AD-A171 438 QUANTUM 1/F NOISE IN SOLID STATE DOUBLE DEVICES IN PARTICULAR HG(1-X) CDX..(U) MINNESOTA UNIV MINNEAPOLIS DEPT OF ELECTRICAL ENGINEERING A VAN DER ZIEL 1/1

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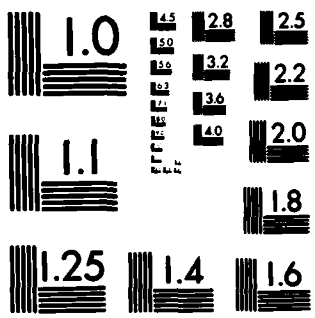

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: ARO 22874.1-EL	2. GOVT ACCESSION NO.: N/A	3. RECIPIENT'S CATALOG NUMBER: N/A
4. TITLE (and Subtitle): Quantum 1/f noise in solid state double devices, in particular $Hg_{1-x}Cd_xTe$ diodes		5. TYPE OF REPORT & PERIOD COVERED: technical report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): A. van der Ziel		8. CONTRACT OR GRANT NUMBER(s): DAAG29-85-K-0235
PERFORMING ORGANIZATION NAME AND ADDRESS: Electrical Engineering Department, University of Minnesota, 123 Church Street S.E., Minneapolis, MN 55455		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
CONTROLLING OFFICE NAME AND ADDRESS: U. S. Army Research Office, Post Office Box 12211, Research Triangle Park, NC 27709		12. REPORT DATE: 5/22/1986
		13. NUMBER OF PAGES
MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report): Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

NA

18. SUPPLEMENTARY NOTES

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Quantum 1/f noise, diffusion noise, recombination noise, Hooge formula, Hooge parameter, coherent and incoherent state 1/f noise, Umklapp noise, intervally scattering noise, normal scattering noise HGCdTe diode, Si diode

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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It is shown how one can discriminate between two modes of diffusion 1/f noise fluctuations in p-n diodes :

(a) all minority carriers contribute to the noise

(b) only the excess minority carriers contribute to the noise

n^+-p $Hg_{1-x}Cd_xTe$ diodes seem to follow case (a) at back bias. For forward biased diodes $S_I(f)/I^2$ is independent of bias, as expected for surface recombination in the p-region.

p^+-i-n Si diodes seem to follow case (b) at first sight, but this would be an erroneous conclusion, since in these diodes the noise is caused by recombination in the space charge region. The experiments give $S_I(f)/|I|$ = constant, as expected for recombination 1/f noise.

Impedance measurements in Si diodes give the carrier time constant τ, whereas the noise measurements give α_H/τ when α_H is the Hooge parameter. The combined experiments give $\alpha_H = 4.3 \times 10^{-3}$, close to what is expected for coherent state quantum 1/f noise.

In $Hg_{1-x}Cd_xTe$ the carrier lifetime has not yet been established, and hence the α_H/τ data cannot be used to evaluate α_H. It seems reasonable, however, that for $x \approx 0.30$ the estimated value of α_H lies between the coherent state value (4.6×10^{-3}) and the incoherent state value (5.0×10^{-5}) depending on the value of τ. More accurate determination of τ (both theoretical and experimental) are being planned.

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ARO 22874.1-EC

Final report DAAG -85-k-0235, 9-16-85 - 3-15-86

A. van der Ziel

The aim of this project is to study quantum 1/f noise in solid state devices in general and in $Hg_{1-x}Cd_xTe$ n^+-p diodes in particular. This period we studied the noise generation mechanism in n^+-p $Hg_{1-x}Cd_xTe$ diodes and in p^+-i-n silicon diodes. we found that in the first case all minority carriers contributed equally to the 1/f noise, whereas in the second case only the excess minority carriers seem to contribute. The data will be discussed and interpreted in subsequent sections.

1. The Hooge equation and quantum 1/f noise (A. van der Ziel)

According to Hooge[1] the relative current 1/f noise of a semiconductor resistor may be written as

$$\frac{S_I(f)}{I^2} = \frac{\alpha_H}{fN} \tag{1}$$

where α_H is the Hooge parameter and N the total number of carriers in the system. For relatively long resistors Hooge found $\alpha_H \simeq 2 \times 10^{-3}$ but for short resistors α_H can be serveral orders of magnitude smaller.[2]

In bipolar transistors or in p-n junctions the current flow is by minority carriers, and the carrier distribution is non-uniform. In that case the device must be divided up into sections Δx, and then for each section Δx at x

$$S_I(x,f) = \frac{I^2(x)\alpha_H}{fN(x)\Delta x} \tag{1a}$$

where N(x) is the carrier density for unit length at x, and α_H is assumed to be independent of x.

We now consider an n^+-p diode in which the current flow is by <u>diffusion</u>. Usually the length w_p of the p-region is larger than the electron diffusion

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length $L_n = (D_n\tau_n)^{1/2}$. One must now distinguish between two cases:

(a) all minority carriers contribute equally to the noise; this means that N(x) must be retained.

(b) Only the excess minority carriers contribute; this means that N(x) must be replaced by $|N'(x)| = N(x) - Np$, where Np is the equilibrium number of carriers.

If one now calculates $S_I(f)$[3] one obtains

$$S_I(f) = \alpha_H \frac{eIf(a)}{f\tau_n} \tag{2}$$

where $I = I_0a, I_0$ is the saturation current and $a = [\exp(eV/kT)-1]$ V the applied voltage, τ_n the electron life time and

$$f(a) = \frac{1}{3} - \frac{1}{2a} + \frac{1}{a^2} - \frac{1}{a^3}\left(\frac{eV}{kT}\right) \tag{2a}$$

for case (a), whereas for case (b)

$$f(a) = \pm 1/3(+\text{ sign for } a > 0, -\text{ sign for } a < 0) \tag{2b}$$

It should be noted that if the noise is diffusion 1/f noise then either case (a) or case (b) must be valid; if one is valid for <u>one</u> device governed by diffusion, it must be valid for <u>all</u> devices governed by the same process.

One can discriminate between cases (a) and (b) as follows. In case (b) $S_I(f)/|I|$ is independent of bias, whereas on case (a) $S_I(f)/[If(a)]$ is independent of bias.

We applied this method in our experiments on the HgCdTe and Si diodes.

In some devices the noise must not be calculated from (1a) but Eq. (1) must be replaced by the formula[4]

$$S_I(f) = \alpha_H \frac{I^2}{fN_{eff}} \qquad (3)$$

where N_{eff} the effective number of carriers, is proportional to I. If τ is the time constant of the system, $N_{eff} = I\tau/e$ and hence

$$S_I(f) = \frac{\alpha_H e|I|}{f\tau} \qquad (3a)$$

This occurs e.g. in silicon diodes at low current; the 1/f noise is here of the generation-recombination type.

As far as the value of α_H is concerned, Handel derived the general quantum expression for α_H[5]

$$S_I(f) = \frac{4\alpha}{3\pi} \frac{\overline{\Delta v^2}}{C^2} \qquad (4)$$

where $\alpha = 1/(137)$ is the fine structure constant, C the velocity of light and Δv the change in carrier velocity during the quantum interaction process. Since $(\overline{\Delta v^2}/c^2) << 1$, $\alpha_H << \frac{4\alpha}{3\pi}$ $(= 3.1\times10^{-3})$ so that Eq. (4) cannot explain the high value $\alpha_H = 2\times10^{-3}$ found by Hooge. For that case Handel derived an alternate formula,[6] which is independent of bias and frequency. If again $\alpha = 1/(137)$,

$$\alpha_H = \frac{2\alpha}{\pi} = 4.6 \times 10^{-3} \qquad (4a)$$

For semiconductor resistors (4a) should be valid for relatively long resistors (L >> 50-100 μ meter) whereas Eq. (4) should be valid for much shorter ones. For other cases we are not yet certain.

For elastic scattering $\overline{\Delta v^2} = 2\overline{v^2} = 6kT/m^*$, where m* is the effective mass of the carriers, so that[2]

$$\alpha_H = \frac{4\alpha}{3\pi} \frac{6kT}{m^* C^2} \qquad (5)$$

Since the actual scattering processes are <u>not</u> elastic, the theoretical values of α_H may be a factor 2-3 larger than those given by (5)[7]. For most devices the observed values of α_H are much larger than those given by (5); only in the case of collector noise in p^+-n-p and n^+-p-n transistors can the observed values of α_H come close to those of Eq. (5).

In Umklapp scattering[6] a carrier takes up a momentum h/a from the lattice (where a is the lattice spacing) or gives up that momentum to the lattice; in that case Δv must be replaced by h/(m*a). Moreover, the right hand side of (4) must be multiplied by the probability $\exp(-\theta_D/2T)$ that a collision process is of the Umklapp type, where θ_D is the Debye temperature. Hence in the Umklapp approximation.

$$\alpha_H = \frac{4\alpha}{3\pi}\left(\frac{h}{m^*ac}\right)2 \exp\left(- \frac{\theta_D}{2T}\right) \qquad (6)$$

There can also be intervally scattering 1/f noise in n-type silicon.[7] Since this also involves a large exchange of momentum, the theoretical value of α_H is comparable to (b). Finally, in the coherent state approximation $\alpha_H = 4.6\times10^{-3}$.

We need these expressions for the interpretation of our data. Measurements on n-channel JFETs and low-noise p-channel MOSFETs agree with Eq. (6) within 30%; apparently Umklapp 1/f noise seems to be present in these devices.[2] Experiments on the collector 1/f noise in p^+-n-p and n^+-p-n transistors indicate definitely that Umklapp 1/f noise is absent here.[2],[8] Also, no intervally scattering noise was observed in the collector current of n^+-p-n transistors.[2]

This does not violate the quantum 1/f noise theory as such. For some interaction processes may be forbidden in some device types; we simply have to learn what rules apply by doing the proper experiments.

