

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE 01-15-92	3. REPORT TYPE AND DATES COVERED Quarterly Technical Report 10-01-91 to 12-31-91
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4. TITLE AND SUBTITLE RF Vacuum Electronics - Quarterly Technical Report	5. FUNDING NUMBERS MDA 972-91-C-0030
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Honeywell Sensor and System Development Center 10701 Lyndale Avenue South Bloomington, MN 55420	8. PERFORMING ORGANIZATION REPORT NUMBER
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9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Defense Advanced Research Projects Agency DARPA/DSO 3701 N. Fairfax Arlington, Virginia 22203	10. SPONSORING/MONITORING AGENCY REPORT NUMBER
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11. SUPPLEMENTARY NOTES

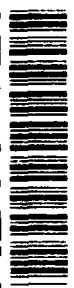
12a. DISTRIBUTION/AVAILABILITY STATEMENT Pending DARPA COTR review, approved for public release; distribution is unlimited.	12b. DISTRIBUTION CODE
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13. ABSTRACT (Maximum 200 words) We summarize our first quarter progress and discuss second quarter plans for the development of an edge emitter based vacuum triode with performance goals of 10 uA/um emission current density at less than 250V and which can be modulated at 1 GHz for 1 hour. Device analysis of previously fabricated devices indicate systematic burnout of the edge. This observation indicates that electron heating of the anode and/or current concentration at localized microtips may be causing the burnout. This hypothesis has directed the design of new emitter structures to improve current emission and density. Use of high resistivity thin films as current limiters in emitter diodes has been laid out and will be fabricated in the next reporting period. TaN appears to have the proper thin film characteristics for use in these diodes. A variety of other devices for diode and thin film characterization have been laid out for subsequent fabrication in the next several reporting periods.

14. SUBJECT TERMS Vacuum microelectronics, edge emitter, thin film technology, high frequency devices	15. NUMBER OF PAGES Seven
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL
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AD-A244 925



Quarterly Technical Report
RF Vacuum Microelectronics
10/1/91 - 12/31/91

Sponsored by: Defense Advanced Research Projects Agency
Defense Sciences Office (DSO)
RF Vacuum Microelectronics
DARPA Order No. 8162
Program Code No. 1M10
Issued by DARPA/CMO under Contract #MDA972-91-0030

Contractor: Honeywell Sensor and System Development Center
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RF Vacuum Microelectronics - Quarterly Technical Report

Background

The objective of the RF Vacuum Microelectronics Program is to establish the technology base for the fabrication of practical, high performance gated vacuum emitters and to develop a new class of RF amplifiers based on these vacuum microelectronic emitters. Our technical approach is to utilize thin film technology and surface micromachining techniques to demonstrate an edge emitter based vacuum triode with emission current density of $10 \mu\text{A}/\mu\text{m}$ at less than 250V which can be modulated at 1 GHz continuously for 1 hour. Figure 1 shows a schematic cross section of our thin film edge emitter approach. Based on our experience with fabricating and testing edge emitter devices, our efforts on this program will be focussed on developing a highly stable, uniform and reliable current emission from the edge. We intend to achieve these qualities by

- use of thin film (200Å) edge emitters with small uniform radius of curvature
- use of refractory metal emitter structure to prevent electromigration and burnout
- use of comb emitter structures to prevent premature emitter burnout during edge formation
- use of current equalization series elements to set bias currents.

This program to develop an edge emitter triode started on October 1, 1991. The baseline portion of the program is for 18 months with the above mentioned objectives as goals. Upon successful completion of this phase, an option phase for 12 months can be implemented by DARPA where the objective will be to achieve 10 GHz modulation with the edge emitter device.

Technical Progress During Quarter (10-1-91 to 12-31-91)

Efforts during this reporting period were focussed on the analysis of results from the literature and on results for devices fabricated at Honeywell previously so as to develop approaches for obtaining uniform current emission from a thin film edge emitter without burnout. Observation of the emitter edge during emission on fabricated thin film edge devices show parts of the edge spontaneously burning out with a concomitant sharp drop in emission current. However, after a period of time (typically 30 minutes), the emission current builds up again indicating another region of the edge is emitting. this cycle often repeats itself several times before the entire edge burns out. The burned out portions of the edge are typically micron sized and form systematically down the edge of the emitter. We also observe, on occasion, that the burnout does not originate from the edge but from the middle of the film.

