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(71) Applicant: **Hino, Taro**
37-18, Shinoharanishi-cho, Kohoku-ku
Yokohama-shi, Kanagawa(JP)

Applicant: **PIONEER ELECTRONIC CORPORATION**
No.41, Meguro 1-chome
Meguro-ku Tokyo(JP)

Applicant: **SHOWA ELECTRIC WIRE AND CABLE CO.,LTD**
1-1, Odasakae 2-chome, Kawasaki-ku
Kawasaki-shi, Kanagawa(JP)

(72) Inventor: **Hino, Taro**
37-18, Shinoharanishi-cho, Kohoku-ku
Yokohama-shi, Kanagawa(JP)

(74) Representative: **Brunner, Michael John et al**
GILL JENNINGS & EVERY 53-64 Chancery Lane
London WC2A 1HN(GB)

(54) Dielectric ultra-low resistivity heterofilm.

(57) A dielectric ultra-low resistivity heterofilm has a structure in which a LB (Langmuir Blodgett) heterofilm (4) composed of polarized dielectric film (4-a) of a Z-type or A-type and non-polarized dielectric film (4-b) of a Y-type are stacked on one another. The LB heterofilm (4) is sandwiched between conductive films (3,5) such as aluminium or gold films, so that the resistivity of the film in the direction of the film surface thereof becomes considerably lower than that of metal films.

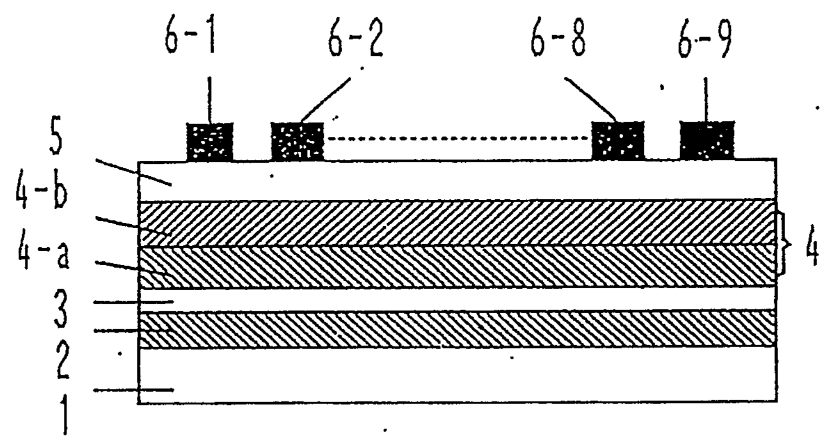

FIG. 2

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DIELECTRIC ULTRA-LOW RESISTIVITY HETEROFILM

The present invention relates to an ultra-low resistivity heterofilm which has a hetero-structure.

According to the present invention there is provided an ultra-low resistivity heterofilm having a hetero-structure composed of polarized and non-polarized Langmuir-Blodgett (LB) films stacked on one another and sandwiched between conductive films, the ultra-low resistivity heterofilm having a resistance value not higher than that of metal in the direction of the film surface thereof at a temperature not lower than room temperature.

The polarized film(s) may be stacked on the non-polarised film(s) or vice-versa and the hetero-structure sandwiched between conductive films so that the resistance of the film in the direction of the film surface becomes much lower than that of metal films.

Generally, a dielectric is also an insulator. A dielectric material according to the invention which shows a resistivity much lower than metals at a temperature no lower than room temperature has nor previously existed.

As produced according to the invention, if a two-dimensional potential well having a depth of several tens of Angstroms (Å) can be formed by polarised and non-polarised heterofilms and the potential well filled with an electron gas, generation of a two-dimensional low resistivity potential well can be expected.

It is necessary to form a two-dimensional electrically-conductive well having a depth of several tens Å filled with an electron gas and to produce a structure in which the two-dimensional conductive well is sandwiched between dielectric films.