References

1. F. N. Hooge, Phys. Lett. A, 29, 139 (1969).

2. A. van der Ziel, P. H. Handel, X. C. Zhu and K. H. Duh, IEEE Trans. El. Dev., ED-32, 667 (1985).

3. J. B. Anderson et al, to be published.

4. A. van der Ziel and P. H. Handel, Physica, 132B, 267 (1985).

5. P. H. Handel, Phys. Rev. Letts., 34, 1992 (1975); Phys. Rev. A, 22, 795 (1980).

6. P. H. Handel, in Noise in Physical Systems and 1/f Noise, (Ed. M. Savelli, G. Lecoy and J. P. Nougier), Elsevier, New York (1983).
   pg. 17; P. H. Handel, in Noise in Physical Systems and 1/f Noise (Eds. A. D'Amico and P. Mazzetti), Elsevier, New York (1986) p. 465.

7. G. Kousik, Ph.D. Thesis, U. of Florida, 1985; G. Kousik, C. M. van Vliet and G. Bosman, Advances in Physics (1986) in press.

2. Noise in P^+n Silicon Power diodes at elevated temperatures (P. Fang).

a) Introduction

The initial motivation of measuring P^+n power diodes at elevated temperatures was to investigate whether all minority carriers or only the excess minority carriers contribute to the 1/f noise. In these measurements, we find that at medium frequencies the P^+n diode shows full shot noise, and, in low frequency, it shows 1/f noise. The plot of $S_I(f)$ vs. qV/kT at back bias is flat. The Hooge parameter α_H was measured by measuring the spectrum and the life time τ. The results reasonably fit with the coherent state quantum 1/f noise theory. There is a modified equivalent circuit model proposed in which a capacitor is added to explain the measurement results.

i) Noise at medium frequencies

With medium frequencies we mean a range of 10K to 100K. By following the corpuscular approach of Prof. A. van der Ziel, the carriers in a p-n junction may be divided into three groups (see Fig. 1). The processes 1 and 3 constitute series independents random events. The contribution to the noise should be:

$$2e(I_p+I_{po}) + 2eI_{po} = 2e(I_p+2I_{po}) \quad (1)$$

The second group gives a contribution (G_p-G_{po}) to the ac conductance which would be full thermal noise $(4q/\alpha)(G_p-G_{po})$. Where $\alpha = \frac{q}{nKT}$, n is the ideality factor of diode. So the total noise spectrum of current fluctuation is:

$$S_I(f) = 2e(I_p+2I_{po}) + (4q/\alpha)(G_p-G_{po}) \quad (2)$$

The spectra at back and forward bias was measured. The results are shown in Fig. 2 and 3. One can see, at medium frequencies, that the spectra show full shot noise, and that the noise increases at higher frequencies as the a.c. conductance G_p increases, matching the theory as expected[1]

(b) Noise at low frequencies

From the Fig. 3 one can see that the spectrum shows 1/f noise. As shown in Fig. 4, $S_I(f)/|I|$ versus (qV/kT) shows a flat curve at back bias. Assuming the 1/f noise to be diffusion noise, we conclude from Section 1 that only the excess minority carriers constitute to the noise, and that

$$SI(f) = \frac{\alpha_H e|I|}{3f\tau}$$

But this is in conflict with the measurements on $Hg_{1-x}Cd_xTe$ diodes in section 3 which indicate that all minority carriers contribute to the 1/f noise. For diffusion 1/f noise it is either the one or the other, and not both.

To remedy the situation we must remember that in silicon diodes at relatively low currents the noise is of the generation-recombination type, and it has

$$S_I(f) = \frac{\alpha_H e|I|}{f\tau} \quad (3)$$

There is now no longer any conflict, because the two diode types correspond to different physical situations.

If $S_I(f)$ is measured, and τ is determined, the value of α_H found from Eq. (3) is a factor 3 larger than the value found from Eq. (3a). As shown in the next section, Eq. (3a) yields an average value $(\alpha_H)_{ave} = 4.3\times10^{-3}$, in very good agreement with the value 4.6×10^{-3} obtained from the coherent state theory (section 1). Eq. (3) would give $(\alpha_H)_{ave} = 1.3\times10^{-2}$, which is too large.

What we do not quite understand and at present is why the noise is full shot noise at intermediate frequencies; theoretically it should be smaller. It further needs explanation why α_H should correspond to the coherent state theory.

(c) To determine the life time τ

The impedance was measured at the same conditions in which the noise spectrum was measured. The conductance g_d vs. f and the reactance bd vs. f were plotted in Fig. 5. One can observe, the reactance b_d (Imaginary part of conductance) changes sign twice at two different frequencies and corresponding to two extreme values of g_d. According to these results, a modified equivalent circuit model was proposed as shown in Fig. 6. We consider this power P^+n diode to be a PIN diode, since the n region of the power diode should be lightly doped in order to obtain high breakdown voltage. So there should be a capacitor C_I. By this model, one can explain the two resonances in our measurements. By these results, lifetime τ can be determined as follows:

ii) Beyond first resonance: one can treat C_J and C_I in series. So:

$$b = \omega \frac{C_J C_I}{C_J + C_I} \doteq \omega C_I \qquad \because \; C_J >> C_I$$

iii) At resonance frequencies, we have:

$$\omega_1^2 L C_J = 1 \quad \text{and} \quad \omega_2^2 L C_I = 1 \quad \text{where} \quad \omega_2 > \omega_1 \; C_J = \left(\frac{\omega_2}{\omega_1}\right)^2 C_I \quad \because$$

iv) According to Prof. A. van der Ziel[2]

$$R_J = \frac{KT/q}{I}(1+m) \qquad m = \frac{\mu_n - \mu_p}{\mu_n + \mu_p}$$

From measurements we know ω_1, ω_2, b, L; hence we know R_J, C_J and hence we get τ.

v) Results:

a) τ:

Diode	ω_1(M)	ω_2(M)	b	C_I(P_I)	C_J(F)	R_J(Ω)	$\tau = R_J C_J$
#1	0.7	50	4×10^{-4}	8	4×10^{-8}	387	1.6×10^{-5}
#2	1.0	35	1.6×10^{-3}	26	3.2×10^{-8}	388	1.2×10^{-5}

b) α_H/τ and α_H

i) diffusion 1/f noise model $S_I = \frac{\alpha_H e I}{3 f \tau}$

T	I(μA)	α_H/τ	$\tau(10^{-5})$	$\alpha_H(x10^{-2})$
380	-4.5	750	1.4	1.1
400	-5.5	890	1.4	1.2
410	-2.0	1100	1.4	1.5
				avg 1.3(x10^{-2})

ii) G-r 1/f noise model $S_I = \frac{\alpha_H e I}{f\tau}$

T	I(μA)	α_H/τ	$\tau(10^{-5})$	$\alpha_H(x10^{-3})$
380	-4.5	750	1.4	3.5
400	-5.5	890	1.4	4.2
410	-20.0	1100	1.4	5.2
				avg 4.3(x10^{-3})

References

[1] R. A. Perala, A. van der Ziel, IEEE Ed. March 1967, p. 172.

[2] A. van der Ziel, Solid State Physical Electronics, 3rd Ed. Chapter 15.

