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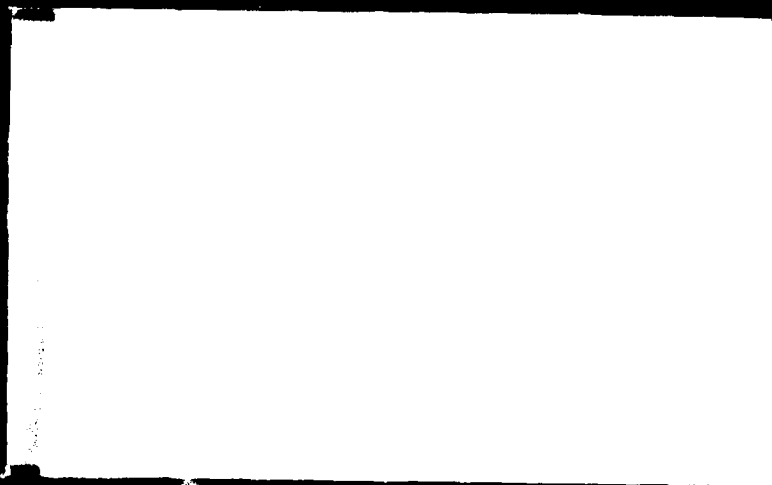
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**Dislocation-Induced Noises in Semiconductors
at Low and High Temperatures.**

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In continuation to research under Grant DAERO-78-6-115 this investigation was concentrated on better understanding of the dislocation structure involved in noise generation process. It is shown that noise power depends on unhomogeneities of dislocation structure especially on randomly distributed dislocation electrical barriers. The annealing of dislocation-point defect complexes does not influence the noise spectrum. It is difficult to find a proper explanation for this surprising result.

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Introduction

The current research came in continuation of the one year program started under the DAERO-78-G-115 grant in January 1979. The main problem we faced in this research was an instability of the low frequency noise in heavily dislocated Si. Another problem which arose was due to the presence of dislocation-point defect complexes. Therefore the current research aims are to investigate in more detail the dislocation structure, noise dependence on inhomogeneities of the structure, noise power dependence on the polarity of the current.

Sample Preparation

The samples were prepared and plastically deformed by the methods described recently [1]. This investigation was carried out on laser irradiated and locally indented specimens. The small area ohmic contacts were made by technological methods developed recently [2].

In order to understand the role played by the internal dislocation electrical field (barrier) the intrinsic n-type Si wafers were cut into narrow strips $50 \times 1 \times 0.3$ mm with the normal $\langle 111 \rangle$ to the big side (see Fig. 1).

The narrow strips were plastically deformed by diamond indenter perpendicular to $[111]$ face of the strip in order to create the dislocation cluster in the center of narrow strip. Then six gold contacts were attached to the specimen (see Fig. 1).

-
1. S. Mil'shtein, "Dislocation-Induced Noises in Semiconductors at Low and High Temperatures" Final Technical Report, Contract Grant DAERO-78-G-115 (May 1980).
 2. S. Mil'shtein, Progress Invention Report DAERO-78-G-115 (May 1980).

Measurements

The characterization of dislocation clusters and their electrical fields in narrow samples were made by electron microscope.

Fig. 2a shows the etch-pits at the [111] surface. One can see the sharp gradient of the etch-pits at the border of dislocation cluster.

Fig. 2b demonstrates the presence of electrical field at the interface between the dislocated and normal parts of the crystal.

In order to measure the parameters of the dislocation internal electric fields we developed a new so called six point potential measurements (6-PPM). Let us briefly describe the idea of the method:

There are two current contacts attached to the opposite ends of a specimen (see Fig. 1). Contacts 1-4 are used for potential measurements. Measuring the voltage drop between contact 1 and 2 one can write:

$$V_{12} = J (\Gamma_1 + \Gamma_2) + \varphi_{12} \quad (1)$$

where J is the current flows along the specimen, φ_{12} is the dislocation electrical potential or barrier (DEB), Γ_1 and Γ_2 the bulk resistance between 1 and 2 contacts.

Electrometer I is used to measure the current, and electrometer II is used for the potential measurements.

Equation (1) can be written for various combinations of the contacts. For example:

$$V_{13} = J(\Gamma_1 + \Gamma_2 + \Gamma_3) + \varphi_{12} \quad (2)$$

or

$$V_{43} = -J(\Gamma_3 + \Gamma_4) + \varphi_{34} \quad (3)$$

One can assume that $\varphi_{12} = \varphi_{34}$. The eq. 1-3 enables us to avoid the measurements of Γ_1 , Γ_2 , Γ_3 etc., which in turn requires the geometrical determination of the contact positions. The I-V characteristics provide the DEB value (φ_{12}). Comparing φ for various specimens with electron microscopy pictures one can even calibrate the electron microscopy contrast (brightness of the area - between dislocated and nondeformed part of the crystal) (Fig. 2).