The Z-type or A-type LB film can be used as a polarized film. It has large polarization substantially the same as saturation polarization of a ferroelectric even if no voltage is applied. In order to form a uniform potential well over a large area, it is necessary to smooth a surface on which a film is deposited. To this end, a SiO_2 film on a silicon wafer can be used. Also, Ta_2O_5 film, ZrO_2 film, glass substrate, and plastic substrate can be used.

In the drawings:-

Fig. 1 is a schematic view showing an embodiment of the dielectric ultralow resistivity heterofilm according to the present invention; Fig. 2 is a sectional view taken on line II-II of Fig. 1; Fig. 3 is a schematic view of the resistance measurement of the ultralow resistivity heterofilm according to the present invention; Fig. 4 is a view showing the voltage drop characteristics of the ultralow resistivity heterofilm according to the present invention; Fig. 5 is a view showing the voltage characteristics of a sample in which the ultralow resistivity heterofilm according to the present invention is not existing; Fig. 6 is a view showing the resistance characteristics of the ultralow resistivity heterofilm according to the present invention; Fig. 7 is a view showing a comparison of the resistivity between the ultralow resistivity heterofilm according to the present invention and metal; Fig. 8 is a view showing the temperature characteristics of the ultralow resistivity heterofilm according to the present invention; and Fig. 9 is a view showing the switching characteristics of the ultralow resistivity heterofilm according to the present invention.

Next, referring to the accompanying drawings, description will be made as to examples of the dielectric ultralow resistivity heterofilm according to the present invention.

[Example 1]

In this example, first, a thin evaporated film 3 of aluminum is formed on a silicon wafer 1 having, on its surface, an insulating SiO_2 film 2 (thickness: about 5000Å) as shown in Figs. 1 and 2. The thickness and width of the evaporated Al film 3 are several hundreds Å and 10 mm respectively, and the resistance value thereof measured across its opposite ends separated away by 30 mm from each other is about 600 Ω. Next, the evaporated Al film 3 is coated, by an LB method, with an LB heterofilm 4 which is composed of an arachidic acid LB film 4-a constituted by 4-6 single molecular layers and an LB film 4-b of 2-pentadecyl-7,7′,8,8′ tetracyanoquinodimethane (C_{15}•TCNQ) constituted by 4-6 single molecular layers. Further, the LB heterofilm 4 is coated with a thin evaporated film 5 of gold so that the dielectric ultralow resistivity heterofilm having a structure of [Al / LB heterofilm / Au] is formed with respect to the perpendicular to the LB heterofilm 4 according to the present invention. In this ultralow resistivity heterofilm, the evaporated Al film and Au film are short-circuited so that potentials of the Al and Au films are maintained in equipotentially. Finally, nine gold electrodes 6 are evaporated on the Au film 5, as the measurement terminals. Here, the arachidic acid LB film (non-polarized Y-type film) shows very small polarization, while the LB film of C_{15}•TCNQ (polarized Z-type film) shows large polarization.

Fig. 3 shows a circuit for measuring resistivity by using a four-point probe technique. A current is made to flow into/from a power source 8 through the outermost pair of electrodes 6-1 and 6-9 of the nine gold electrodes formed, through evaporation, on the dielectric ultra low resistivity heterofilm of the present invention, and a voltage drop v across another pair of electrodes 6-a and 6-b is measured by a voltmeter 10 to thereby obtain the resistance value of the dielectric ultralow resistivity heterofilm across the electrodes 6-a and 6-b. In this case, the internal resistance of the voltmeter 10 is sufficiently high, and therefore the voltage drop v across the electrodes 6-a and 6-b can be accurately measured. An ammeter 9 measures a current I flowing across the outermost electrodes 6-1 and 6-9. Since the insulating SiO_2 film 2 is so thick to be 5000Å as to have a very good insulating property, the current flowing across the electrodes 6-1 and 6-9 passes through the very thin evaporated Al film 3, the LB heterofilm 4, and the evaporated Au film 5. The resistance value R of the foregoing thin film across the electrodes 6-a and 6-b separated about 3.3 mm can be obtained through the following expression (1).