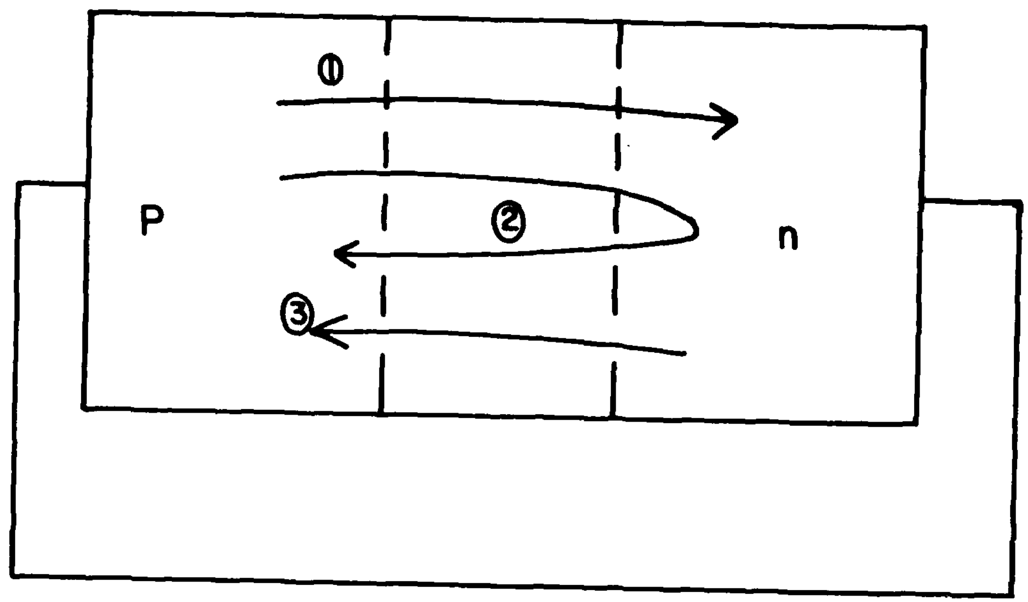

Fig. 1

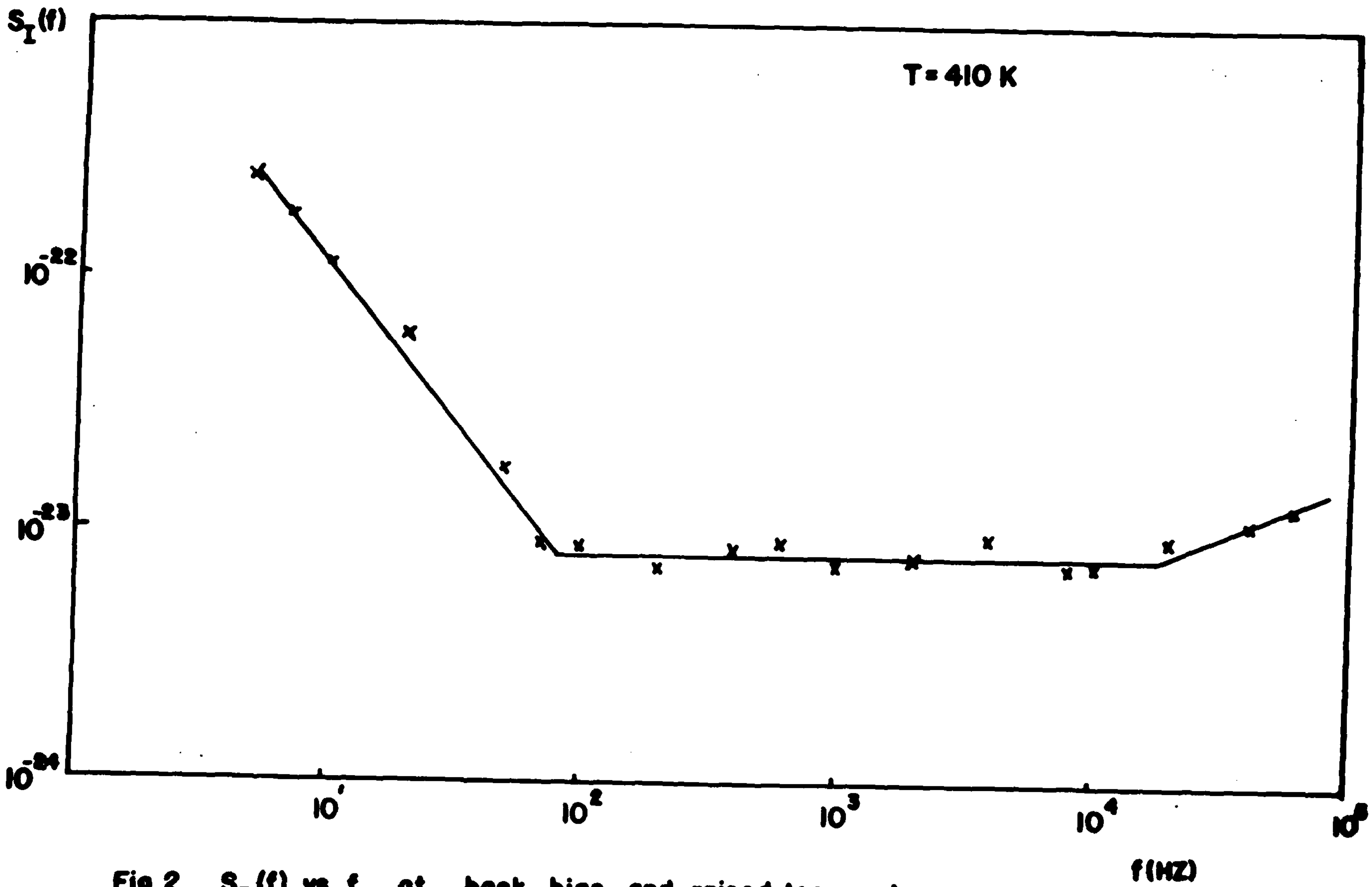

Fig.2 $S_I(f)$ vs. f at back bias and raised temperature.

