AD-777 869

VIDICON UNIFORMITY

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General Electric Company

Prepared for:

Air Force Cambridge Research Laboratories

15 December 1973

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5285 Port Royal Road, Springfield Va. 22151

ARPA Order Number

2444

Program Code Number

4010

Name of Contractor

General Electric Company

Effective Date of Contract

June 1, 1973

Contract Number

F19628-73-C-0267

Principal Investigator and Phone Number

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Contract Expiration Date

August 31, 1974

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Unclassified

Security Classification

AD-777869

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* General Electric Company Space Division/Space Sciences Laboratory P. O. Box 8555, Philadelphia, Pennsylvania 19101	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

VIDICON UNIFORMITY

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Scientific. Interim.

5. AUTHOR(S) *(First name, middle initial, last name)*

James P. Spratt

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
15 December 1973	19	5

8a. CONTRACT OR GRANT NO. ARPA Order No. 2444 F19628-73-C-0267 b. PROJECT, TASK, WORK UNIT NOS. 2444 n/a n/a c. DOD ELEMENT 61101E d. DOD SUBELEMENT n/a	9a. ORIGINATOR'S REPORT NUMBER(S) Semiannual Technical Report 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* AFCRL-TR-74-0016

10. DISTRIBUTION STATEMENT

A - Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
This research was supported by the Defense Advanced Research Projects Agency	Air Force Cambridge Research Laboratories (LQ) L. G. Hanscom Field Bedford, Massachusetts 01730

13. ABSTRACT

During the first half of this program, work has been done on developing a theory of high beam velocity operation of a vidicon camera tube. Silicon Schottky diode arrays having low barrier heights (e.g. Pd/P-Si) can be used in such tubes as infrared vidicon retinae. The uniformity of the resultant vidicon should be superior to that afforded by other approaches. A theoretical and experimental study of this uniformity was initiated.

DD FORM 1 NOV 65 1473

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Infrared vidicons						
Schottky barrier diode arrays						
High beam velocity vidicons						
Deltacon						

VIDICON UNIFORMITY

I. SUMMARY

A. Technical Problem

The ability to form images using infrared radiation has become increasingly important to the military. In the past ten years, the techniques for performing this task have improved dramatically and appetites have now been whetted to the point where widespread deployment of infrared imagers is being demanded. Unfortunately, the recent progress in imagery has not been matched by reductions in cost. FIRS (Framing Infra-Red Systems) continue to be so expensive as to preclude use in many of the applications desired. The reasons for these high costs are many and complex, and DDR&E is actively exploring ways to reduce them. One factor which has been shown to contribute is the use of exotic detector materials for which no other widespread applications exist. Because of the unique requirements of FIRS, each system requires, in effect, a materials research program to develop the detectors needed. Little advantage has been taken of the tremendous sums spent by the government and private industry over the last ten years in developing silicon integrated circuit technology, since silicon devices do not normally permit the detection of infrared (except for the very near IR). It has recently been realized however that silicon technology could be used to advantage in infrared imagers.[1,2]

Internal photoemission in metal-silicon Schottky barrier diode structures has long been known to permit the detection of infrared radiation of wavelengths longer than the fundamental absorption edge in silicon. This process, while generally analogous to photoemission into vacuum, has certain features which are unique and have no direct counterpart in the older technology, e.g. photoemission of holes as well as electrons. The former is interesting because it permits the attainment of low barriers (therefore long cut-off wavelengths) with high work function photocathodes, such as the precious metals (Au, Ag, Pt, Pd). The quantum efficiency of internal photoemission is low, as shown by the modified Fowler relationship.[3]

$$Q.E. = CA \frac{(h\nu - \Phi_0)^2}{h\nu}$$

where Q.E. = quantum efficiency

C = constant ≈ 0.1/e.v.

A = optical absorptance

Φ_o = barrier height

Using the value for barrier height obtained in the Pd-Si system (Φ_o = 0.34 e.v.) one obtains a Q.E. ≈ 0.1% at a wavelength of 2.7 μm. While this value is low compared to that attainable with photoconductive or photovoltaic detectors, the ability to fabricate these devices in large arrays recommends their use for electron beam scanned infrared vidicon retinae (λ > 1 μm), where storage mode operation permits one to overcome to some extent the disadvantages of low efficiency.