$R = v / I$ (1)

Fig. 4 shows voltage drops among nine electrodes with currents of 0.16, 0.55 and 1.1 A as parameters, measured with respect to samples (Si-5L) of the dielectric ultralow resistivity heterofilm using the LB heterofilm constituted by the arachidic acid LB film and the C_{15}•TCNQ LB film each constituted by five single molecular layers (5L) according to the present invention. As seen in the figure, across the electrodes 6-2 through 6-8, the voltage drop is generally small, and when the voltage drop across adjacent electrodes is converted into a resistance value by using the expression (1), the resistance value is about 10^{-2} to $10^{-3}\Omega$ while the value varies slightly depending on specific positions of the adjacent. electrodes. On the other hand, the voltage drop is large across the electrodes 6-1 and 6-2 and across the electrodes 6-8 and 6-9, which may be caused by the contact resistance between the electrode and the LB film.

Fig. 5 shows voltage drops measured with respect to samples (Si-0L) in which only the LB heterofilm is eliminated from the sample shown in Figs. 1 and 2. The voltage drop generated when each of three kinds of currents 1, that is, I=0.026A (0L-1), I=0.013A (0L-2), and 1=0.0026 (0L-3), was made to flow was proportional to a distance from an electrode 6-7 when the measurement was performed from the electrode 6-7. Across the outermost electrodes 6-1 and 6-7, the resistance is about 28 Ω and the resistance value across adjacent electrodes is 4.4 Ω. This resistance value is substantially equal to that of the evaporated film of Al/Au just underneath the electrodes.

Fig. 6 shows a comparison of the resistance value across adjacent electrode terminals obtained from the results of Figs. 4 and 5 between the Si-0L having no LB heterofilm and Si-3L, Si-4L, and Si-5L each having the LB heterofilm. The resistance value is reduced to 10^{-3} times only by interposition of the LB film having only a thickness of 189Å (Si-3L), 252Å (Si-4L), or 315Å (Si-5L) between the Al and Au evaporated films. This fact shows that the current passes in the inside of the surface of the very thin LB heterofilm.

Since the thickness of the LB heterofilm is known, the resistivity of the LB heterofilm can be obtained from the thickness, the width of the electrode, and the interval between the electrodes. Fig. 7 shows the values of the resistivity plotted with respect to the current flowing in the LB film. The values within a range of 10^{-8} to 10^{-9} Ωcm were obtained, and each of the values was $10^{-3} \sim 10^{-4}$ times the illustrated value of metal (M) (about 10^{-5} Ωcm).

From the experiments described above, it has been found that the dielectric heterofilm having the LB film according to the present invention has a resistance value much lower than that of metal.

[Example 2]

The resistivity of the dielectric heterofilm constituted by the LB films according to the present invention hardly changes in a range of from the room temperature to about 80 °C. Fig. 8 shows an example as to the sample of Si-4L. The temperature of the silicon substrate was measured a thermocouple. The resistivity is about 8.6 x 10^{-8} Ωcm (4L-1). The temperature rise is caused by heat generated from the sample in a way of making an applied voltage high. Also, current values at various temperatures are shown (4L-2). From this experiment, it can clearly be seen that no current passes the silicon wafer of the substrate. This is because the resistivity of silicon rapidly decreases with temperature and therefore if the current passes in the silicon wafer, the resistivity cannot be kept constant as illustrated in the drawing but it must decrease with the temperature.

[Example 3]

A current of about 1A is flowing in the LB ultralow resistivity heterofilm according to the present invention as shown in Fig. 8, and if converted, the current value corresponds to a current density having a large value of 400,000 A/cm². Further, at this time, the temperature rises to 80 °C as shown in Fig. 8. This

LB heterofilm, however, was never damaged. Moreover, even if the applied voltage was further increased in order to increase the current, a switching phenomenon as shown in Fig. 9 was caused to thereby rapidly decrease the current, and the current did not increase more.