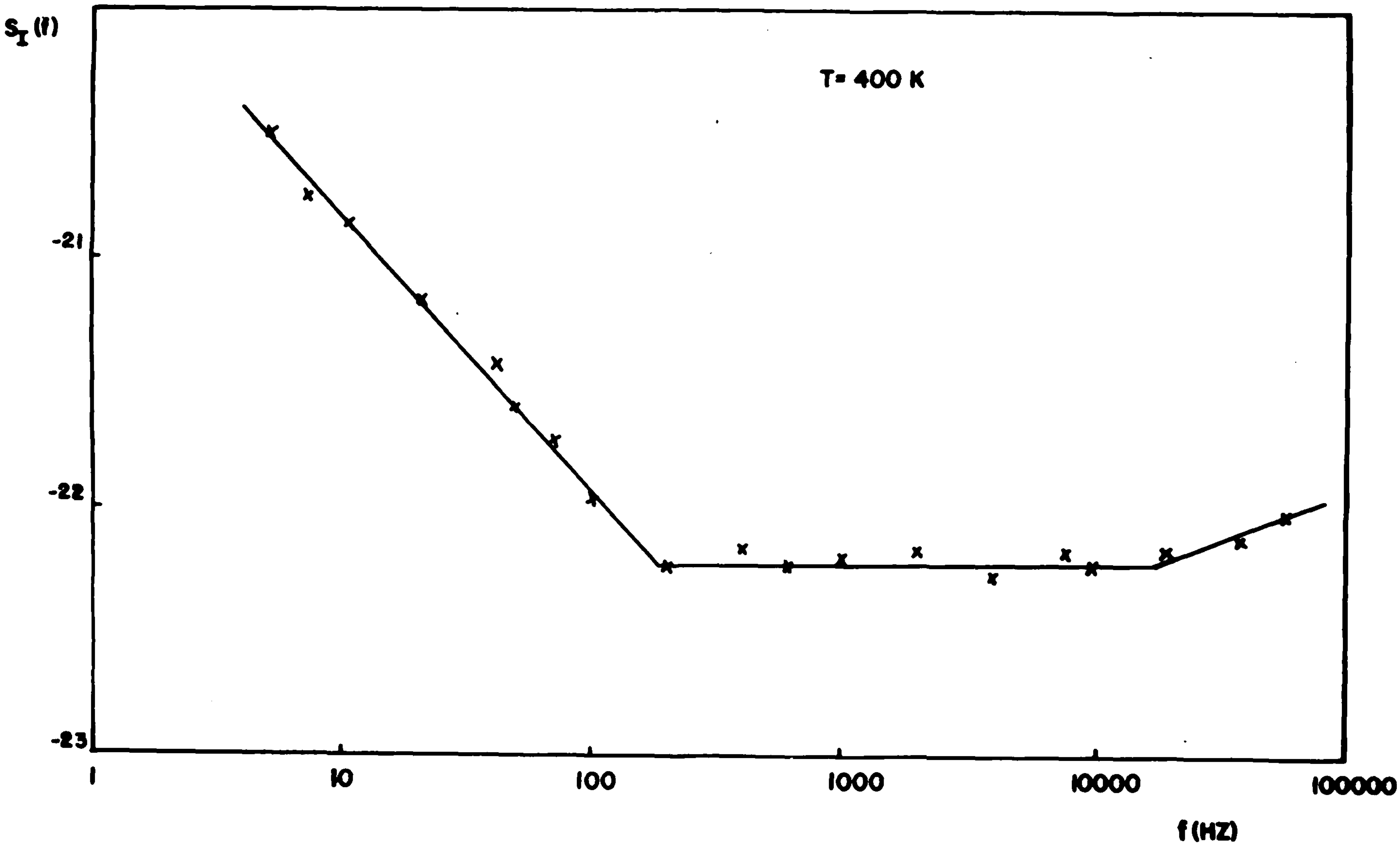

Fig. 3 $S_I(f)$ vs. f at forward bias and raised temperature

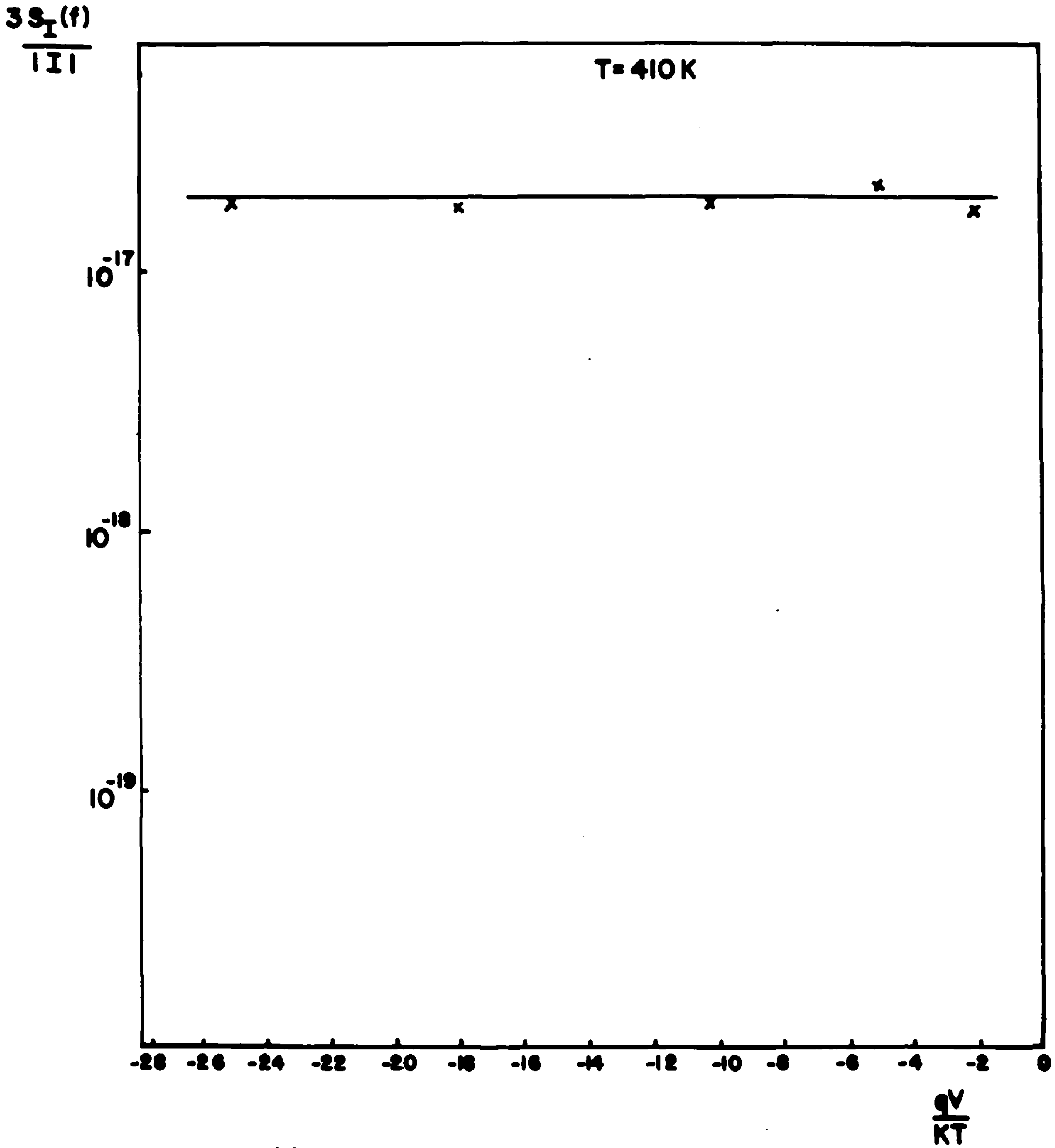

Fig. 4 $\frac{S_I(f)}{|I|}$ vs. $\frac{qV}{KT}$ at back bias

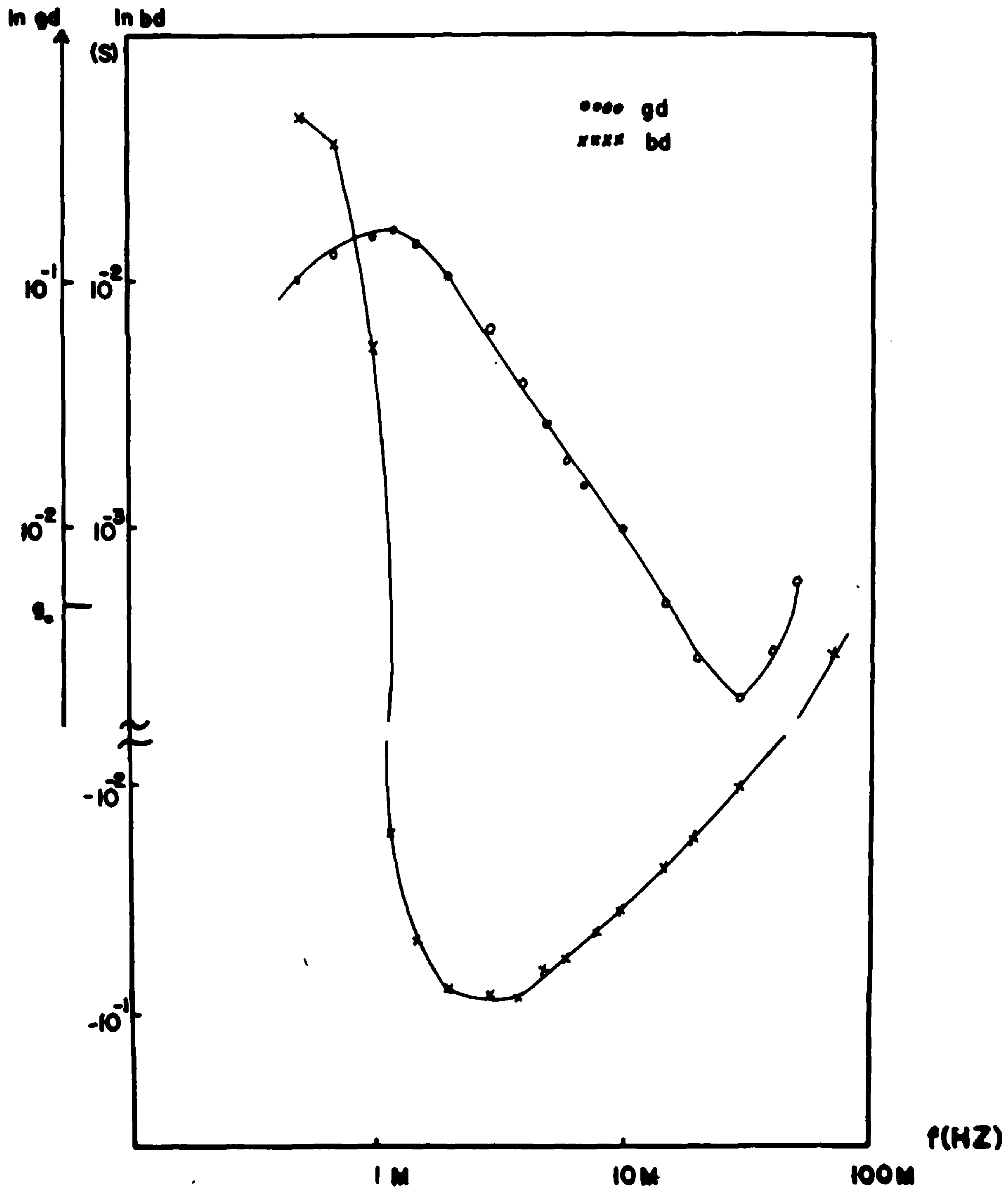

Fig.5 gd and bd vs. f at T= 410K $gd_o = \frac{dI}{dV}$

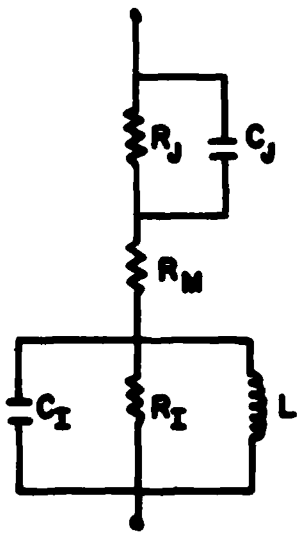

Fig.6 The equivalent circuit of $P^{+}N$ power diode.

3. 1/f noise in n^+-p $Hg_{1-x}Cd_xTe$ diodes with x=0.30 at 193°k (X. L. Wu).

a. Experiments

The whole noise characteristic of the n^+-p diodes #4-100 and #3-454 which are made from two different epitaxial layers by Rockwell International Corporation have been studied at T = 193°k without exposing the diode to radiation.

α) The I-V characteristics were measured and yielded I_0 = -9.83 μA and I_0 = -2.93 μA for diode #4-100 and #3-454, respectively.

β) The noise spectra were measured for diode #4-100 at V = -0.04V, V = 0.02V and I = 0.0000 respectively. Also, the noise spectra were measured for diode #3-454 at V = 0.02V, V = 0.02V and V = 0.0000V.

γ) The 1/f noise at f = 20 Hz versus applied voltage V in the range between -0.07V and +0.07V for the diode #4-100 and the voltage range from -0./V to +0.07V for the diode #3-454. Also, the shot noise at f = 70 kHz for the diode #4-100 and at f = 100 kHz for the diode #3-454 were measured in the applied voltage ranges indicated above.

b. Results

α) The noise spectra are given in Fig. 1 and Fig. 2 for the diode #4-100 at V = -0.04V and V = 0.02V, respectively. They both give very clear 1/f noise spectra in the low frequency regime. The noise spectra are also given in Fig. 3 and Fig. 4 for the diode #3-454 at V = -0.02V and V = 0.02V, respectively. They both also give very clear 1/f noise spectra at low regime. However, the 1/f noise spectra were not observed in the case for I = 0.0000 for diode #3-454 as expected.

β) The curves $\frac{S_I(20) - S_I(\infty)}{|I|}$ vs. $\frac{qV}{kT}$ are given in Fig. 1 and Fig. 6 for the diode #4-100 and the diode #3-454, respectively. Also, the curves

$\frac{S_I(20) - S_I(\infty)}{|I|f(\alpha)}$ vs. $\frac{qV}{kT}$ are given in Fig. 7 and Fig. 8a for the diode #4-100 and the diode #3-454, respectively. Furthermore, the curves $\frac{S_I(20) - S_I(\infty)}{I^2}$ vs. $\frac{qV}{kT}$ are given in Fig. 9 and Fig. 10 for diode #4-100 and #3-454, respectively.

III. Discussions

A) Shot Noise

At the high frequency end of the spectra, full shot noise was observed. The data of the shot noise obtained at high frequency end of the noise spectra given in Fig. 1-4 are compared with the theoretical values calculated from the full shot noise situation $S_I shot = 2e(I+2I_0)$. The experimental data and theoretical values are in a very good agreement. The following Table shows these results.

Diode #	V(v)	I(μA)	Io(μA)	SI,theory(A2/Hz)	SI,mean(A2/Hz)
4-100	0.02	12.4	9.8	1.02×10^{-23}	1.0×10^{-23}
	-0.04	-8.2	9.8	3.6×10^{-24}	3.4×10^{-24}
3-454	-0.02	-1.9	3	1.3×10^{-24}	1.2×10^{-24}
	0.02	4	3	3.2×10^{-24}	2.7×10^{-24}

Table 1 - The comparison of the theoretical values of the shot noise and the experimental data.

In the reverse bias region, full shot noise was observed for both devices. However, at forward bias, since $R_s << R_d$, the full shot noise should still predominate in both diodes.

