Samples from this sequence were also characterized by the ultraviolet scattering (UVS) haze method. This method provides information about the surface texture and the symmetry of surface features that are not discernible in microscope views. Several traces are shown in Figure 2 for GaAs layers on sapphire substrates. Examination of the trace for Sample M42 shows that there are peaks at 27, 142, and 258 degrees of rotation. These peaks are spaced about 120 degrees apart, indicating a three-fold symmetry of the surface texture, consistent with the predominant 111 surface plane orientation, as determined from the x-ray texture camera pattern shown in Figure 1. The three peaks specified also coincide very well with the major peaks seen in the first sample of Figure 11 in the previous quarterly report. The trace for M42 also shows two additional peaks, indicating that the surface texture is more complex than simply 111 orientation alone. This is also consistent with the finding of an appreciable density of twins from the x-ray results. Further comparisons will be carried out to establish the relationship of the UVS observation of surface texture and symmetry with the film orientation and structure as determined by x-ray and TEM. The advantage of the UVS method, once the traces can be reliably interpreted, is that the technique is rapid and non-destructive.

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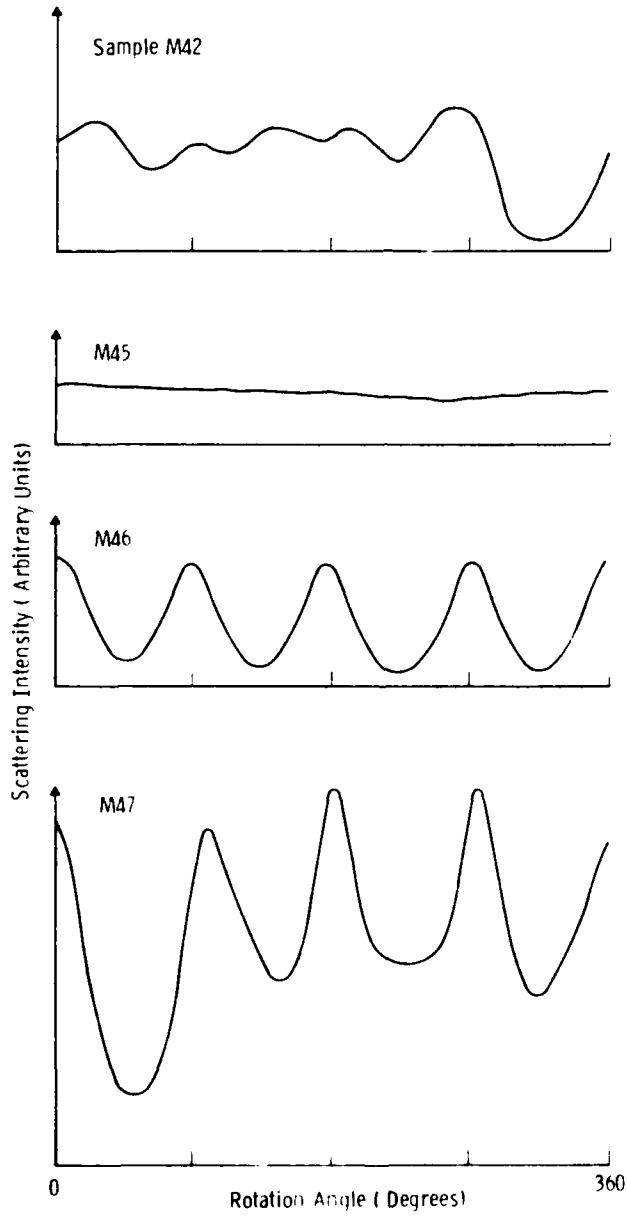


Figure 2. Ultraviolet scattering (UVS) haze traces for GaAs epilayers on sapphire substrates.

Also shown in Figure 2 are traces for three other samples. Sample M45 was produced by the three-step method. A nucleation layer was deposited at 420°C, and anneal was carried out at 650°C for 30 minutes; the GaAs layer was grown at 650°C to a thickness of 1.5 μm. In this case, the layer contained 30% AlAs. The UVS haze trace shows no sign of symmetrical texture in the surface. The surface morphology is rough and grainy. This indicates that the GaAs layer is fine-grain poly with no tendency to orient with respect to the substrate, a result which is consistent with all of our other attempts to use this method. The three-step process works very well on silicon substrates and for deposition on the silicon epilayer of SOS, but none of our attempts to date to use it on sapphire have been successful.

The traces for M46 and M47 have very clear four-fold symmetry. Sample M46 was produced by using a prebake in hydrogen at 800°C, then deposition of a 20 nm layer with 30% AlAs, followed by a 1.5 μm thick GaAs layer, all at 650°C. Preparation of Sample M47 involved the standard arsine prebake and GaAs deposition at 650°C, but the sapphire substrate was etched in phosphoric acid before the run. The surface layer orientation has not yet been confirmed by x ray analysis. However, it is highly likely that the layer has 100 orientation, judging by the UVS traces. This shows that it is possible to control the GaAs layer orientation by means of the surface preparation and preconditioning methods.

4. CONCLUSIONS

The sequence of runs on sapphire substrates has been partially characterized. The surface morphology of such samples is not yet as good as that obtained for deposition onto the silicon epilayer of SOS. The GaAs film structure, however, appears to be highly oriented with respect to the substrate, and controllable to obtain 111 or 100 orientation depending on preparation, preconditioning, and run conditions. The best results have been obtained with single-temperature deposition cycles, in strong contrast to the three-step deposition that works best with silicon or silicon epilayer substrates. Because of the prospective advantages of deposition directly onto the sapphire, further optimization of MOCVD deposition techniques on sapphire substrates will be performed, while the main thrust of the program will be directed to devices fabricated in GaAs layers deposited onto the silicon epilayer of SOS substrates.

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