B. General Methodology

This program has as its goal the determination of the theoretical and experimental limits of the uniformity of silicon-metal Schottky barrier array vidicon targets. (It is being conducted in parallel with Contract No. F19628-73-C-0221, "Infrared Vidicon Development," aimed at showing the feasibility of a camera tube employing such targets.) The specific material system selected for study was palladium silicide on P-type silicon. (Metal silicides on silicon most closely approach ideal metal silicon diodes, since no silicon dioxide insulating layer can form at the interface to interfere with carrier transport there.) With this diode polarity it is necessary to interrogate the retina with an electron beam which lands at high velocity (V_p ≈ 200 volts). Such a beam will generate secondary electrons, and charge the diode array positively. (Conventional P on N silicon diode array vidicon targets operate in the low beam velocity mode, where the beam charges the diode array negatively.) While such operation has been shown by Dresner[(4)] using Sb_2S_3 targets, it has never been widely used, and no attempts to use it in conjunction with silicon diode arrays have been reported.

The approach taken to this program is as follows:

1. Develop a theoretical understanding of high beam velocity operation of vidicon camera tubes. The structure of such tubes should be extremely important in determining imaging uniformity, e.g. the spacing between target and collecting mesh will affect redistribution of secondaries, temperature of the retina/mesh structure will affect target leakage and mesh spacing, etc.

2. Determine the uniformity of imagery produced under the parallel program.

3. Relate the experimentally determined uniformity to the above mentioned theory, and to structural and material characteristics of the retinas as determined by ion mass analysis.

C. Technical Results

During the first half of this program, effort has been concentrated on developing a theory describing the operation of a high beam velocity camera tube, and relating the performance of such a tube to fabrication and operation parameters. The important results obtained to date are

1. A comprehensive theory has been developed for the operation of high beam velocity camera tubes. Such tubes offer numerous potential advantages over conventional low beam velocity tubes, so that a special name for such tubes was deemed justified and necessary. The name proposed is Deltacon, based upon the dependence of such tubes on a high secondary electron yield, δ.

2. Based on this theory, changes have been made in the design of metal-silicon Schottky barrier diode retinas for use in the experimental portion of the program.

3. Visual examination of retinas has led to criteria for selecting such retinas for optimum uniformity.

4. Preliminary imaging studies were initiated to determine image uniformity.

D. DoD Implications

The results obtained to date under this program provide a firm theoretical foundation on which the experimental portion of the program can be based. The initial assumption that Schottky diode arrays could be operated in the high velocity mode with high uniformity has received theoretical confirmation. Experimental efforts aimed at showing the feasibility of such imagery and the resultant uniformity can now proceed with confidence.

In addition, however, the theoretical results of the first half of this program are felt to have implications beyond this program. High beam velocity operation should be applicable to visible camera tubes as well as infrared. Superior performance is expected in uniformity and reduced lag, especially at low light levels. In view of the serious problem encountered in these areas with present low light level TV systems, these performance advantages would be quite useful.

II. DETAILED TECHNICAL DISCUSSION

A. High Beam Velocity Tube Design

Conventional camera tubes use electron beams which land at a few volts potential to charge individual picture elements to the negative potential at which the cathode of the electron gun sits. Because of the polarity of the diodes used in these retinae, it is necessary to use an electron beam landing at an energy sufficiently high to dislodge secondary electrons with a yield $\delta > 1$, thereby charging individual picture elements positively.[(4)] Figure 1 shows a schematic of a high beam velocity camera tube. The collector mesh is a high transparency screen used to collect secondaries from the target surface (the Pd_2Si array). The combined action of the beam current, I_B, and the secondary emission current going to the mesh, I_M, will charge the floating target surface to a potential V_{FT}. Assuming that the secondary electrons are Maxwellian, one obtains[(5)] the following equations

$$I_M = \int_{V_{FT}}^{\infty} \frac{di_s}{dV_z} \, dV_z = i_s \exp(-V_{FT}/\overline{V})$$

$$= \delta \, I_B \exp(-V_{FT}/\overline{V})$$

where $\overline{V}$ is the average energy of secondaries.