The above observations lead us to speculate on the causes of the burn-out:

- Electron heating of the anode (from the emission current) resulting in desorption of positive ions which are accelerated to the emitter by the electric field. This results in additional heating of the emitter and the resultant burnout.
- Current concentration at localized microtips on the emitter. This leads to very high current densities with the resulting temperature rise and subsequent melting of the area adjacent to the microtip.

We believe that both processes are occurring with the latter being dominant. This belief is supported by the gradual burnout of the edges until the whole edge stops emitting current.

The conclusions drawn from our device analysis suggest several approaches to developing an edge emitter which is essentially immune to burnout and has uniform emission characteristics. These approaches include:

- using comb edges with high valued resistors in series to act as resistive voltage drops
- using comb edges with non linear resistors or current sources that presets the current per comb
- using comb edges with non-linear resistors which can be bypassed after the edges have developed
- developing a process that will smooth the thin film edge after the sacrificial layer is removed, e.g., electropolishing.

We are implementing the above approaches in several emitter designs and test devices which will be fabricated in the next reporting period. Our intent will be to increase the magnitude and uniformity of emission from the edge emitter. We will examine the problem of device operation by using a variety of test structures to measure the following:

- Emission uniformity - multiple parallel emitters with separate connections
- Electron trajectories - multiple anodes with separate connections
- Emitter temperature effects - directly heated emitter to verify its effect on emission and its uniformity
- Film resistance - metal film resistance patterns to evaluate film quality
- Dielectric film strengths and constants - a variety of capacitance structures
- Emission magnitude - variety of emitter/anode geometries to study the effects of emitter structures and distributed anode/electron collection.

Figure 2 shows a schematic diagram of a field emission diode with current equalization resistors to improve the emission current levels of the emitter. Such devices will be included in the mask set design presently being developed.

Concurrent with the design development has been the development of a suitable thin film resistor for achieving uniform current emission. Our initial estimates indicate that the material must have a resistivity of 1 to 10 M Ω /square. Three candidates are being explored for this application: tantalum nitride, polysilicon and a cermet material such as silicon oxide doped with chrome or gold. Our initial experiments with TaN indicate many of the necessary thin film properties for the edge emitter application including controllable resistivity and process compatibility. Figure 3 is a plot of sheet resistance vs. nitrogen concentration for 1000 \AA TaN films reactively sputtered (rotational mode) in a PE-2400 system. The N₂ concentration range of 20-80% (N₂ in Ar) gives sheet resistance values of less than 10² Ω /square to greater than 10⁶ Ω /square. TaN will be used in the first emitter fabrication runs. Lightly doped polysilicon is also being explored because of its high resistivity and because its resistivity is voltage dependent, the resistivity increasing with increasing bias. We have ordered a lightly doped polysilicon sputtering target and will begin depositing and characterizing thin films of the material during the next reporting period.

Plans for upcoming quarter

Our efforts during the next quarter will focus on the following:

- complete test structure designs for edge emitter studies (1/92)
- fabricate first edge emitters (diodes) with TaN current limit resistors (2/92)
- demonstrate high resistivity polysilicon thin films (3/92)
- carry out detailed dielectric studies of PECVD and MRC deposited nitrides and oxides as well as BSQ thin films (3/92)
- complete first analysis of mechanical and electrical stability of triode device structures using ANSYS (3/92)
- begin triode device design (2/92).

Figure 1a.