B) 1/f Noise

If we assume first that the diffusion fluctuation is the noise mechanism, then, according to the model obtained from transmission line theory, for a long diode, we have

$$S_I(f) = \alpha_{Hn} \frac{eI}{fI_n} f(\alpha)$$

where $f(\alpha) = \frac{1}{3} - \frac{1}{2\alpha} + \frac{1}{\alpha^2} - \frac{1}{\alpha^3}(\frac{eV}{kT})$ for case (a) and $f(\alpha) = \pm \frac{1}{3}$ for case (b). In other words, if all the carriers contribute to the 1/f noise which is case (a), a voltage dependence of the values $\frac{S_I(20) - S_I(\infty)}{|I|f(\alpha)}$ should be observed. However, if only the excess carrier contribute to the 1/f noise, which is case (b), then the voltage independence of the values of $\frac{S_I(20) - S_I(\infty)}{|I|}$ should be obtained. The experimental results given in Fig. 1-4 show that the 1/f noise at f = 20 Hz predominate at both forward and reverse bias for both diodes. Also, the Fig. 5 and Fig. 6 show that a clear voltage dependent of values of $\frac{S_I(20) - S_I(\infty)}{|I|}$ for both diodes. Furthermore, the Fig. 7 and Fig. 8 show that at only reverse bias in both diodes, the values of $\frac{S_I(20) - S_I(\infty)}{|I|f(\alpha)}$ is a constant where $f(\alpha)$ does obey the relationship in case (a) mentioned above. Weconclude from this that <u>all</u> minority carriers contribute to the 1/f noise. This indicates that the 1/f noise is of the <u>diffusion</u> type as outlined in Section 1.

The 1/f noise may ultimately originate from quantum effects which include coherent state and incoherent state. The incoherent state includes Umklapp processes, g-R processes and Injection-Extraction processes and only the first is a form of diffusion noise. Since the Hooge parameters of last two processes are much smaller than in the coherent state and in the Umklapp processes, we can conclude that if the quantum effect which caused 1/f noise is an incoherent state process the Umklapp type 1/f noise should be observed unless it is absent.

The measurements give α_H/τ_n. In the coherent case $\alpha_H = 4.6\times10^{-3}$ theoretically, and in the incoherent Umklapp case $\alpha_H = 5.0\times10^{-5}$ theoretically. Choosing these values accordingly we can calculate τ_n in each case. The results are shown in table 2.

Diode #	Quantum States	α_H	τ_n(see)	$\frac{S_I(20) - S_I(\infty)}{I f(\alpha)}$	Bias
4-100	Coherent	4.6×10^{-3}	1.0×10^{-8}	8×10^{-16}	ReV
	Umklapp	5.0×10^{-5}	3.4×10^{-10}		
3-454	Coherent	4.6×10^{-3}	1.2×10^{-7}	1.5×10^{-16}	
	Umklapp	5.0×10^{-5}	2.7×10^{-9}		

Table 1 - Electron Carrier Lifetime Calculated from the Noise Data and Quantum Theory

Since the values in the last column differ by about a factor 5 and α_H should be the same we can safely conclude that τ_n is about 5 times larger in diode #3-454 than in diode #4-100. The reason for this might be the difference in doping density of the different epitaxial layers. However, at this point we cannot discriminate between coherent and incoherent state noise. We are presently trying to evaluate τ_n from the data and so evaluate α_H. At present the indications point to rather large values of α_H.

The discussion given above is for the reverse bias. However, the situation for forward bias is different. The Fig. 9 and Fig. 10 show that the values of $\frac{S_I(20) - S_I(\infty)}{I^2}$ for both diodes are independent of bias. This phenomena can not be described as diffusion noise. It might be caused by the carrier recombination at the surface of the p-region or of the emitter-base charge region, as 1/f noise studies of BJTs indicate; the noise process in the n^+-p diode should be quite similar. The only difference is that in BJTs, the base region is much shorter than in p-region of the diode.

According to the concepts of the surface recombination, the 1/fnoise caused by surface recombination is given by van der Ziel as a modified Hooge-type formula

$$S_{I_R} = I_R^2 \frac{\beta_H}{f N_T}$$

where β_H is modified Hooge consistant which is independent of bias, N_T is the effective number of centers. This holds for recombination at the surface of the p-region as well as for recombination of the surface of the space charge region, but with different values of N_T and I_R. If we denote these recombination currents by I_{R1} and I_{R2} respectively, then I_{R1} is proportional to I, since the electrons have all passed the barrier before recomining, and I_{R2} is proportional to I^{α}, since the electrons have only crossed part of the barrier before recombining; here $1/2 < \alpha < 1$. It thus seems that recombination 1/f noise predominates over diffusion 1/f noise at forward bias, whereas the reverse is true for back bias.

We thus conclude that diffusion 1/f noise in the p-region predominates for back bias and that recombination 1/f noise at the surface of the p-region predominates for forward bias. The reasons for such behavior requires further study.

5. Program for next interval

(a) We plan to calculate more accurate values of the life time τ_n in n^+-p $Hg_{1-x}Cd_xTe$ diodes, as soon as we have more detailed data for our samples.

(b) We want to establish for these diodes the presence or absence of diffusion 1/f noise of the Umklapp type described by Eq. (6); the applicability of certain infrared detection schemes is determined by an answer to this question.

(c) NVEOL is making n^+-p $Hg_{1-x}Cd_xTe$ diodes of simpler geometry with much less series resistance. They will be measured as soon as they become available.

(d) We want to measure 1/f noise in our n^+-p $Hg_{1-x}Cd_xTe$ diodes over a much wider temperature range.

(e) We want to understand better what the exact nature is of the 1/f noise at forward bias. The relative spectrum $S_I(f)/I^2$ is independent of bias, this seems to indicate that the 1/f noise generation is due to surface recombination in the p-region and is not of fundamental origin. The theory of this model needs further development.

(f) We plan to measure the input admittance of the n^+-p HgCdTe diodes and so determine the life time τ_n more accurately.

(g) We intend to measure 1/f noise in HgCdTe resistors as a function of the device length L to investigate the possibility of resistors of high noise (high α_H) to low noise (low α_H) at intermediate length.

(h) We plan further study of the 1/f noise in our layer silicon p^+-i-n diodes. In particular we need a better theory of the equivalent circuit and a more accurate determination of the time constant τ of the system. Moreover we need to know how the coherent state theory can apply to these devices.

(i) BJT's made on different crystal faces [(100),(111),(110)] will become available within the next few weeks. These are theoretical expectations that

Umklapp 1/f noise in the collector current may be present for some of these interfaces. The means of testing this are available and the measurements will be performed under this contract. All other 1/f noise studies on these devices will be performed under the grant.

(j) We will attempt to obtain $Hg_{1-x}Cd_xTe$ n^+-p diodes from different sources and made by different processing techniques.

(k) The fundamental problem of 1/f noise in n^+-p and p^+-n diodes is whether there are fundamental limits to the 1/f noise and (or) whether these limits can be broken by proper techniques.

