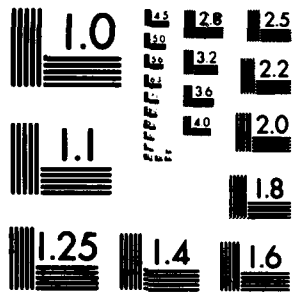




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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  
This research investigated the composition, structure and electrical properties of thermal and anodic oxides of the III-V compounds. The composition of the oxides was determined by XPS profiling. Models for the structure of the oxides were obtained from current-voltage, X-ray diffraction and XPS data. The chemical composition and electrical properties of anodic oxides of InP were found to be highly dependent on the growth conditions but the oxides on GaAs and InAs were not. This appears to be related to the basic difference in the structure of the oxides. The anodic oxide could be formed in such a

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20. ABSTRACT CONTINUED

way as to have good insulating properties. The thermal oxides were always poor insulators.

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**CORRELATION BETWEEN THE COMPOSITION/BONDING AND INSULATING  
PROPERTIES OF GROWN OXIDES ON III-V COMPOUND SEMICONDUCTORS**

**Final Report**

**by**

**C. W. Wilmsen**

**January 1982**

**U. S. Army Research Office**

**DAAG29-78-G-0197  
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**Colorado State University  
Fort Collins CO 80523**

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## I. Problem Statement

This research investigated the composition, structure and electrical properties of thermal and anodic oxides of the III-V compounds. The composition of the oxides was determined by XPS profiling the grown oxides. Models for the structure of the oxides were obtained from current-voltage, X-ray diffraction and XPS data.

## II. Summary of Results

A. Anodic Oxides. The anodic oxides of GaAs, InP and InAs were investigated. The compositional profiles of the InP anodic oxides were found to be highly dependent on growth conditions where as the anodic oxides of InAs and GaAs were not. Similarly it was found that the insulating properties of the InP anodic oxides changed dramatically with growth condition while those of InAs and GaAs did not. For the InP oxides, Fig. 1 illustrates the large change in oxide resistivity with composition.

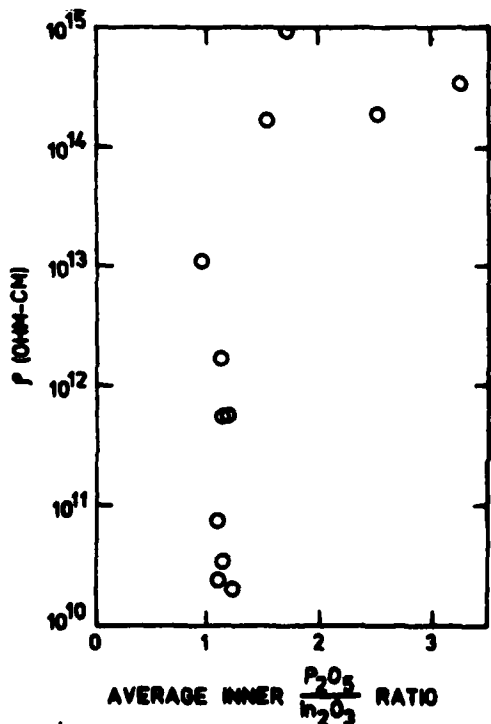


Fig. 1. InP anodic oxide resistivity at a field of  $5 \times 10^4$  V/cm as a function of the average  $P_2O_5/In_2O_3$  ratio of the inner oxide layer.

These observations led to the conclusion that the InP anodic oxide is phase separated into islands of  $\text{In}_2\text{O}_3$  and  $\text{P}_2\text{O}_5$  with the electrical conduction determined by electron tunneling or hopping between the islands. The anodic oxides of InAs and GaAs, on the other hand, do not appear to be phase separated and are more or less homogeneous. The island structure of InP anodic oxides seems to allow preferential dissolution of one or the other oxide species while the anodic oxides of InAs and GaAs tend not to dissolve selectively.