The net target current is

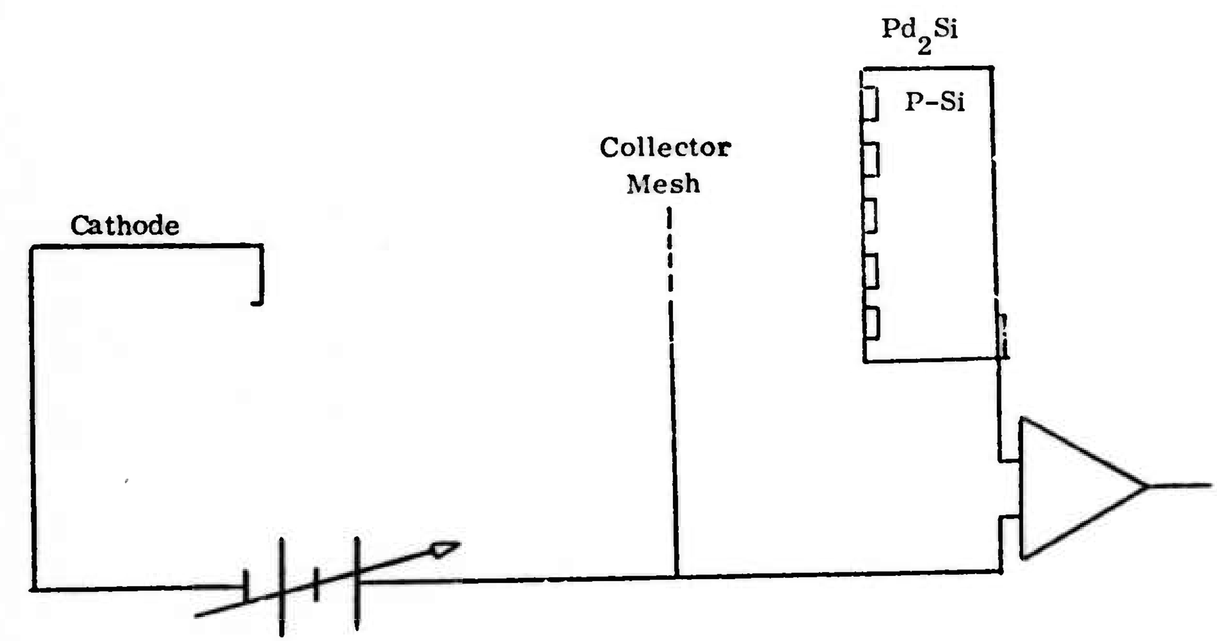
$$I_T = I_B - I_M = I_B \left[1 - \delta \exp(-V_{FT}/\overline{V})\right] ; \quad V_{FT} \geq 0$$

$$I_T = I_B (1 - \delta) \qquad ; \quad V_{FT} \leq 0$$

Neglecting leakage, the floating target will charge to V_{FT} such that $I_T = 0$, i.e.

$$V_{FT} = \overline{V} \, \ell n \, \delta$$

If the electron beam is scanned across the retina in raster fashion, it will charge the floating target to this potential. Optically induced leakage will discharge the target surface down toward mesh potential during the frame time, so that a signal will be generated between retina and mesh when the beam returns to this spot during the next scan.



SCHEMATIC DIAGRAM OF HIGH BEAM VELOCITY VIDICON

FIGURE 1

1. Transmission Secondary Emission

It can be shown that, for the landing velocities required for this type of camera tube, the primary beam will penetrate only about 10 Å into the Pd_2Si film. This is sufficient to excite the required secondaries, and yet is too small for reasonable Pd thickness to produce transmission secondary emission into the silicon, which would discharge the floating target surface. Consequently, the Pd_2Si thickness which is preferred is about 5000 Å.

2. Equivalent Circuit for High Beam Velocity Tube

The target-to-mesh current can be rewritten as

$$I_{TM} = -I_B (\delta - 1) + \delta I_B \left(1 - \exp - \{ V_{TM}/\bar{V} \}\right)$$

The first term can be represented by an equivalent current generator driving a positive current from mesh to target if $\delta > 1$. The second term represents a current controlled by the target to mesh voltage, V_{TM}, and can therefore be represented in an equivalent circuit by a voltage dependent resistor, r_b, in parallel with the current generator.

$$\frac{1}{r_b} = \frac{d}{d V_{TM}} \left\{ \delta I_B \left(1 - \exp - \{ V_{TM}/\bar{V} \}\right) \right\}$$