Fig. 9 shows an example of the switching phenomenon, and shows a current I (5L-8) and a voltage drop (5L-9) between the adjacent electrode terminals 6-8 and 6-9, with respect to an applied voltage V. As apparent form the drawing, the current rapidly falls from 1.3A to 3 x 10^{-4}A, and at the same time the voltage drop rises to 15.5V. The voltage drop is substantially equal to a voltage applied from the power source to the sample at this point of time. If the applied voltage is lowered, the current rapidly increases again (at the point of the applied voltage of 2V) so as to return to the original value. At the same time, also the resistance value decreases so as to return to the original one. That is, as the applied voltage increases/decreases, the current changes through a course of 0-a-b-c-d-a-0, and, on the other hand, the voltage drop changes through a course of 0-e-f-b-g-h-a-e-0. Such a switching phenomenon was generated even when the experiment was repeated again and again. Further, the same phenomenon was observed also with respect to the sample of Si-4L.

Various applications in the future of the dielectric ultralow resistivity heterofilm using the LB films according to the present invention can be considered. Finally, the characteristics of the heterofilm according to the present invention are summarized in Table 1. All the characteristics are values obtained at a temperature not lower than room temperature.

Table 1

material	Si-3L	Si-4L	Si-5L
Thickness of LB heretofilm [Å]	189	252	315
Resistance between two adjacent electrodes (width 10mm, distance 3.3mm) [Ω]	0.024	0.012	0.0037
		0.0004	0.001
Resistivity of LB heterfilm [Ωcm]	1.5×10^{-7}	8.5×10^{-8}	3.9×10^{-8}
		3.4×10^{-9}	1.0×10^{-8}
Switching current [A]		0.91	1.3
Maximum current dentisty [A/cm^3]	2.4×10^4	3.6×10^5	4.1×10^5

Claims

1. An ultra-low resistivity heterofilm having a hetero-structure composed of polarized (4-a) and non-polarized (4-b) dielectric films stacked on one another and sandwiched between conductive films (3,5), the ultra-low resistivity heterofilm having a resistance value not higher than that of metal in the direction of the film surface thereof at a temperature not lower than room temperature.

2. A heterofilm as claimed in claim 1, wherein the conductive films (3,5) are short-circuited to maintain their potentials thereof in equipotential.

3. A heterofilm as claimed in claim 1 or claim 2, wherein at least the polarized dielectric film (4-a) is a Langmuir Blodgett's film of Z-type or A-type.

4. A heterofilm as claimed in any of claims 1 to 3, wherein at least the non-polarized dielectric film (4-b) is a Langmuir Blodgett's film of Y-type.

5. A heterofilm as claimed in any of claims 1 to 4, wherein a potential well is generated in the inside of the heterofilm and the potential well is filled with an electron gas so as to form a two dimensional conductive plane.

6. A heterofilm as claimed in any of claims 1 to 5, the ultra-low resistivity heterofilm being formed on an insulating film (2).

7. A heterofilm as claimed in claim 5, the insulating film is at least one of SiO_2 film, Ta_2O_5 film, ZrO_2 film, glass substrate, and plastics substrate.

8. A heterofilm comprising:

a silicon wafer (1) on which an insulating film (2) is formed;
a thin evaporated Al film (3) formed on the insulating film;
a thin heterofilm (4), formed on the thin evaporated Al film, composed of polarized (4-a) and non-polarized (4-b) dielectric films stacked on one another; and
a thin evaporated Au film (5) being formed on the heterofilm.

9. A heterofilm as claimed in claim 8, wherein the Al film and Au film are short-circuited to maintain their potentials thereof in equipotential.

10. A method of manufacturing an ultra-low resistivity heterofilm comprising the steps of:
forming an insulating film (2) on a silicon wafer (1);
forming a thin evaporated Al film (3) on the insulating film;
forming a thin heterofilm (4) on the thin evaporated Al film, the thin heterofilm being composed of polarized (4-a) and non-polarized (4-b) dielectric films stacked on one another; and
forming a thin evaporated Au film (5) on the heterofilm.