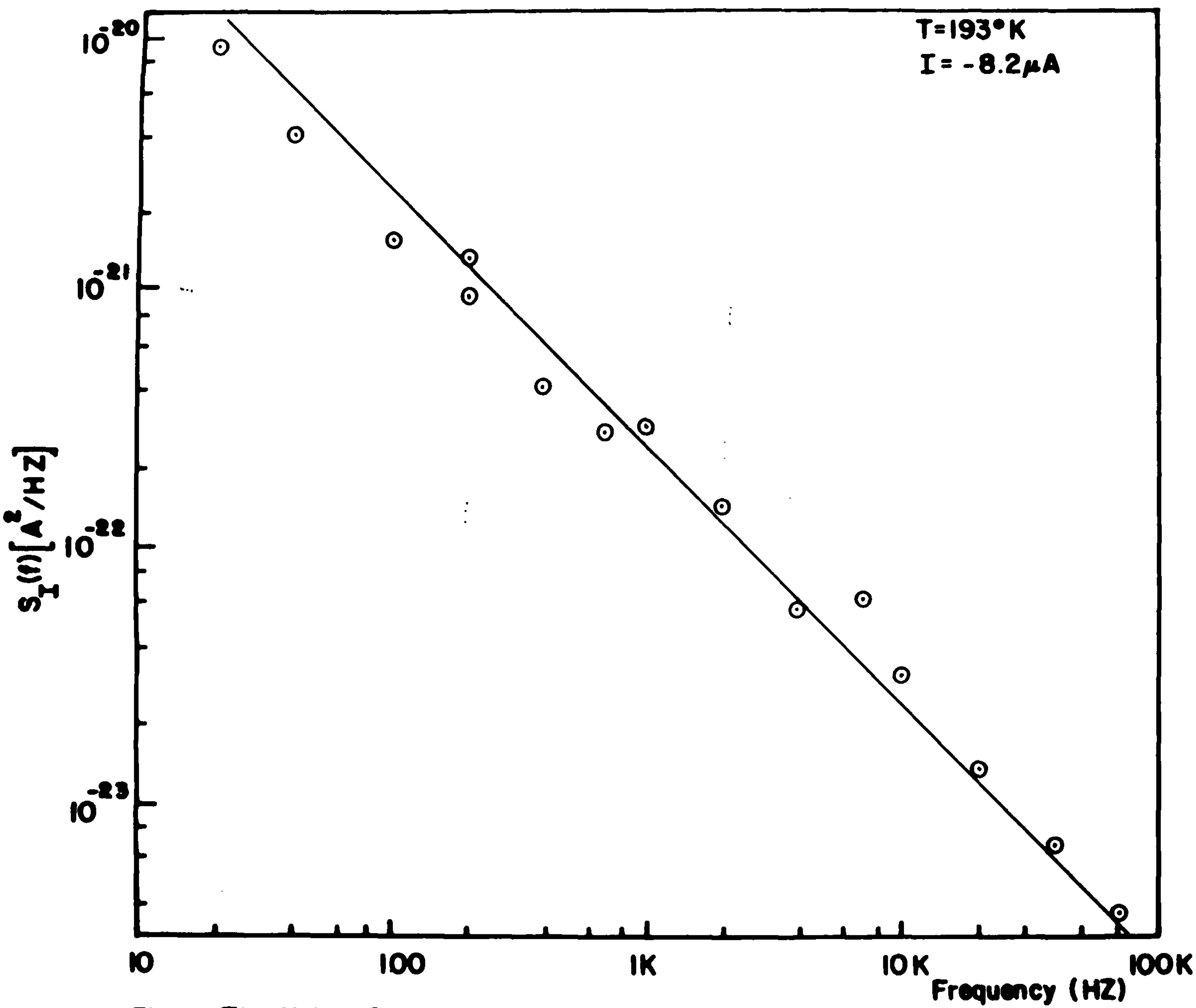

Fig.1- The Noise Spectra for Diode # 4-100 at V= -0.04V

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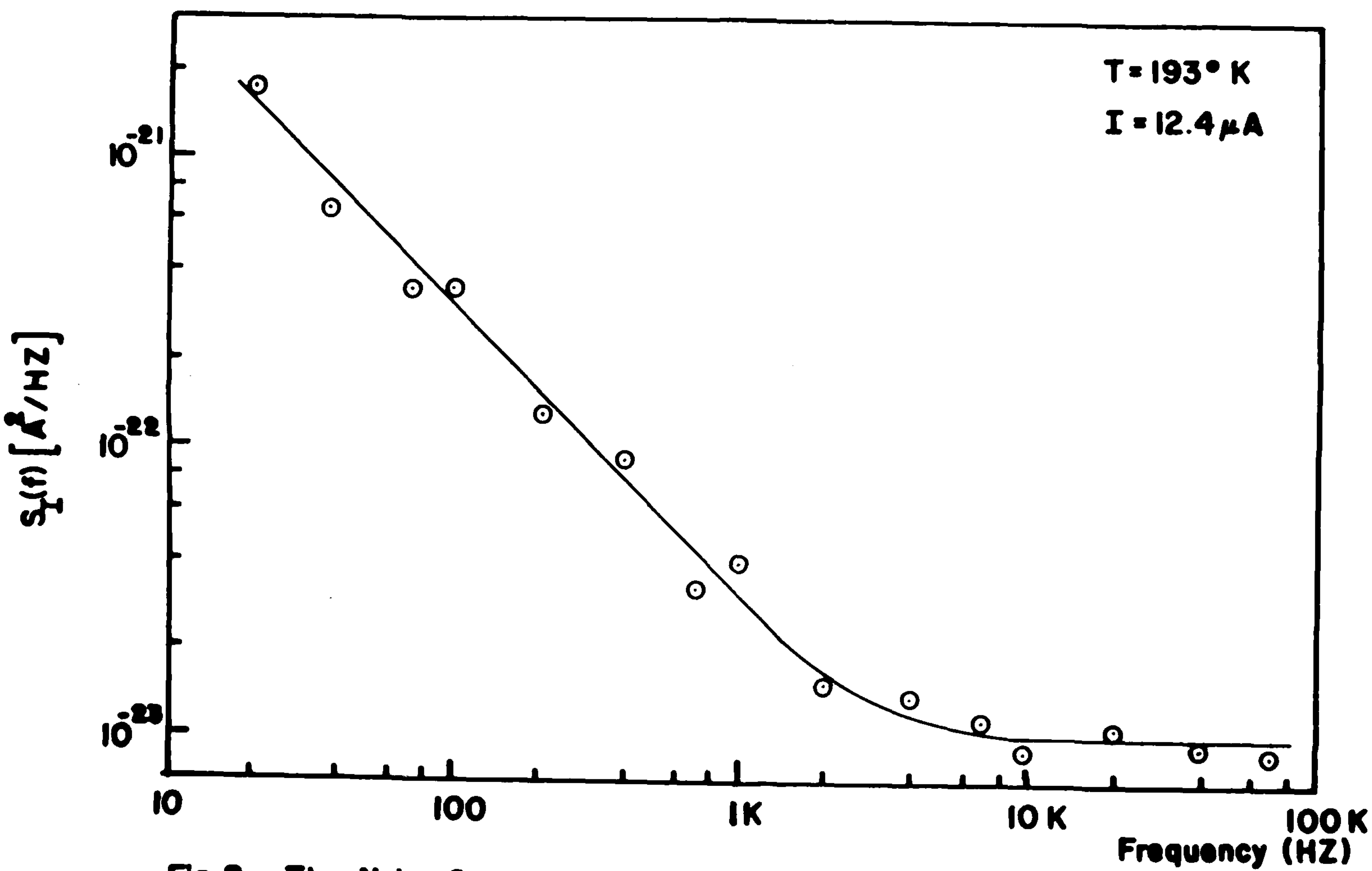