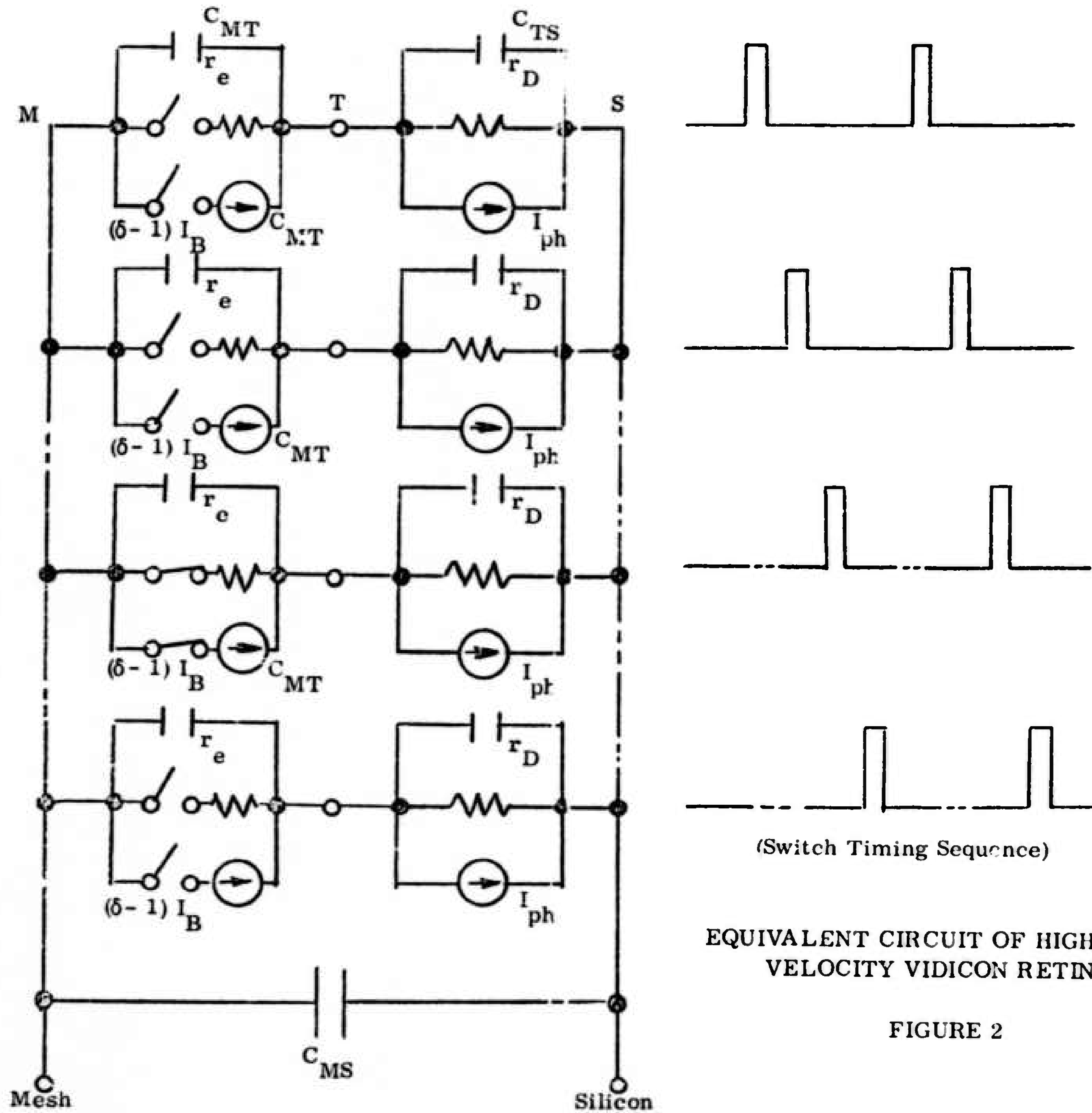
$$= \frac{\delta I_B}{\bar{V}} \exp (- V_{TM}/\bar{V})$$

In operation, V_{TM} will vary from zero to $\bar{V} \ln \delta$, so that r_b will vary between the following two limits

$$\frac{\bar{V}}{\delta I_B} \lesssim r_b \lesssim \frac{\bar{V}}{I_B}$$

Consequently, r_b does not vary over too wide a range.