11. A method as claimed in claim 10, further comprising the step of:
shorting the Al film (3) and Au (5) film to maintain the potentials thereof in equipotential.

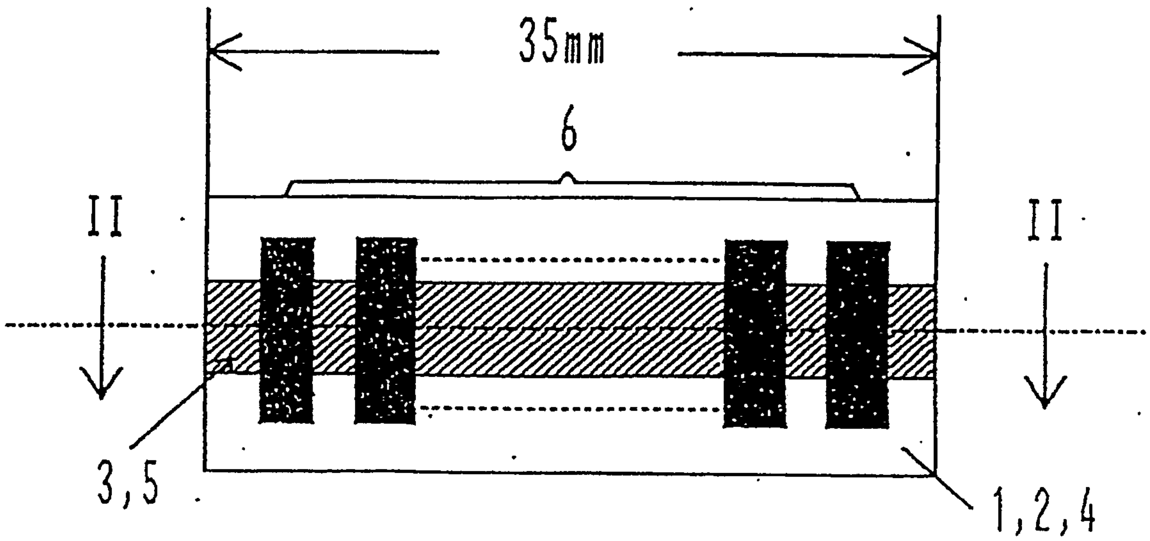

FIG. 1

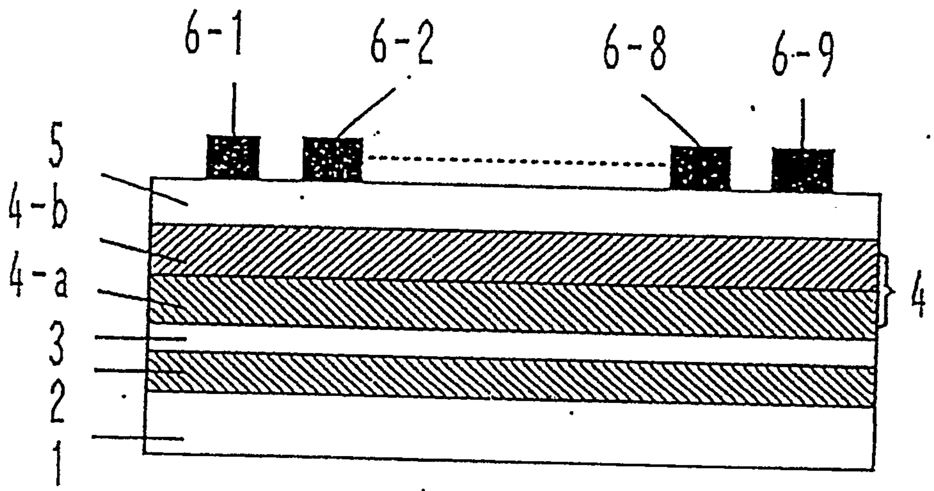

FIG. 2

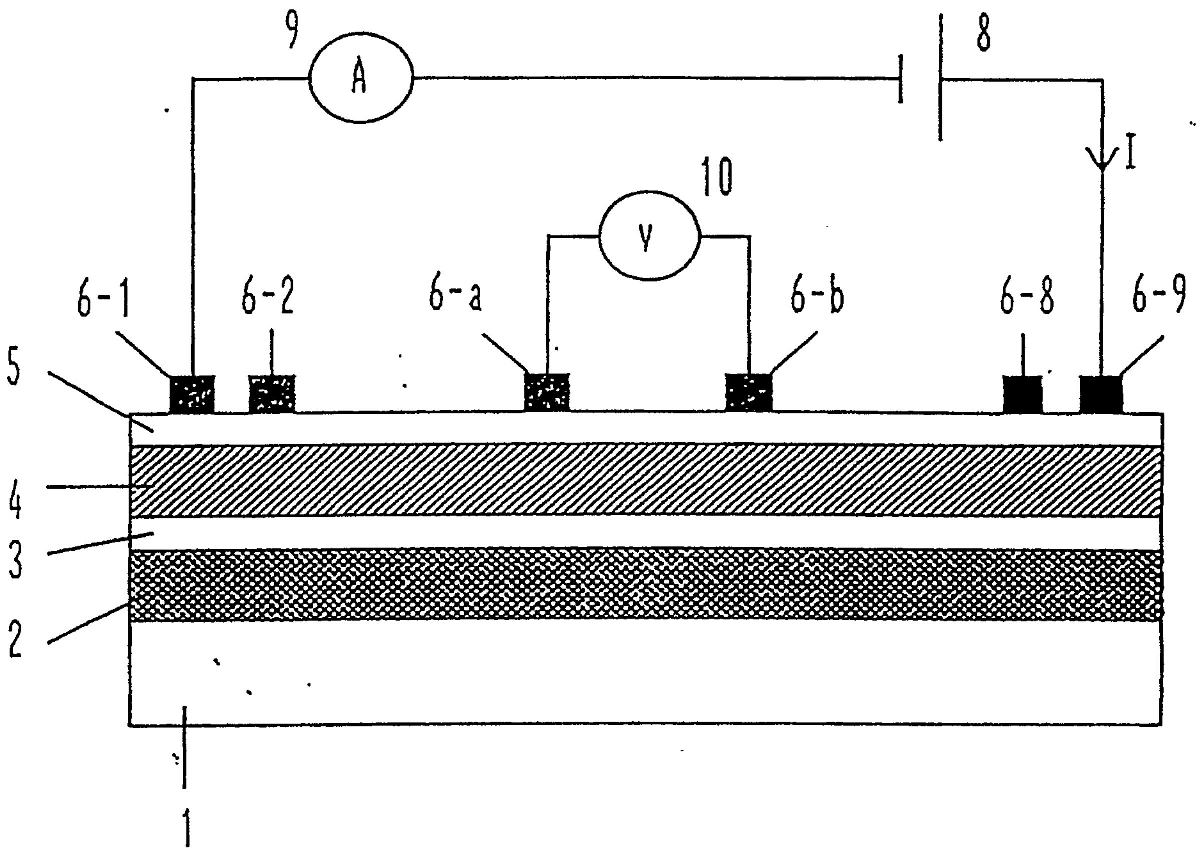

FIG. 3

