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13. ABSTRACT (Maximum 200 words) We summarize our fifth quarter progress towards developing a thin film edge emitter vacuum triode capable of 1 GHz modulation for sustained (>1 hour) periods of time. We completed fabrication of the first thin film edge emitter vacuum transistors this quarter. Significant DC characterization of these devices was carried out. Triode characteristics have been observed on many devices. Low frequency (1 KHz) modulation of the devices has been shown. These vacuum transistors have high currents (50 μ A), high current densities (10 μ A/ μ m) and estimated transconductances of >1.5 μ S. Such device parameters are above those required to achieve 1 GHz operation.					
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R&D Status Report
RF Vacuum Microelectronics
Quarterly Progress Report #5
(10/1/1992 - 12/31/92)

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10701 Lyndale Avenue South
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Effective Date of Contract: September 30, 1991

Contract Expiration Date: March 31, 1993 (Baseline)

Contract Amount: Baseline \$1,315,650

Option: \$ 772,532

Principal Investigator: Tayo Akinwande 612/887-4481

Program Manager: David K. Arch 612/887-4404

Title of Work: **RF Vacuum Microelectronics**

I. Executive Summary

Technical Approach: Our technical approach is to utilize thin film technology and surface micromachining techniques to demonstrate an edge emitter based vacuum triode. The edge emitter triode approach offers several potential advantages to achieving high frequency device operation (compared to cone emitters or wedge emitters):

- The fabrication process is a planar process, compatible with most silicon IC manufacturing.
- Thin film processes for the films used in the triode process are well controlled and reproducible. Control of film thicknesses to within 5% for the emitter film thickness is easily attainable resulting in a well-controlled edge emitter.
- Device capacitance for the edge emitter is less than that achievable for cones or wedges resulting in potentially higher frequency operation.

Program Objective: Demonstrate an edge emitter based vacuum triode with emission current density of $10 \mu\text{A}/\mu\text{m}$ at less than 250 V which can be modulated at 1 GHz continuously for 1 hour.

Key Achievements (this reporting period)

- Demonstrated a thin-film emitter vacuum transistor with symmetrically layered gate/control electrodes and integrated anodes.
- Demonstrated low frequency (1 KHz) modulation of a thin-film emitter transistor for the first time.

II. Milestone Status

	<u>Completion Date</u>	
	Planned	Actual (estimate)
1. Field Emitter Development		
Test Structure Design Complete	12/91	1/92 (complete)
Determine Workable Emitter Structure	3/92	3/92 (complete)
Demonstrate Emission Current of $10 \mu\text{A}/\mu\text{m}$	11/92	11/92 complete
Deliver 10 Field Emitting Diodes	12/92	12/92 (on plan) (delivered 10/13/92)
2. Process Development		
High Resistivity Thin Film Resistor	4/92	9/92 (complete)
Complete Dielectric Studies	5/92	6/92 (complete)
Mechanical and Electrical FEM Analysis	5/92	8/92 (complete)
3. Triode Development		
-Triode Design Complete	4/92	5/92 (complete)
-Demonstrate Reliable/Uniform Current Emission	7/92	10/92 (complete)
-Demonstrate Modulated/Edge Emitter Triode	8/92	12/92 (complete)
-Demonstrate 1 GHz Modulation of Triode	2/93	12/92 (behind plan)
-Deliver 2 Triodes	3/93	2/93 (on plan)
4. Final Report (Baseline)	4/93	4/93 (on plan)

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III. Technical Progress

Efforts during this reporting period focussed on fabrication and testing of the thin film edge emitter vacuum transistors.

Task 1. Field Emitter Development

This task was completed at the end of the last quarter.

Task 2 Process Development

This task was completed at the end of the last quarter.

Task 3 Triode Development

Our efforts on the program this quarter were primarily focussed on triode development. Three fabrication runs were completed which incorporated the process enhancements outlined in the Quarterly Progress Report #4. Figure 1 shows an SEM of a completed device. The thin film 400Å edge is readily observable. The structural integrity of the device looks excellent and agrees well with our design expectations.