Representing the secondary emission process by means of this current generator and resistor, one can describe the operation of a high beam velocity tube by means of the equivalent circuit of Figure 2. The switches in the mesh to target loop are closed during the read time, t_R, and are open during the storage time, $t_F - t_R$ (t_F = frame time). The



EQUIVALENT CIRCUIT OF HIGH BEAM VELOCITY VIDICON RETINA

FIGURE 2

behavior of a camera tube represented by such an equivalent circuit has been analyzed for three cases of interest, viz. (1) uniform, time independent illumination, (2) uniform illumination except for one diode which undergoes a step function change in light level at time $t = 0$, and (3) a time independent optical image on the retina. Important results for cases 1 and 2 are presented below.

a. Uniform, Time Independent Illumination

The signal current supplied to a short circuit load by such a camera tube is given by

$$I_S = n(\delta - 1) I_B - \sum_n \frac{V_{TM}}{r_b} - \sum_N C_{TM} \frac{d V_{TM}}{dt}$$

where n = number of diodes being read

N = total number of diodes in array

If $n >> 1$,

$$\sum_n \frac{V_{TM}}{r_b} \approx \frac{n}{t_R} \int_0^{t_R} \frac{V_{TM}(t)}{r_b} dt$$

$$\sum_N C_{TM} \frac{d V_{TM}}{dt} \approx \frac{N}{t_F} \int_0^{t_F} C_{TM} \frac{d V_{TM}}{dt} dt \equiv 0$$

for the cyclic state, i.e. the situation where the retina returns to its initial conditions every frame. Using these equations to solve for I_S, we get

$$I_S = n \left[\frac{r_b}{r_b + r_D} (\delta - 1) I_B + \frac{r_D}{r_b + r_D} \left\{ y\, i_{ph} + \frac{V}{r_D} \right\} \right]$$

$$\cdot \left[1 + \frac{r_D}{r_b} \frac{C r_{||}}{t_F} f \right]$$

where r_D = leakage resistance of diode

y = diode responsivity in amps/watt

i_{ph} = light current in watts

V = target bias

$r_{||}$ = parallel combination of r_b and r_D

C = $C_{TM} + C_{TS}$

f = fraction of maximum voltage excursion which diodes actually experience.

This equation suggests a number of diagnostic measurements which may be made under uniform illumination conditions, e.g.

$$\frac{dI_S}{dI_B} = n\,(\delta - 1)\,\frac{r_b}{r_b + r_D}\,A$$

$$\frac{dI_S}{d(y\,i_{ph})} = n\,\frac{r_D}{r_b + r_D}\,A$$

$$\frac{dI_S}{dV} = n\,\frac{1}{r_b + r_D}\,A$$

where A = tube amplification factor

$$= \left[1 + \frac{r_D}{r_b}\,\frac{C\,r_{||}}{t_R}\,f\right]$$

By measuring these quantities vs. temperature (thereby varying r_D/r_b) the elements of the equivalent circuit can be obtained.

b. Step Function Change in Illumination on One Diode at t = 0

It can be shown that the tube will approach its new equilibrium state with a time constant

$$\tau = \frac{t_F}{\left(\dfrac{t_R}{C\,r_{||}} + \dfrac{t_F - t_R}{C\,r_D}\right)}$$

For low leakage diodes, this approaches the limit

$$\lim_{r_D \to \infty} \tau \approx \frac{t_F}{t_R} \frac{I_B}{\overline{V}C}$$

Since I_B remains constant even at low light levels, lag for this tube should be much less serious than for low beam velocity tubes, where the beam impedance gets very large at low light levels.

B. Diode Array Uniformity

Figures 3 through 7 show photographs of palladium-silicon Schottky diode arrays for two different Pd thicknesses at five different magnifications. The much higher degree of uniformity obtained for the 5000 Å film of Pd is seen clearly in Figures 5A and 5B. Also, the step-and-repeat pattern used in producing the mask set can be seen in Figures 4A and 4B. It is planned to compare photographs of this type with infrared images obtained using retinas like these to determine the significance of different types of visually observed defects.