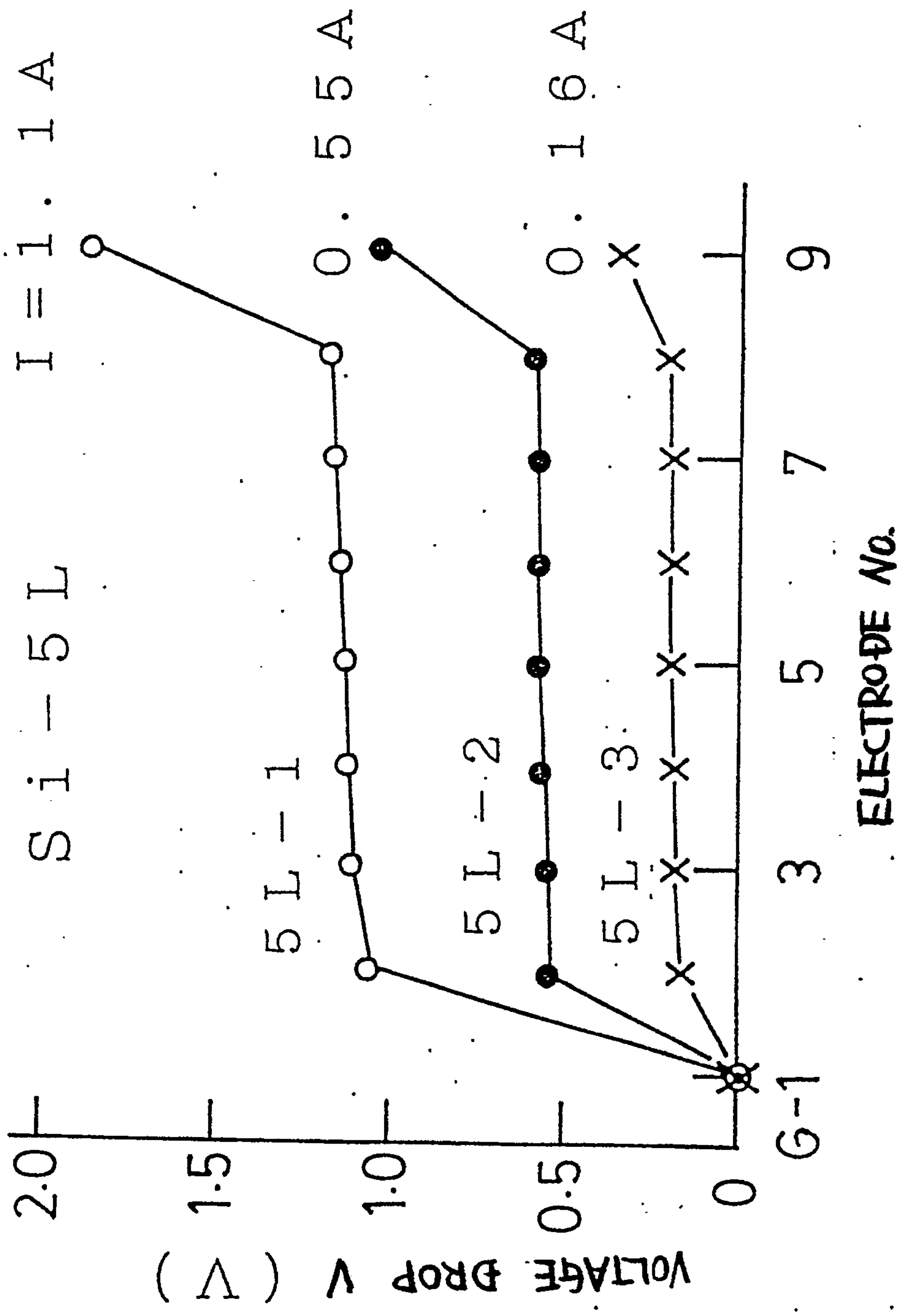
Si - 5L
I = 1.1A
5L - 1
0.55A
5L - 2
0.16A
5L - 3
VOLTAGE DROP V (V)
2.0
1.5
1.0
0.5
0
G-1
3
5
7
9
ELECTRODE No.