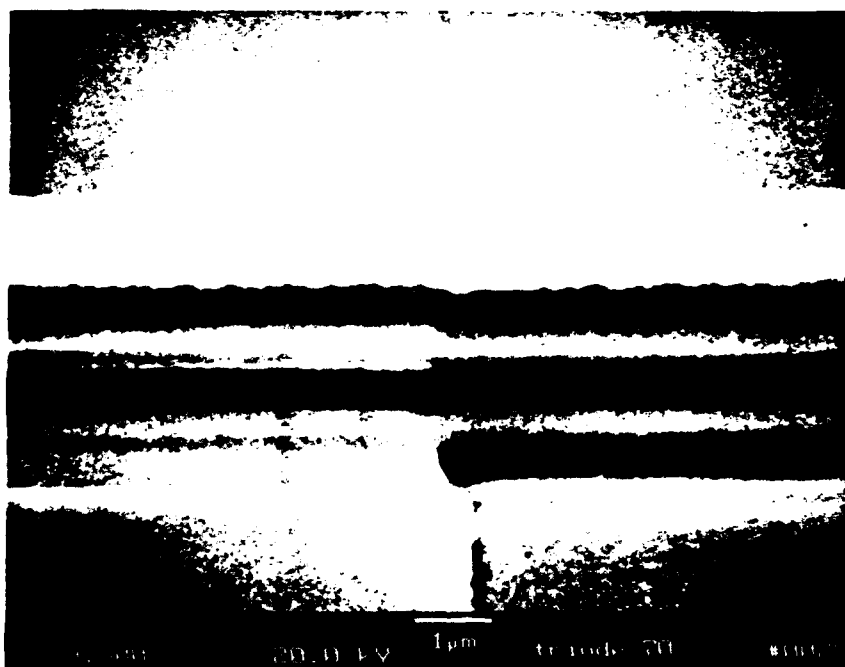
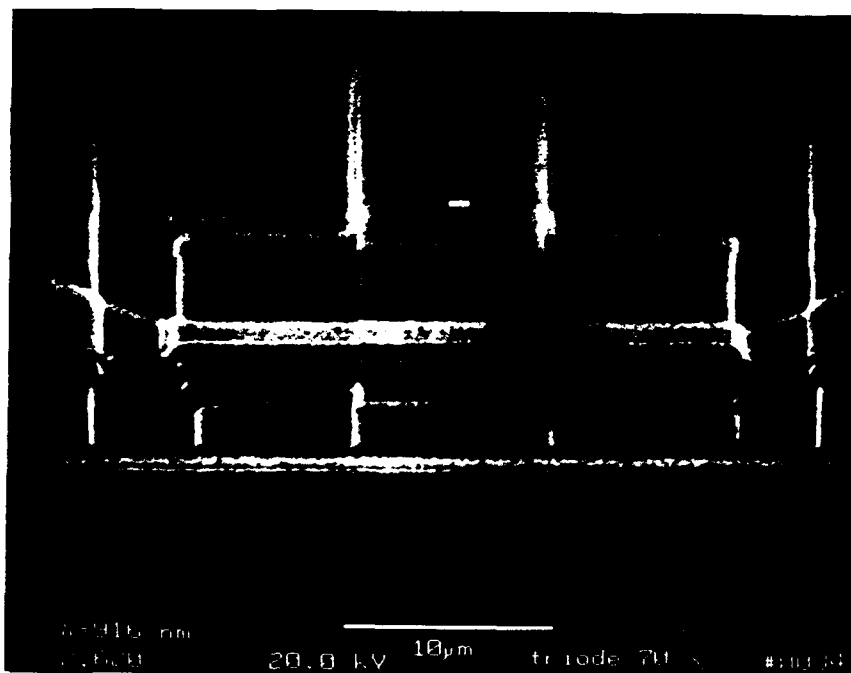
We have carried out extensive testing of the vacuum triode devices. Most of the efforts to date have been towards DC characterization of the triodes. Anode current measurements versus control voltage (gate voltage) show as expected triode action. Monitoring the output characteristics versus control/gate and anode voltages indicate little, if any, interception by the gate of electrons emitted by the emitter. This is consistent with previous modeling results (as reported in Quarterly Technical Progress Reports #2 and #3) which show that emitted electrons are controlled predominantly by the anode voltage in a dual control electrode structure.

We have begun modulation testing of the edge-emitter triode devices. Low frequency modulation of a triode has now been shown which is a first for a thin film edge triode.

Figure 1. SEM photographs of a completed thin film edge emitter triode.
The emitter can readily be seen in the 9800x photo.