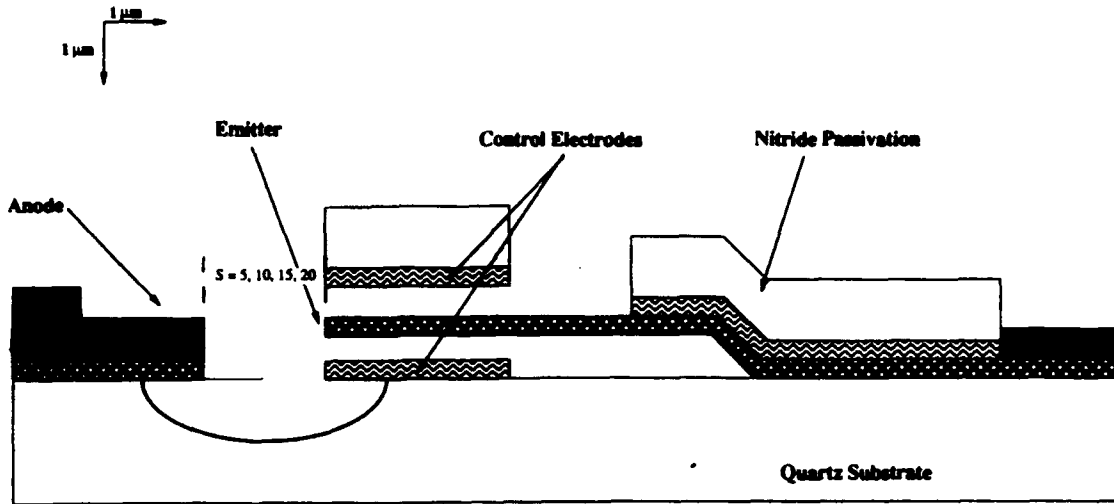


Figure 1b.

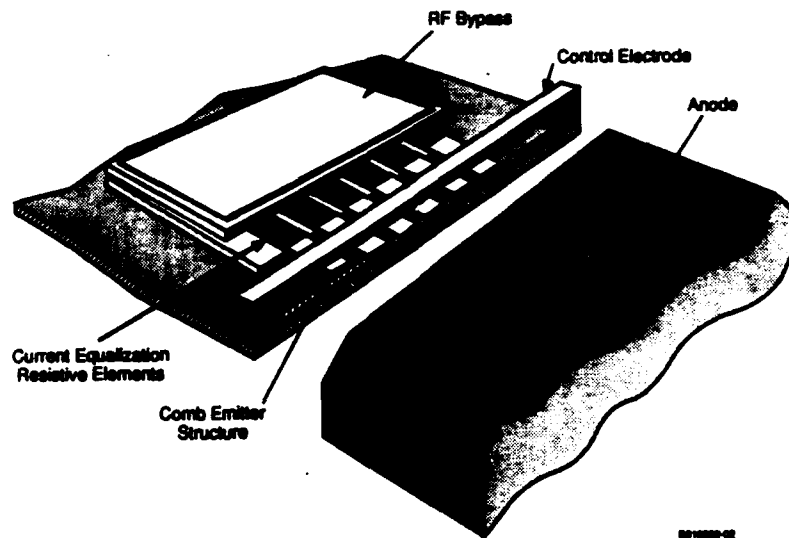


Figure 1. Schematic cross section of the edge emitter approach to be investigated on this program. Figure 1a illustrates a side view, while Figure 1b illustrates that the edge emitter may be segmented in a comb or sawtooth structure with current equalization elements used to ensure uniform current emission from "each" edge of the emitter. A variety of similar structures will be investigated as well as the materials technology required to achieve high/uniform current emission.