The noise measurements were performed by two schemes. Fig. 3a presents the 4-term voltage fluctuation measuring system and Fig. 3b shows the 2-term current fluctuation measuring circuit. Fig. 4 and 5 present the 4-term voltage noise measured on plastically deformed and thermally annealed specimen w68. The $\log_{10} S_V(f) / \langle V \rangle^2$ is plotted versus $\log_{10} f(\text{Hz})$ in frequency range from $3 \cdot 10^{-2}$ to 10^{-2} Hz for both polarities of the bias voltage. One can see that both curves represent approximately the same $1/f$ like spectrum.

The measurements being repeated in two hours (Fig. 5) demonstrate some drop of the noise power.

The intrinsic silicon specimens have high resistivity and after plastic deformation their resistance is 20 times higher, that prevents us from using a true current source. There are two pairs of contacts at each specimen. Fig. 6 and 7 present the plot $\log_{10} S(f) / \langle J \rangle^2$ versus $\log_{10} f(\text{Hz})$ in the frequency range $3 \cdot 10^{-2} - 10^3$ Hz for specimen No. 68. Using one pair of contacts at this specimen we obtained approximately

the same noise spectrum $1/f$ like both polarities of the current. (fig. 6) Using another pair of contacts we obtained different noise power for both polarities of current. (fig. 7) The value of the forward and reverse current shows that one of the contacts of last pair is somewhat non-ohmic.

The current noise measurements of the plastically deformed and thermally annealed specimen N69 are shown on figs. 8 and 9. One can find a strong dependence of the noise power on the current polarity.

Discussion

1) The noise measurements of the areas containing randomly distributed electrical fields around dislocations (see the bright areas on the electron microscopy pictures fig. 2) shows the noise power dependence on the current polarity: the difference in the noise is of about two orders of magnitude for reverse and forward direction of current. Recently we found this difference in a case of dislocation p-n junctions [1].

It must be pointed out that the potential measurements of ϕ_{12} value and electron microscopy show that electrically charged areas around dislocations are not true p-n junctions.

One can assume an existence of some average electrical field which fluctuates in time and modulates the conductivity of the specimen. Originally, this field could fluctuate because the number of electrons trapped at defect sites changes in time and in turn the charge of defects (dislocations or complexes) fluctuates.

2) The plastically deformed and thermally annealed Si samples demonstrated $1/f$ like spectrum in frequency range $10^{-2} - 10^3$ Hz. The most surprising result is that thermal annealing does not influence almost either noise power or the shape of the noise spectrum.

It is well established by many research groups [3-5] that plastic deformation creates various densities of point defects. The stable point defect-dislocation complexes could be formed as a result of both elastic and Coulomb type of interaction. So using the parameters appropriate to an fcc lattice R. Jonson [6] found that a vacancy will migrate around the edge dislocation to the compressional side. On the other hand, the charged edge-type dislocations being surrounded by clouds of charged point defects or impurities interact strongly with the latter [7]. Our C-V measurements [8] being performed on the same specimens (like N 68-69) had demonstrated that part of the dislocation-point defects remain after long thermal annealing. Thus two alternative conclusions are possible:

- a) The observed $1/f$ noise spectra is a "pure dislocation" effect and dislocation-point defect complexes do not influence the noise generation process (?)
- b) Neither the number of dislocation dangling bonds nor the density of defects influence the noise power but the internal randomly distributed electrical fields (surrounding the dislocation segments) are the main factor in observed phenomena. Recently, a detailed investigation carried out in our laboratory [9], showed that an extended (in intrinsic materials about 100 μm) electrical field exists around the dislocations in Si and Ge.

To clarify the picture additional research on the defect complexes behavior is necessary. More details about electrical barriers of the dislocated crystals are needed.

3 The 6-PPM method of the local electrical potentials was developed. This method provides straight information about the Fermi level position in locally damaged areas if one knows the Fermi energy in the initial material. It must be pointed out that any changes of Fermi level as a result of plastic deformation, ion-implantation radiation or other type of damage could be found by the 6-PPM method.

Comments

The aim of this research is better understanding of $1/f$ noise generation in dislocated crystals. Unfortunately it is very difficult to separate the dislocation effects from the activity of various point defects, since the dislocation-point defects complexes remain even after laser annealing.

The crystal containing misfit dislocations (misfits) seems to be a "pure" dislocation object. The misfits are uniform periodical structures with one type of dislocation. That still does not solve the problem of defect complexes because no data exists on annealing of "misfits". Our last year program includes the research on misfit dislocations induced noises. We could not accomplish the program because our cooperators in Germany are unable to grow the epitaxial layers containing the "misfits".