SEM of Vacuum Transistor

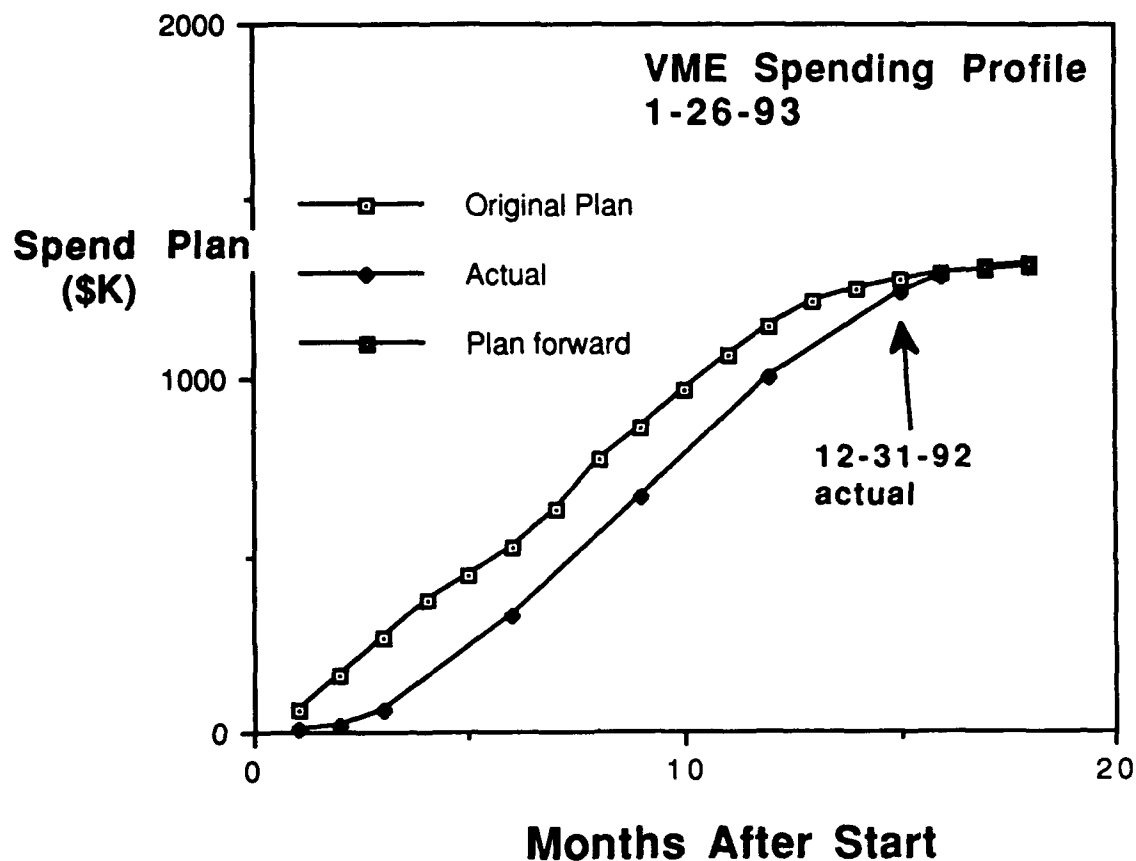
SEM Shows the Upper Control Electrode and the Thin-Film-Edge



Plans for Next Reporting Period

- Continue DC and AC testing of fabricated triode devices.
- Review program status with DARPA VME committee.

IV. Fiscal Status



Expenditures this quarter	\$ 236K
Total expenditures to date	\$1,235K
Projected expenditures:	
1/93 - 3/93	\$ 80K
Total Projected Cost for Baseline Program	\$1,315,650

V. Problem Areas

We are encountering a problem with high frequency testing of the triodes. The output impedance of the triodes, as designed, are significantly higher than the input impedance of the test system (megaohms versus 50 ohms). Consequently, we have not been able to modulate the devices at high frequency. Several alternative approaches are being explored and will be discussed with DARPA at the February review.

VI. Visits and Technical Presentations

- A paper entitled "Nanometer Scale Thin-Film-Edge Emitter Devices with High Current Density Characteristics" was presented at the International Electron Devices Meeting (IEDM) held in San Francisco in December. The work was sponsored by this program and acknowledged so.