The insulating properties of the GaAs anodic oxides are approximately independent of growth conditions and the  $\text{Ga}_2\text{O}_3/\text{As}_2\text{O}_3$  ratios are approximately equal to one for all cases. The InAs anodic oxides have similar characteristics but growth in basic solutions decreases the oxide resistivity. Table I summarizes the insulating properties of the anodic oxides.

Table I. Insulating Properties of the Anodic Oxides

| III-V Compound | P, ohm-cm           | Breakdown field, V/cm    |
|----------------|---------------------|--------------------------|
| InP            | $10^{10} - 10^{15}$ | $10^5 - 3 \times 10^6$   |
| InAs           | $10^{13} - 10^{15}$ | $10^6 - 3.7 \times 10^6$ |
| GaAs           | $10^{15} - 10^{16}$ | ?                        |

The initial growth of the anodic oxides of GaAs and InP were also investigated. It was found that initial growth has a nucleation and island stage and that the oxide island of GaAs are different from those of InP. Photomicrograph of the GaAs anodic oxide islands are illustrated in Fig. 2.

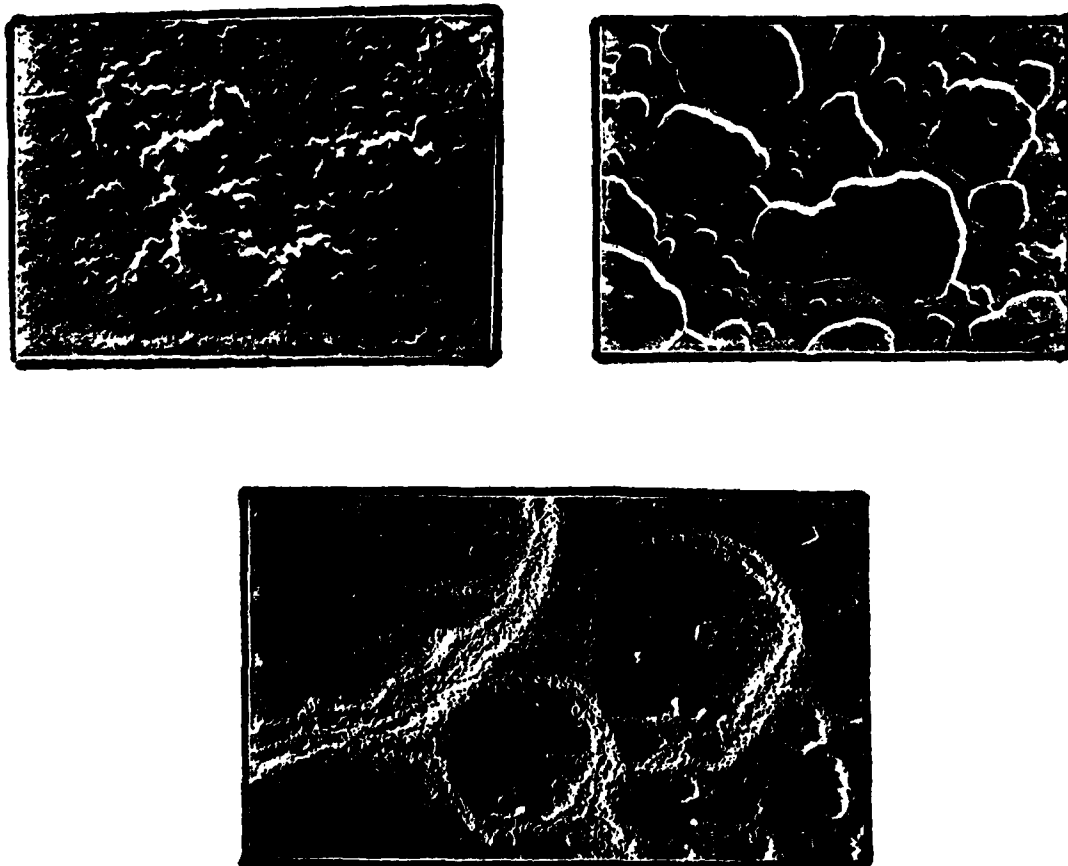


Fig. 2. Transmission electron micrographs of the nuclei and islands of anodic oxide on GaAs (Makky and Wilmsen).