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Captions *

- Fig. 1. Set-up for electrical measurements on defect semiconductor crystals.
- Fig. 1.a. V-I characteristic of dislocated crystals.
- Fig. 2. Electron microscopy of the Si crystal with dislocations
(a) interface between dislocated and dislocation-free parts of the crystal.
(b) electrical fields (bright areas) around single dislocations.
- Fig. 3. Set-up for noise measurements:
(a) four-term voltage noise measuring circuit.
(b) two-term current noise measuring circuit.
- Fig. 4. Four-term noise measurements on specimen w 68.
- Fig. 5. Four-term noise measurements on specimen w 68 repeated in 2 hours.
- Fig. 6. Two-term noise measurements on specimen w 68.
- Fig. 7. Two-term noise measurements on specimen w 68 repeated in a 1/2 hour.
- Fig. 8. Two-term noise measurements on specimen w 69.
- Fig. 9. Two-term noise measurements on specimen w 69 repeated in 1 hour.

* The noise measurements on Figs. 4-9 are accompanied by detailed information printed at the left side of each figure.

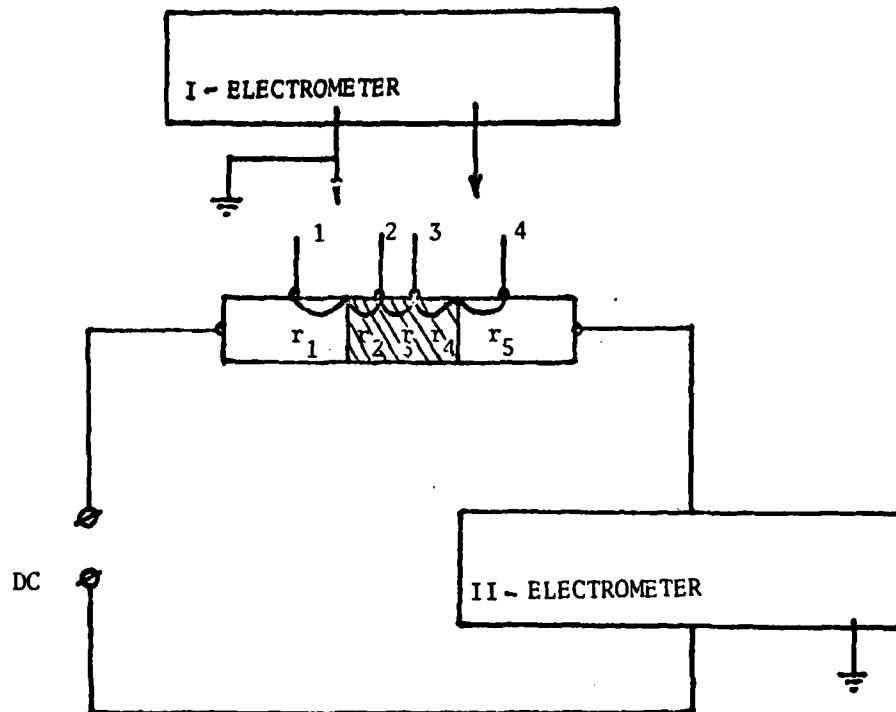


Fig. 1

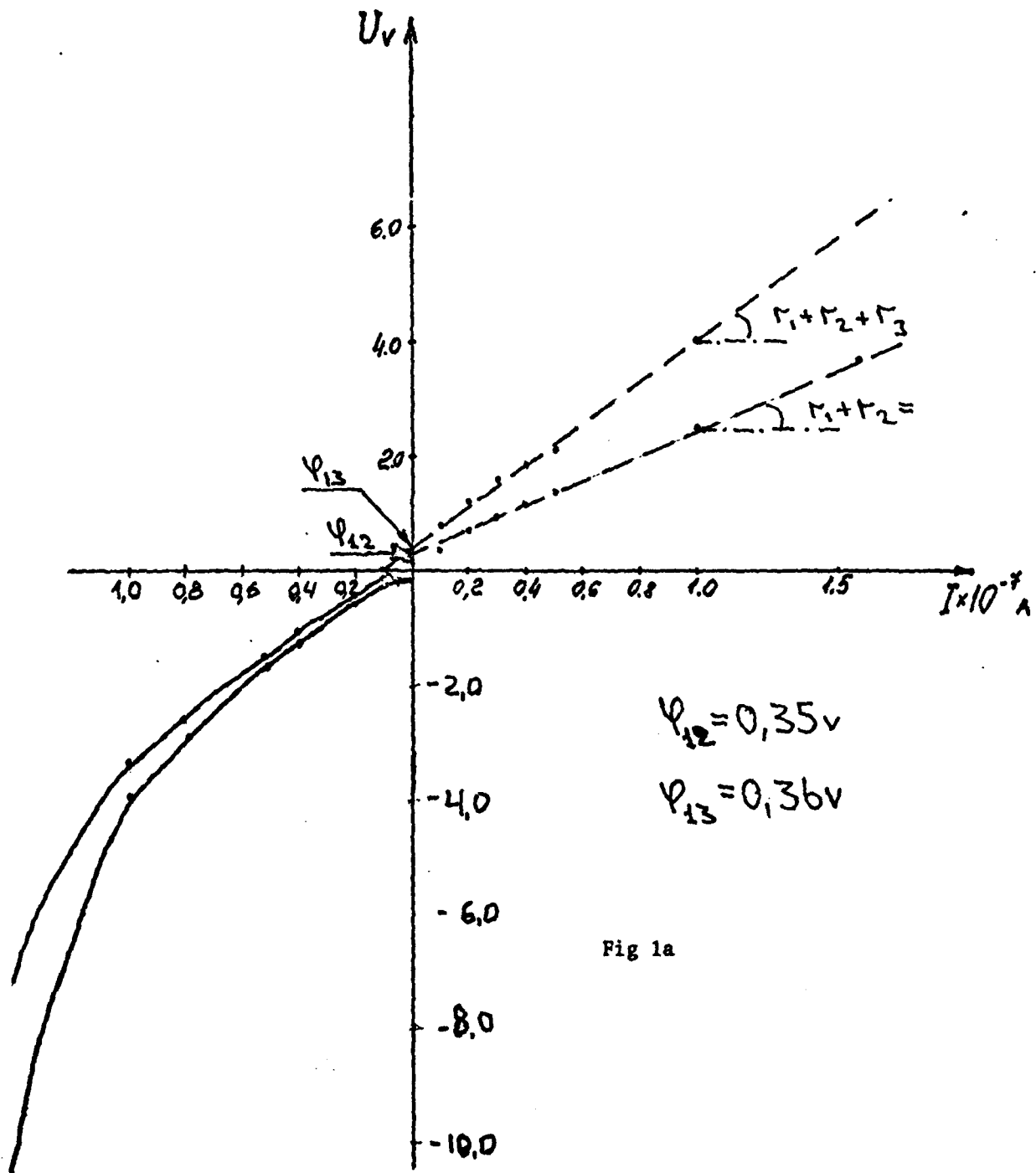


Fig 1a

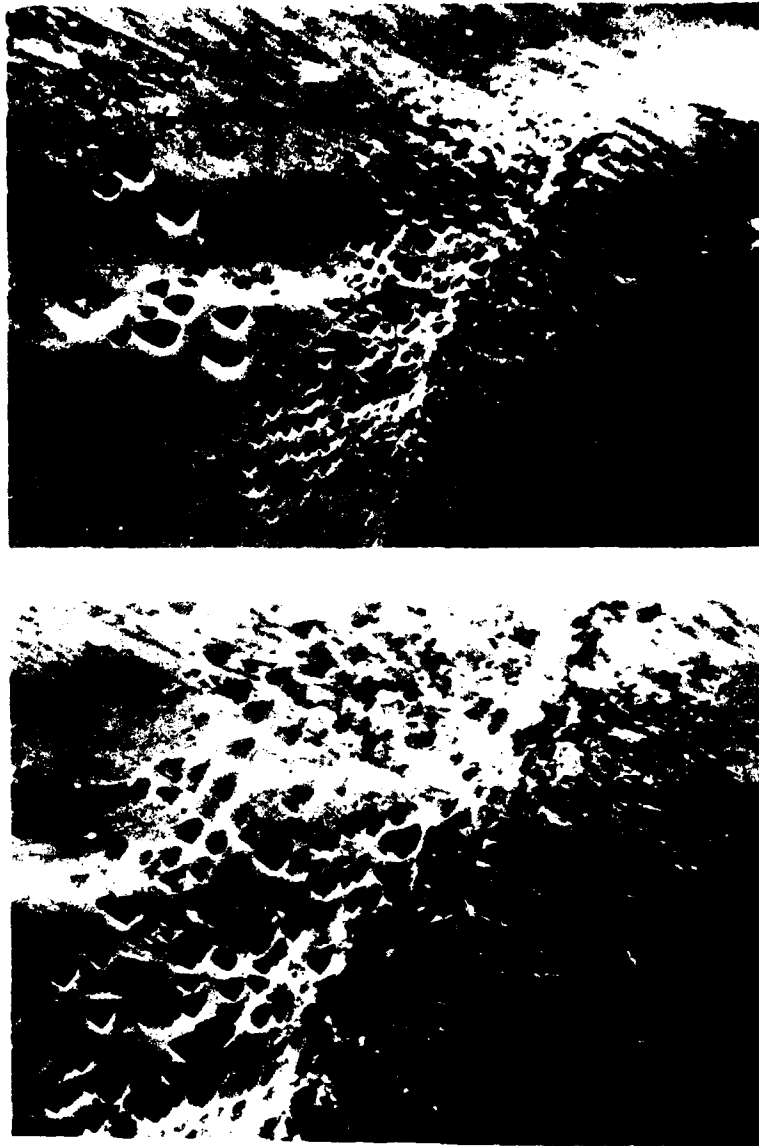


Fig. 2

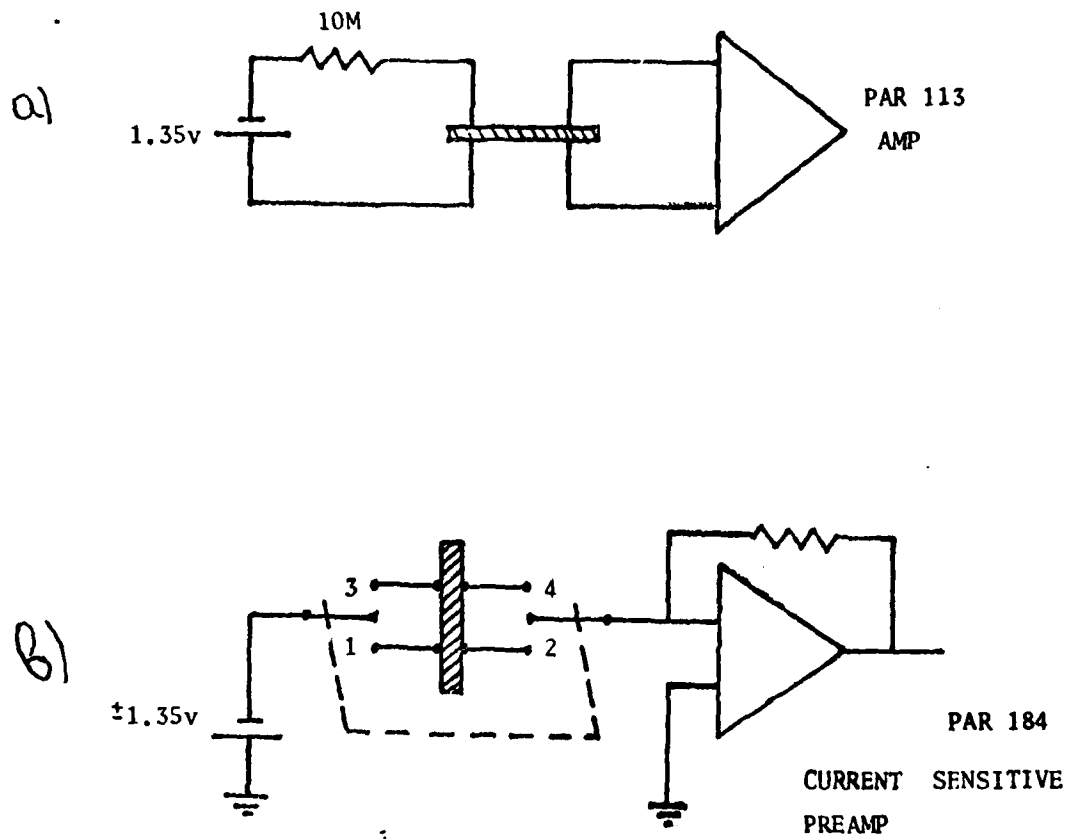


Fig 3

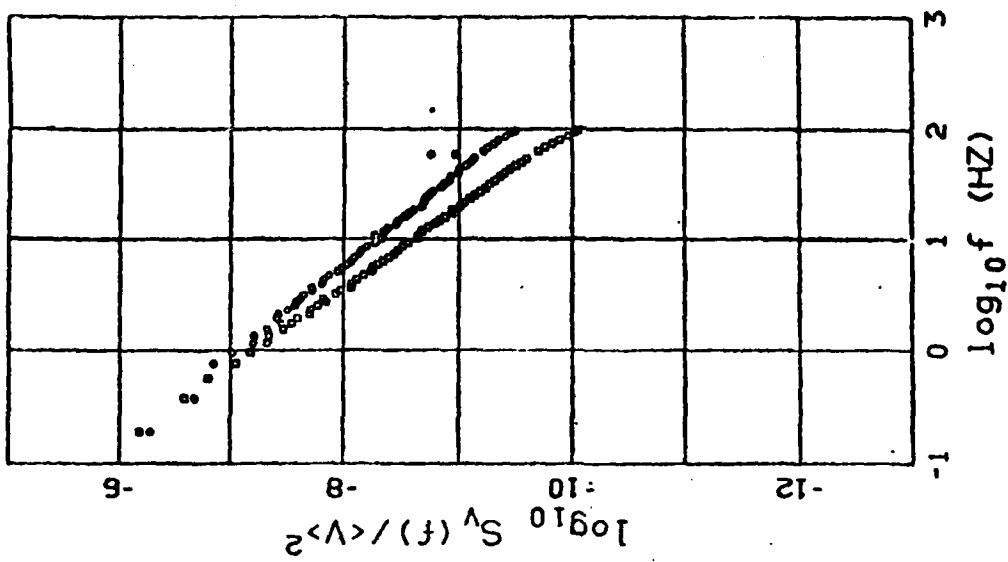


Fig 4

TIME
14 30
• FILE 1
DISLOCATED S1 (S.M.) 300K I=1.35V/10M I+(B1) I-(A1) V+(B2) V-(A2)
SPEC(2,1)=10<V>. 113 AC .03-10K HZ G=1000 3322LPMF C=1 100HZ
FILE 2 SUBTRACTED AS BACKGROUND
<V> = .3570

6 26 80 14 53
• FILE 3
DISLOCATED S1 (S.M.) 300K I=1.35V/10M I+(B1) I-(A1) V+(B2) V-(A2)