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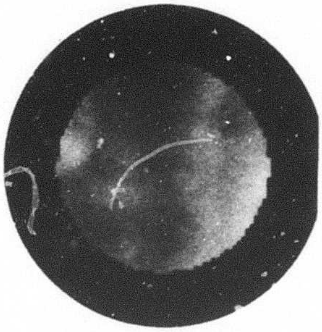

Figure 3. Metal-Silicon Schottky Barrier Diode Array Infrared Vidicon Retina. Pd Thickness 5000 Å, Magnification X1

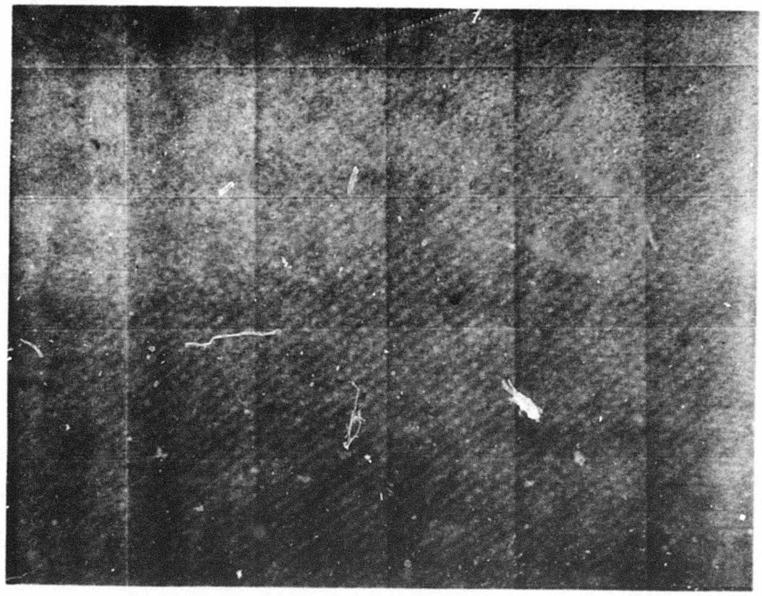

Figure 4A. Metal-Silicon Schottky Barrier Diode Array Infrared Vidicon Retina. Pd Thickness 500 Å, Magnification X30

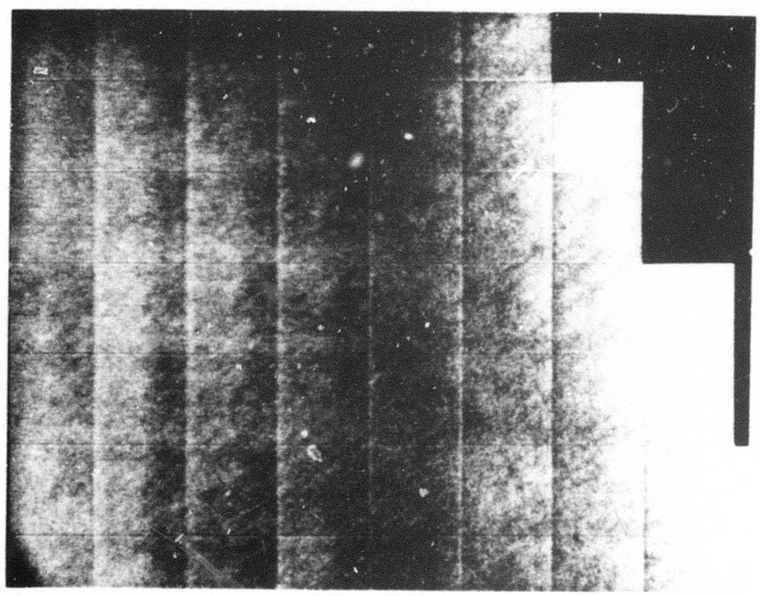

Figure 4B. Metal-Silicon Schottky Barrier Diode Array Infrared Vidicon Retina. Pd Thickness 5000 Å, Magnification X21