From these and other photomicrographs it was determined that:

1. Nucleation is a continuous process
2. The island area and the island height are directly proportional up to an island area of  $\approx 0.1 \mu^2$
3. Above  $0.1 \mu^2$  the island height is independent of area
4. Coalescence occurs, probably by an increased growth rate in the neck regions and not by surface diffusion.

B. Thermal Oxides. The thermal oxides of InP, InAs and GaSb were investigated. Table II summarizes the results. The electrical Conduction of all these oxides was high.

### III. List of Publications

1. "Thermal Oxidation of InAs," D. H. Laughlin and C. W. Wilmsen, Thin Solid Films, **70**, 325 (1980).
2. "Anodic Oxide Insulators on InP and InAs," D. A. Baglee, D. H. Laughlin, C. W. Wilmsen and D. K. Ferry in The Physics of MOS Insulators, edited by G. Lucovsky, S. T. Pantelides and F. L. Galeener, Pergamon Press, 1980.
3. "Inversion Layer Transport and Properties of Oxides on InAs," D. A. Baglee, D. K. Ferry, C. W. Wilmsen and H. H. Wieder, J. Vac. Sci. Tech., **17**, 1032 (1980).
4. "Inversion Layer Transport and Insulator Properties of Indium Based III-V's," D. A. Baglee, D. H. Laughlin, B. T. Moore, B. L. Eastep, D. K. Ferry and C. W. Wilmsen, Institute of Physics Conference Series Number 56, 1980.
5. "An Improved Anodic Oxide Insulator for InP Metal-Insulator-Semiconductor Field-Effect Transistors," D. H. Laughlin and C. W. Wilmsen, Appl. Phys. Lett., **37**, 915 (1980).
6. "Chemical Composition and Formation of Thermal and Anodic Oxide/III-V Compound Semiconductor Interfaces - Critical Review," C. W. Wilmsen, J. Vac. Sci. Technol., **19**, 279 (1981).
7. "Initial Anodic Oxide Growth on GaAs," W. Makky, F. Cabbara, K. Geib, and C. W. Wilmsen, submitted to J. Electrochem. Soc.

Table II. Composition and Crystallinity of the Thermal Oxides of InP, InAs and GaSb

| III-V Compound | Growth Temp. | Composition   | Crystallinity   |
|----------------|--------------|---|-----------------|
| InP            | 350-600°C    | In <sub>2</sub> O <sub>3</sub> and InPO <sub>4</sub><br>in a ratio of ≈4:1<br>with elemental P at<br>the interface              | Non crystalline |
|                | 600-700°C    | Primarily InPO <sub>4</sub><br>with no elemental<br>P at the inter-<br>face   | Crystalline     |
| InAs           | 350°C        | In <sub>2</sub> O <sub>3</sub> and As <sub>2</sub> O <sub>3</sub><br>in ≈ equal pro-<br>portions                                | Non crystalline |
|                | 425-450°C    | In <sub>2</sub> O <sub>3</sub> and As <sub>2</sub> O <sub>3</sub><br>in a ratio 3 to 1<br>with elemental As<br>at the interface | Non crystalline |
|                | 475-500°C    | In <sub>2</sub> O <sub>3</sub> /As <sub>2</sub> O <sub>3</sub> ≈ 3<br>with elemental<br>In and As                               | Crystalline     |
| GaSb           | 300-500°C    | Ga <sub>2</sub> O <sub>3</sub> and<br>Sb <sub>2</sub> O <sub>3</sub>  | Non crystalline |

**IV. Participating Scientific Personnel**

C. W. Wilmsen - PI  
Kent Geib - Research Associate  
D. A. Baglee - Post Doc  
Dennis Laughlin - M.S. August 1980  
Art Nelson - M.S. Student (August 1982)  
Wagih Makky - Ph.D. Student (December 1982).

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