SPEC(2,1)=10<V>. 113 AC .03-10K HZ G=1000 3322LPMF C=1 100HZ
FILE 2 SUBTRACTED AS BACKGROUND
<V> = -.4199

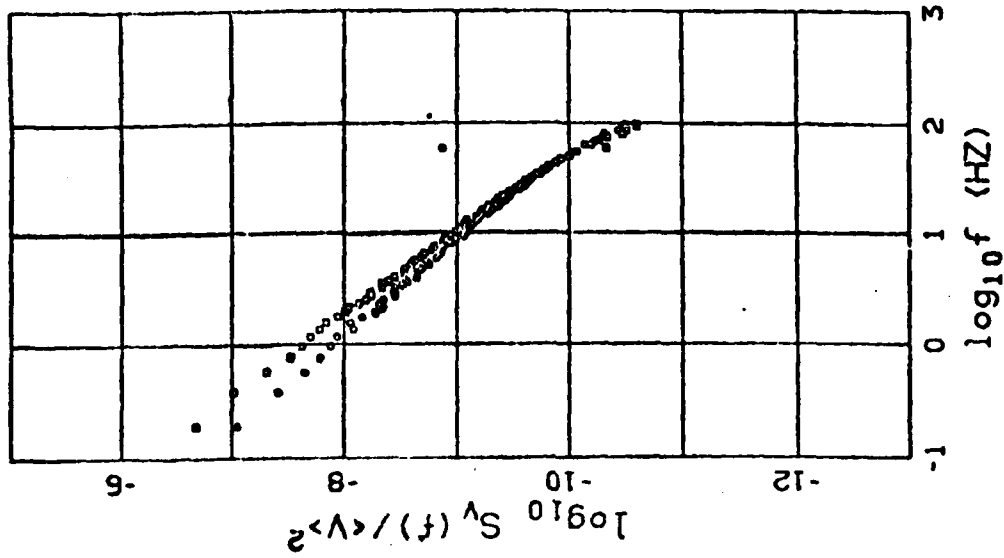


Fig 5

TIME

● FILE 4 16 27
 DISLOCATED S1 (S.M.) 300K 1-1.35V/10M 1-(B2) 1-(A2) V-(B1) V-(A1)
 SPEC(2.1)-10<<V>. 113 AC .03-10K HZ C-1000 3322.PNF C-1 100KZ
 FILE 6 SUBTRACTED AS BACKGROUND
 <V> = .6225

● FILE 5 6 26 80 16 54
 DISLOCATED S1 (S.M.) 300K 1-1.35V/10M 1-(B2) 1-(A2) V-(B1) V-(A1)
 SPEC(2.1)-10<<V>. 113 AC .03-10K HZ C-1000 3322.PNF C-1 100KZ
 FILE 6 SUBTRACTED AS BACKGROUND
 <V> = -.5972