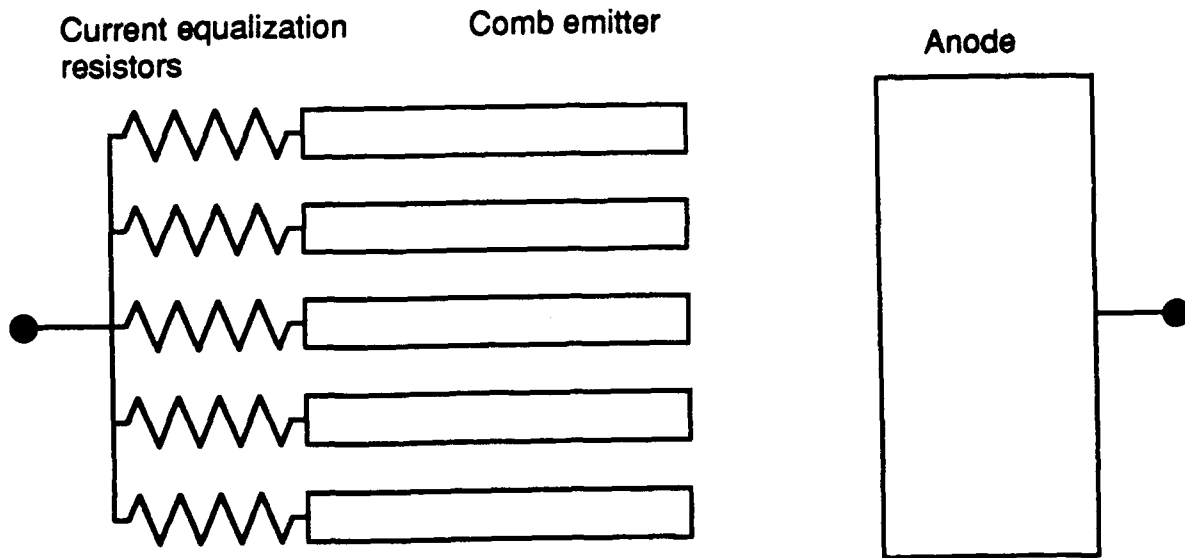


Figure 2. Schematic diagram of a field emission diode showing connection of current equalization resistors to improve diode current capabilities.

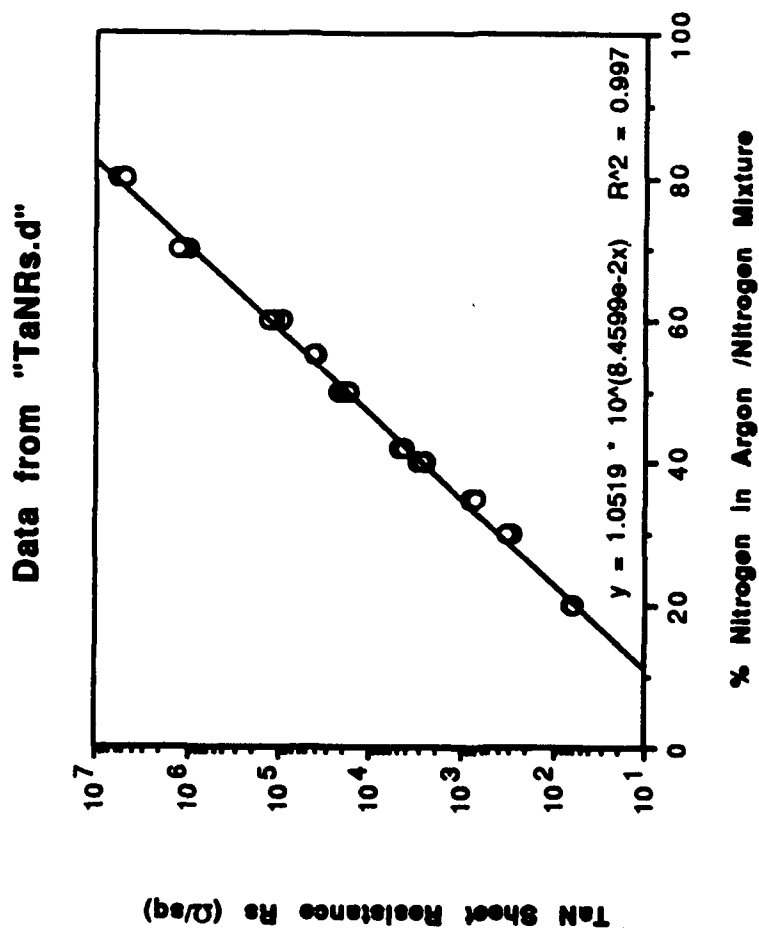


Figure 3. Sheet resistance vs. nitrogen concentration for 1000Å TaN thin films reactively sputtered.