Fig. 2- The Noise Spectra for Diode # 4-100 at V = 0.02V

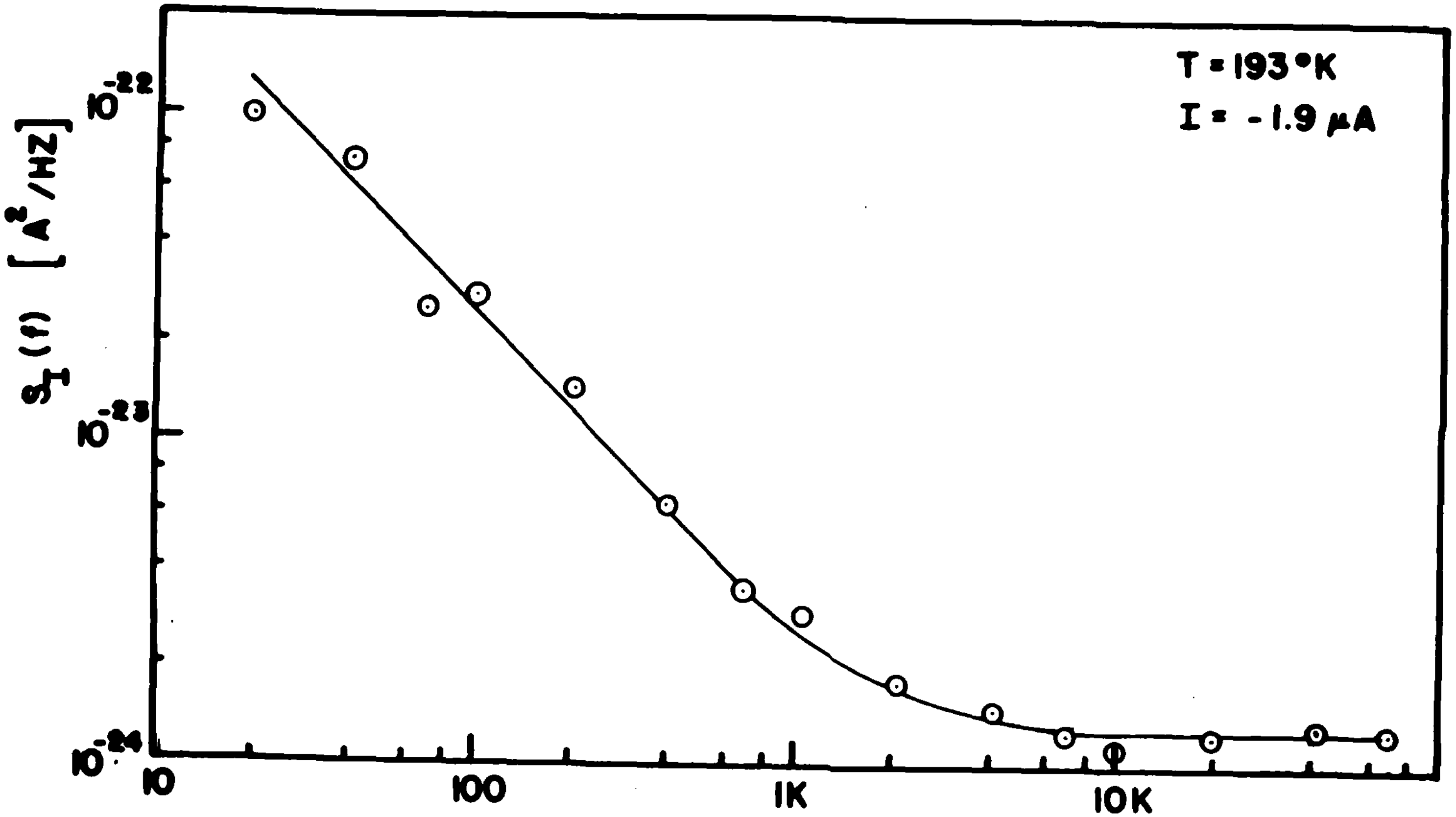

Fig. 3- The Noise Spectra for Diode # 3-454 at V = -0.02V

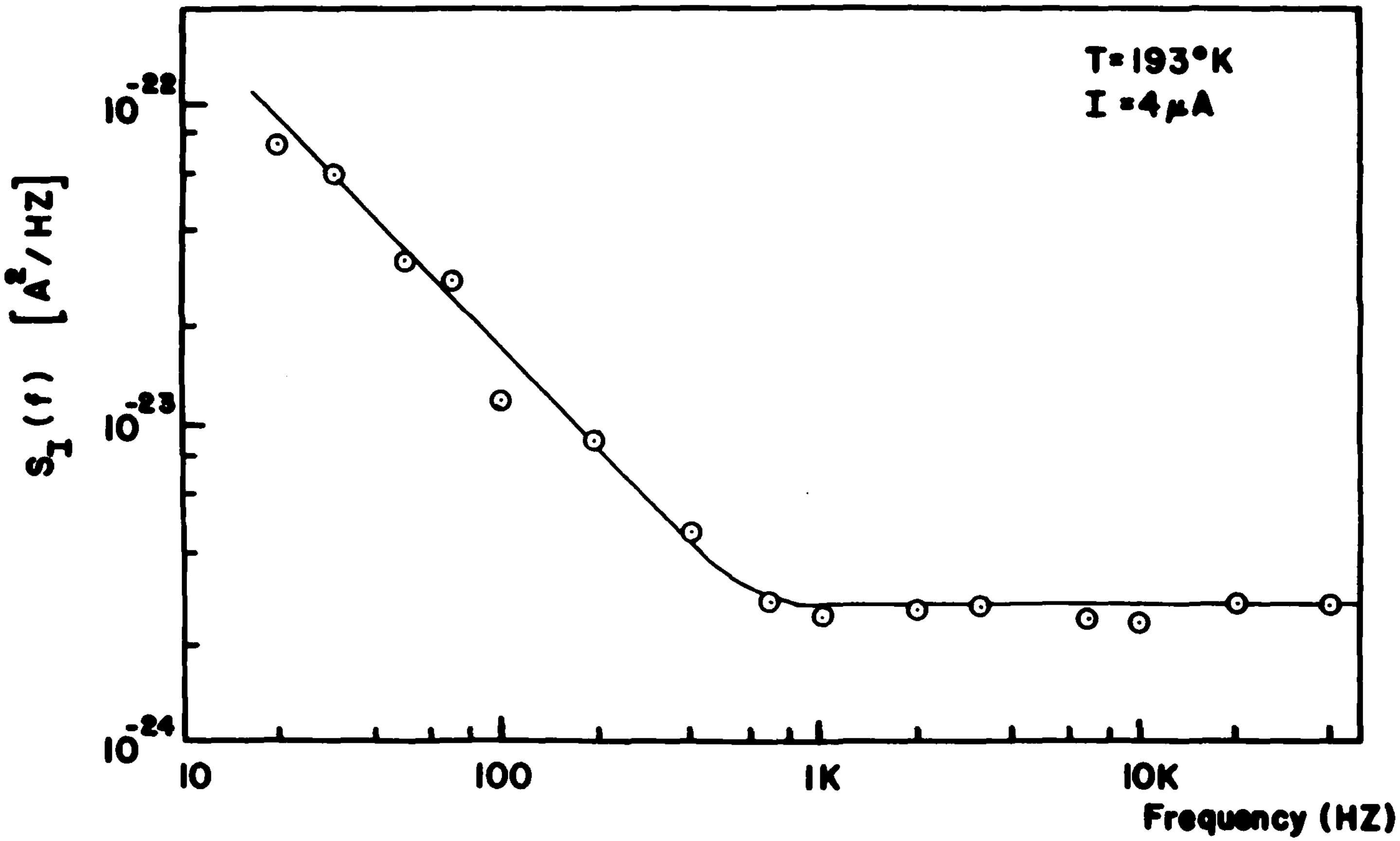

Fig. 4 - The Noise Spectra for Diode # 3-454 at V = 0.02V

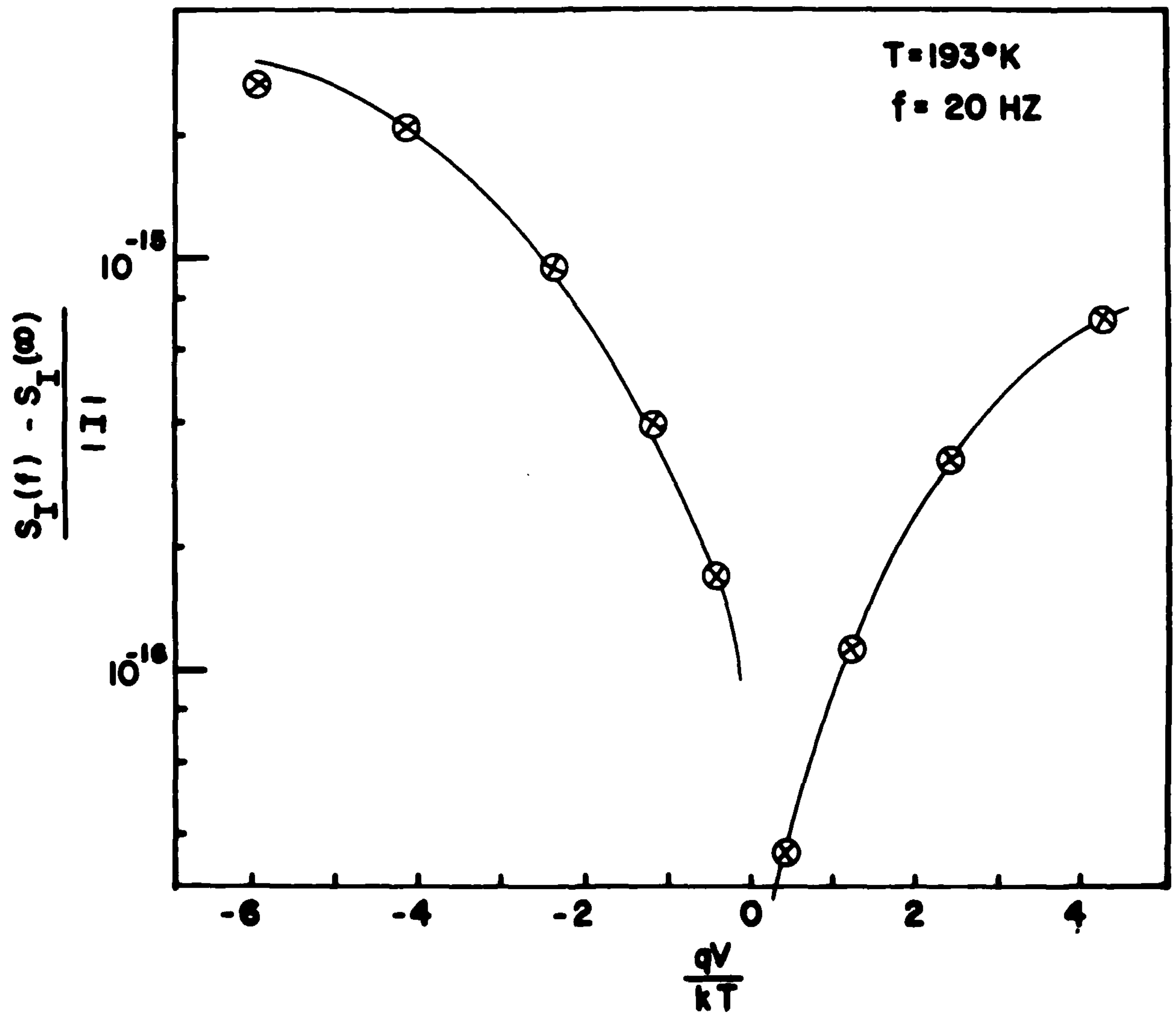

Fig. 5- The Ratio of 1/f Noise and Current vs. Normalized Voltage Curve for Diode # 4-100

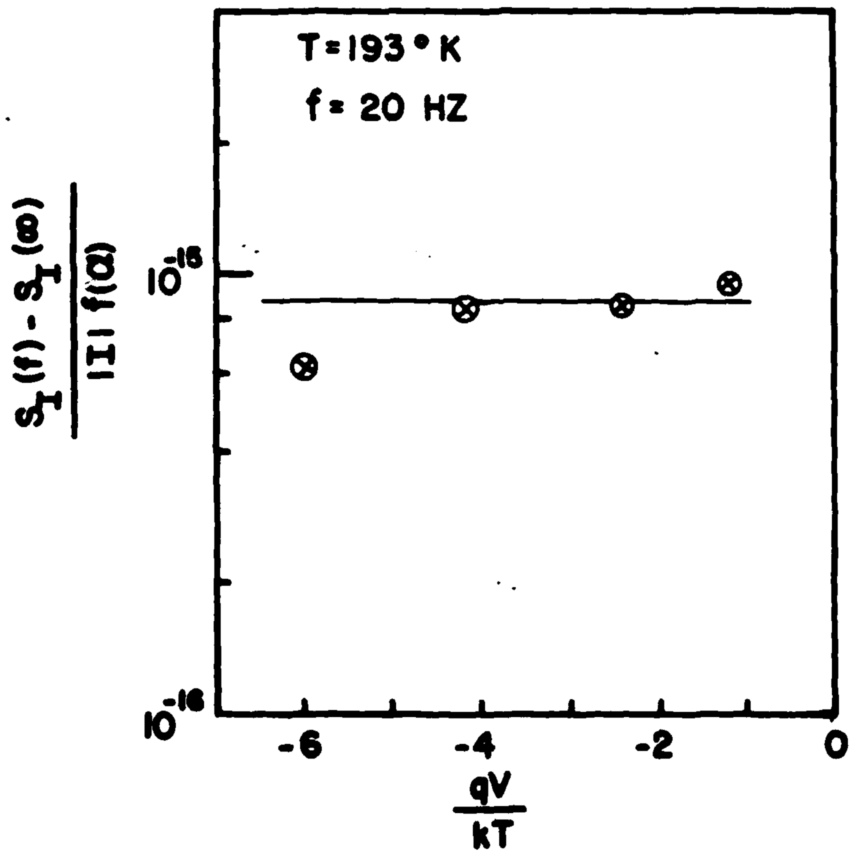

Fig. 7 - The Ratio of 1/f Noise and the Product of Current and f(a) Curve for Diode # 4-100