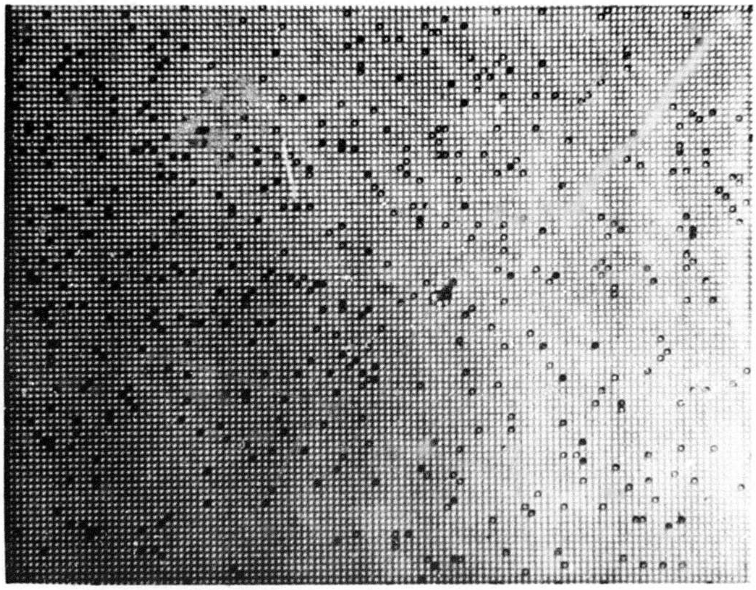

Figure 5A. Metal-Silicon Schottky Barrier Diode Array Infrared Vidicon Retina. Pd Thickness 500 Å, Magnification X100

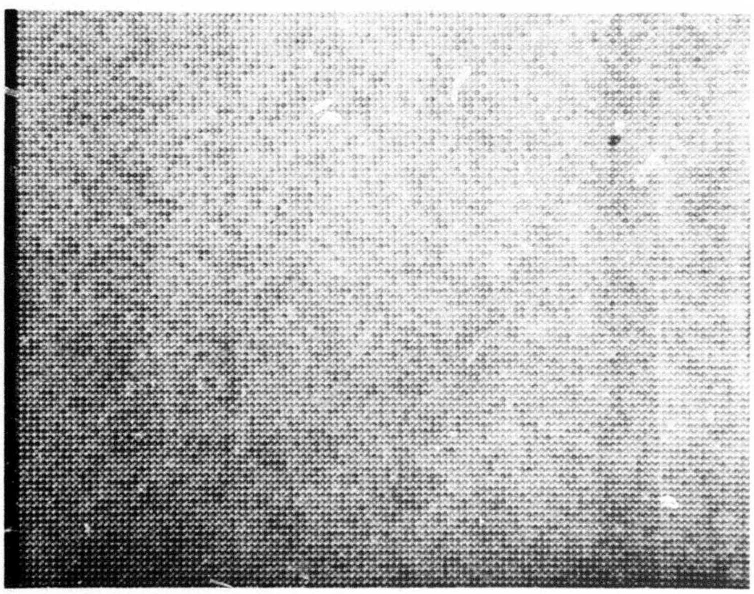

Figure 5B. Metal-Silicon Schottky Barrier Diode Array Infrared Vidicon Retina. Pd Thickness 5000 Å, Magnification X100

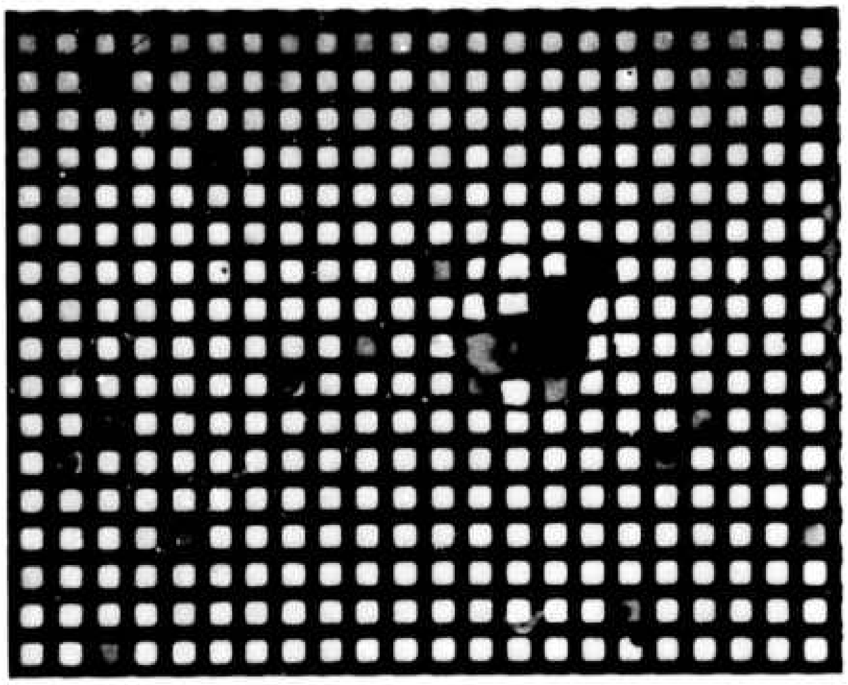

Figure 6A. Metal-Silicon Schottky Barrier Diode Array Infrared Vidicon Retina. Pd Thickness 500 Å, Magnification X500