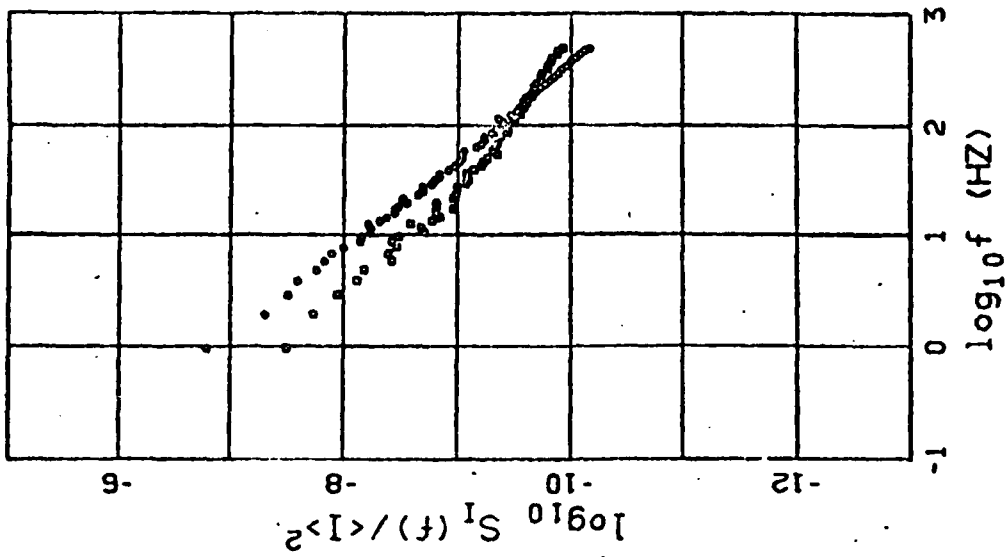


Fig 6

• FILE 9 9 59
 DISLOCATED S1 (S.M.) 300K V=1.35V (A1) .(B1) 184 1E-7A/V
 SPEC(2.1)=184 MON. 113 AC .03-10K HZ G=200 3322LPMF C=1 500-HZ
 •I> = 6.47E-08

 • FILE 10 6 27 80 10 4
 DISLOCATED S1 (S.M.) 300K V=-1.35V (A1) .(B1) 184 1E-7A/V
 SPEC(2.1)=184 MON. 113 AC .03-10K HZ G=1000 3322LPMF C=1 500-HZ
 FILE 11 SUBTRACTED AS BACKGROUND

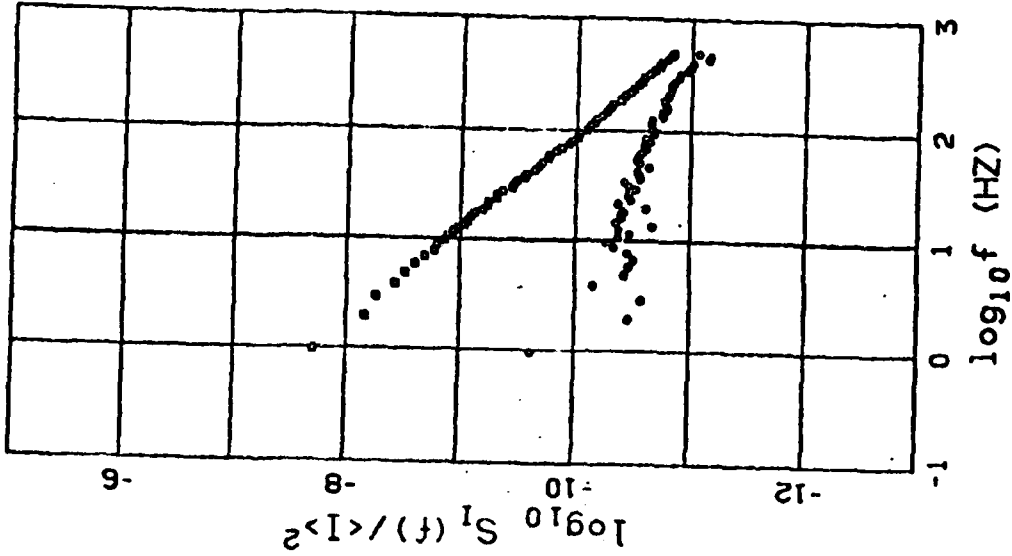


Fig 7

TIME
 10 26
 • FILE 14
 DISLOCATED SI (S.M.) 300K V=1.35V (A3) .(B3) 184 IE-8A/V
 SPEC(2.1)=184 MON, 113 AC .03-10K HZ G=1000 3322LPMF G=1 500HZ

FILE 15 SUBTRACTED AS BACKGROUND

$\langle I \rangle = 5.80E-09$

• FILE 16 6 27 80 10 43
 DISLOCATED SI (S.M.) 300K V=1.35V (A3) .(B3) 184 IE-7A/V
 SPEC(2.1)=184 MON, 113 AC .03-10K HZ G=1000 3322LPMF G=1 500HZ