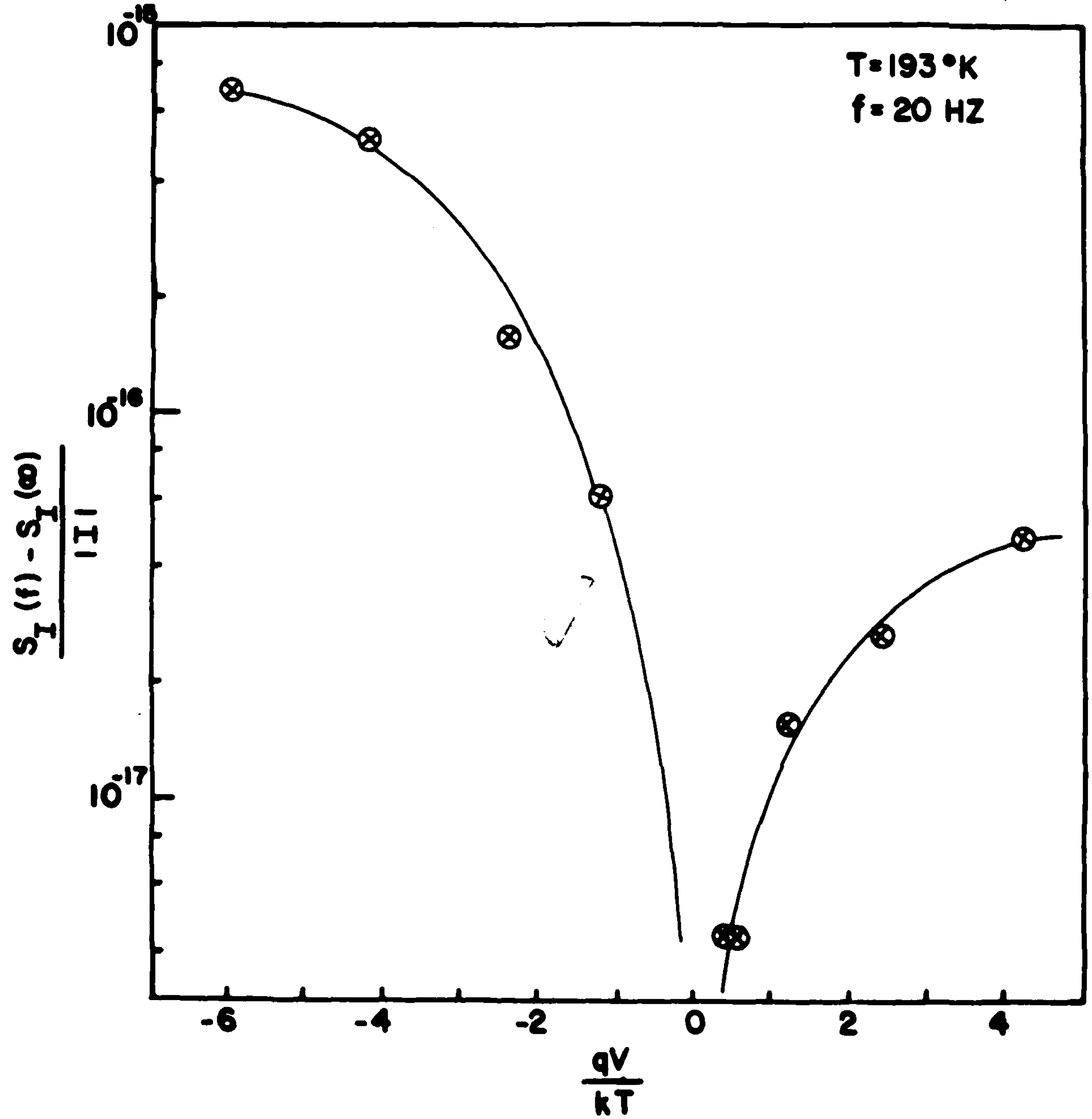

Fig.6 - The Ratio of 1/f Noise and Current vs. Normalized Voltage Curve for Diode # 3-464

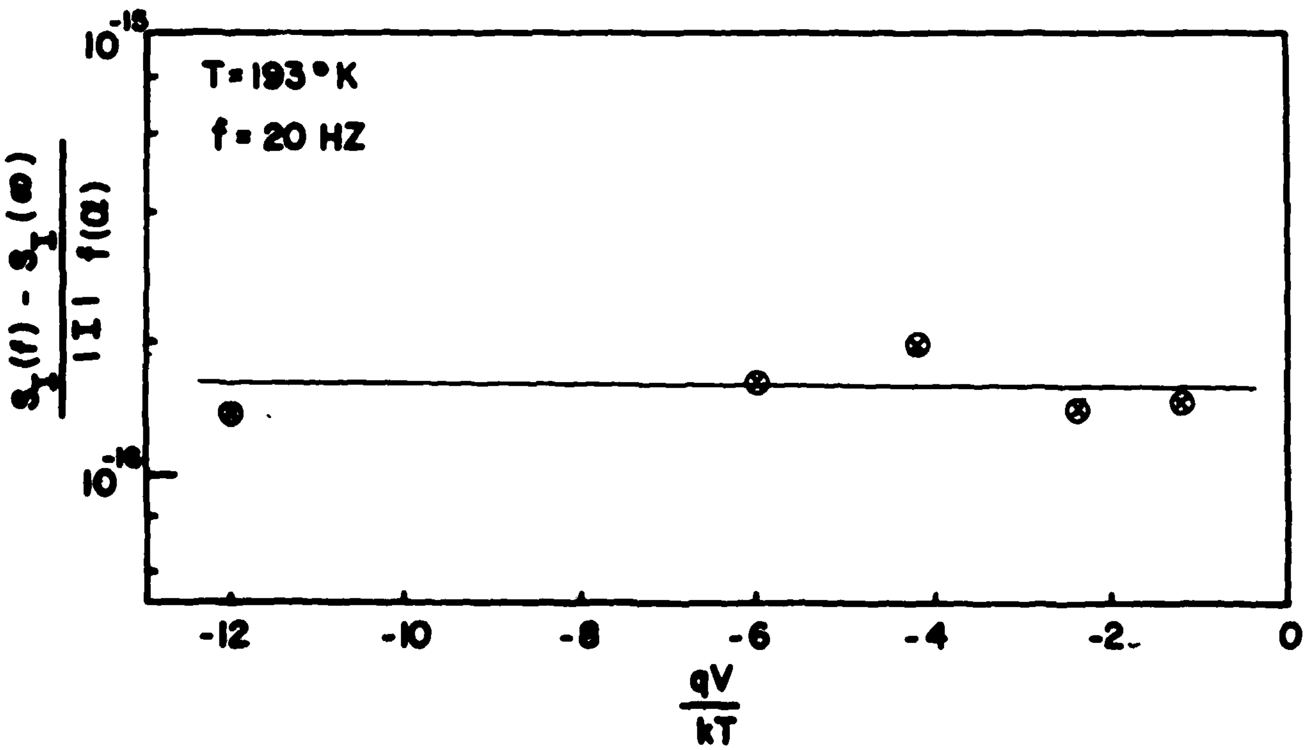

Fig. 8— The Ratio of 1/f Noise and the Product of current and f(a) Curve for Diode # 3-484

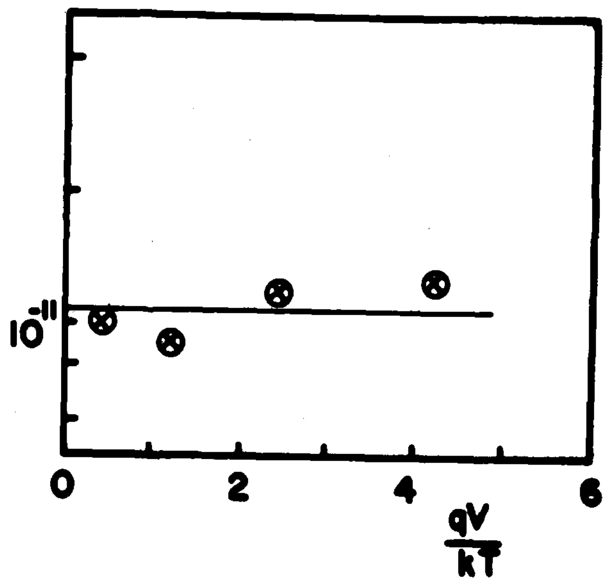

Fig.9 - The Ratio of 1/f Noise and Current Square vs. Normalized Voltage Curve for Diode # 4-100

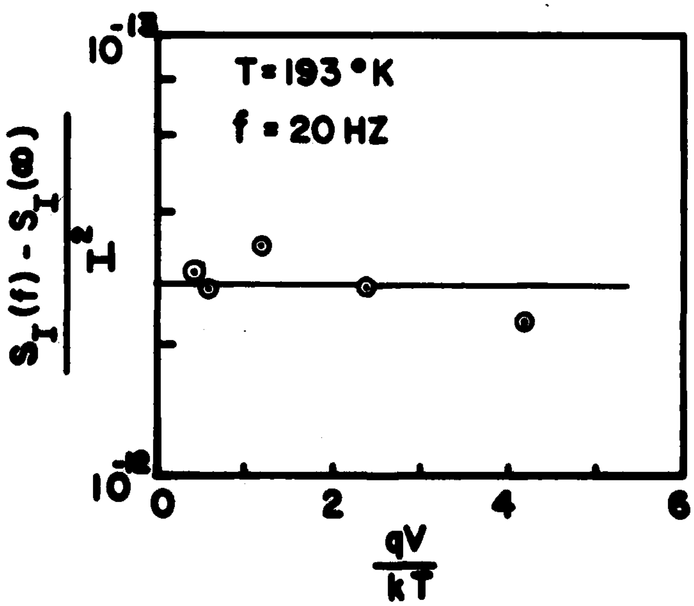

Fig. 10— The Ratio of $\frac{1}{f}$ Noise and Current Square vs. Normalized Voltage Curve for Diode # 3-454

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