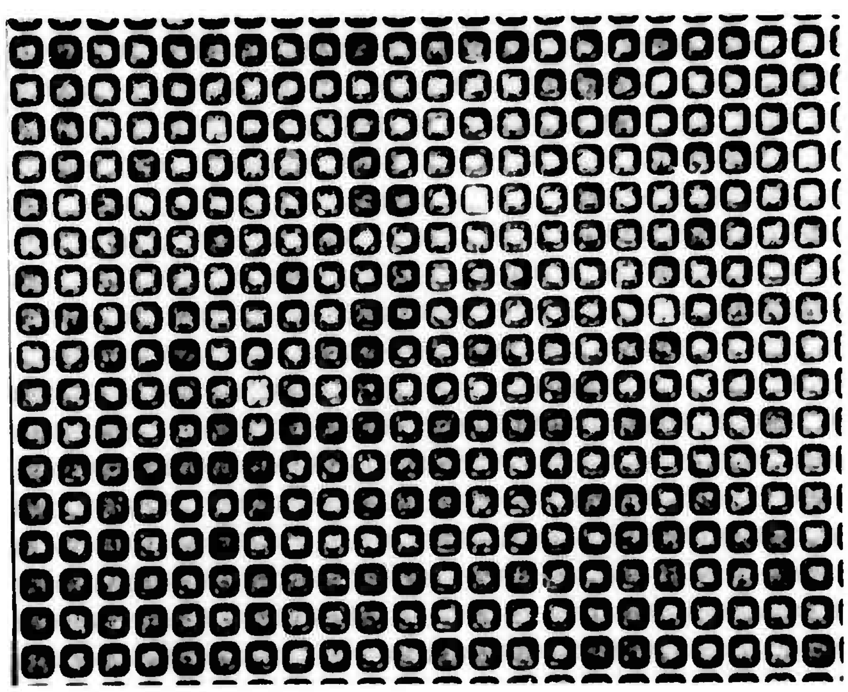

Figure 6B. Metal-Silicon Schottky Barrier Diode Array Infrared Vidicon Retina. Pd Thickness 5000 Å, Magnification X500

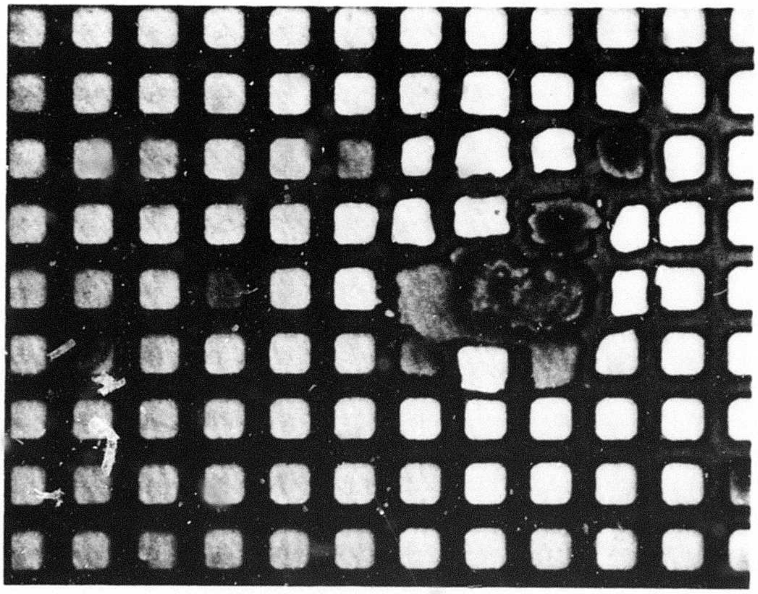

Figure 7A. Metal-Silicon Schottky Barrier Diode Array Infrared Vidicon Retina. Pd Thickness 500 Å, Magnification X1000

Figure 7B. Metal-Silicon Schottky Barrier Diode Array Infrared Vidicon Retina. Pd Thickness 5000 Å, Magnification X1000