$\langle I \rangle = -7.37E-08$

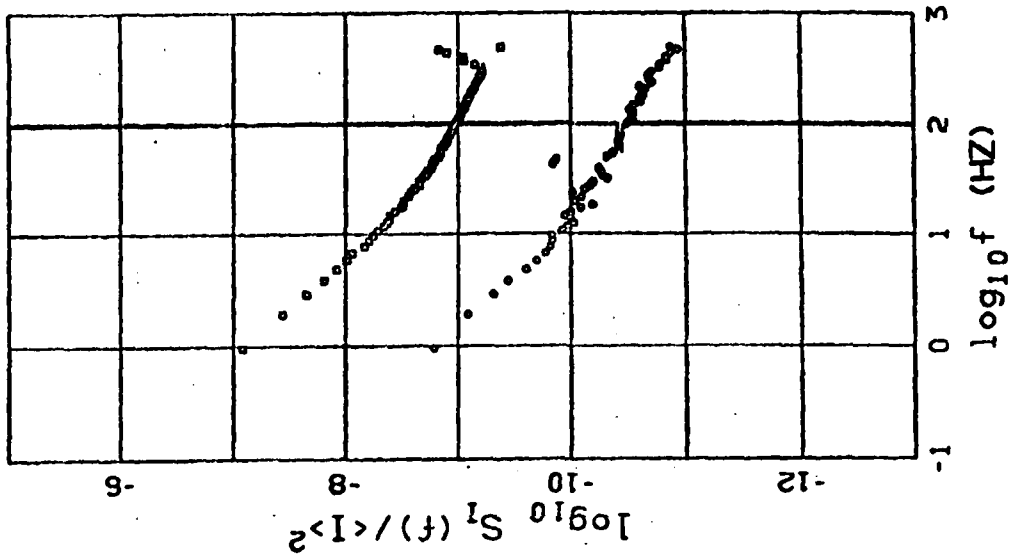


Fig 8

TIME

• FILE 17 11 15
 W69 DISLOCATED S1 (S.M.) 300K V=1.35V (A8) .(B8) 184 1E-8A/V
 SPEC(2,1)=184 MON. 113 AC .03-10K HZ G=1000 3322LPMF G=1 500-HZ

FILE 18 SUBTRACTED AS BACKGROUND
 <I> = 5.12E-09

• FILE 19 6 27 80 11 30
 W69 DISLOCATED S1 (S.M.) 300K V=1.35V (A8) .(B8) 184 1E-7A/V
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<I> = -4.98E-08

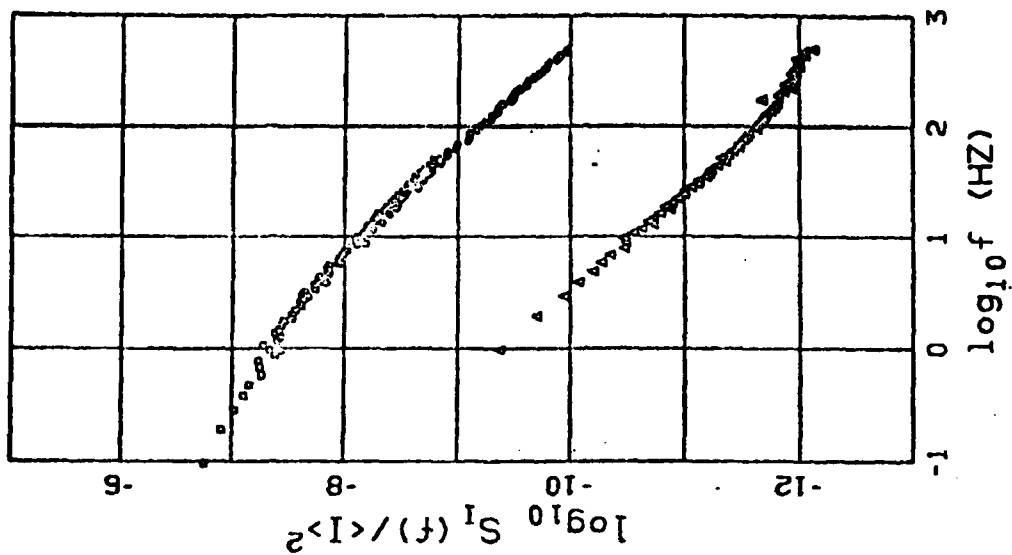


Fig.9

• FILE 20 12 38
 W69 DISLOCATED SI (S.M.) 300K V=1.35V (A7) (B7) 184 1E-7A/V
 SPEC(2.1)=184 MON. 113 AC .03-10K HZ G=500 3322LPNF G=1 500-HZ
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 • FILE 21 6 27 80 12 41
 W69 DISLOCATED SI (S.M.) 300K V=1.35V (A7) (B7) 184 1E-7A/V
 SPEC(2.1)=184 MON. 113 AC .03-10K HZ G=500 3322LPNF G=1 500-HZ
 <I> = 1.00E-07

 Δ FILE 22 6 27 80 13 5
 W69 DISLOCATED SI (S.M.) 300K V=-1.35V (A7) (B7) 184 1E-7A/V
 SPEC(2.1)=184 MON. 113 AC .03-10K HZ G=2E3 3322LPNF G=1 500-HZ
 FILE 23 SUBTRACTED AS BACKGROUND
 <I> = -1.00E-08

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