FIG. 4

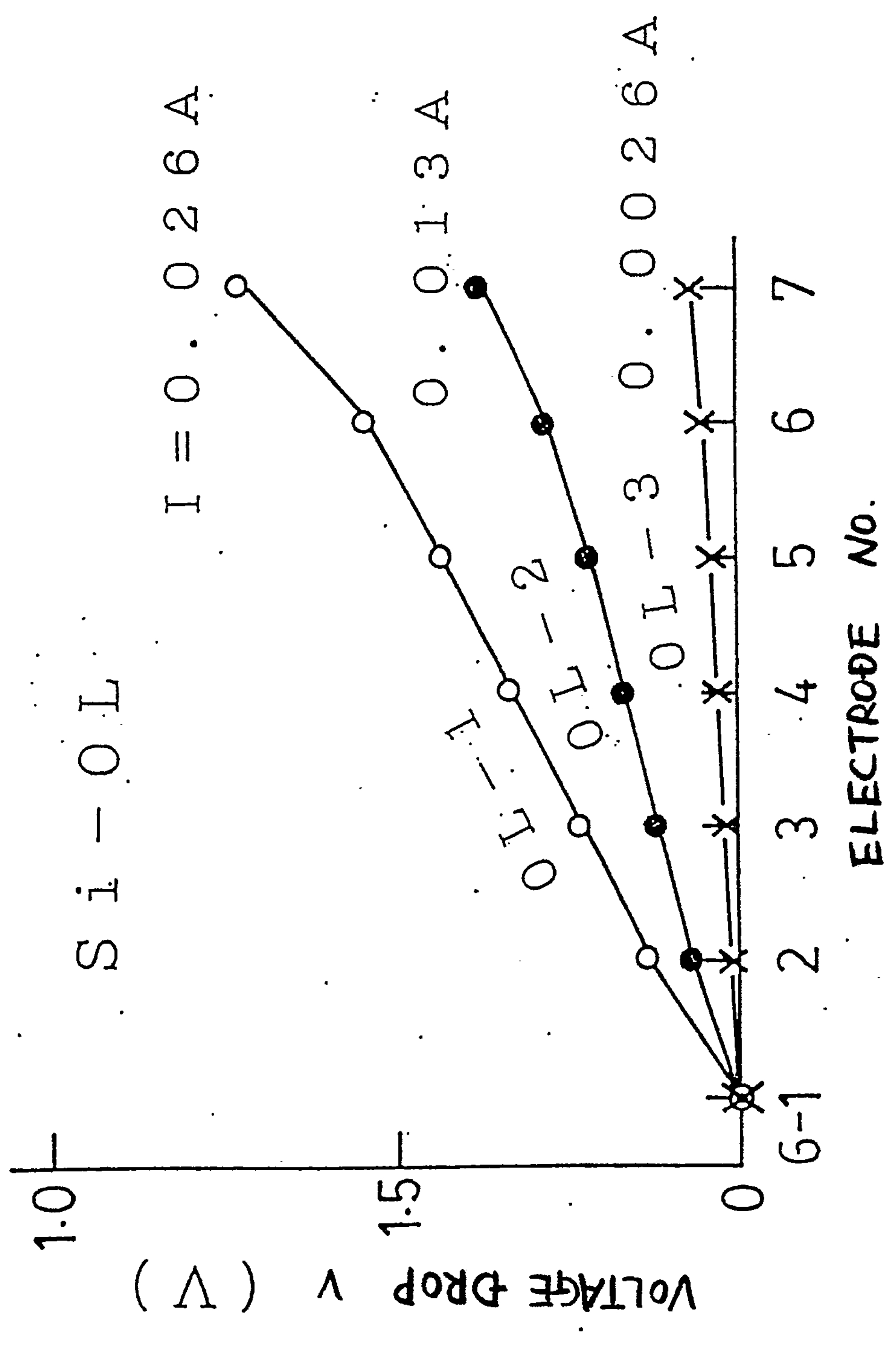
Si - OL
I = 0.026 A
0.013 A
0.0026 A
OL-1
OL-2
OL-3
VOLTAGE DROP v (V)
1.0
1.5
0
ELECTRODE No.
G-1
2
3
4
5
6
7

FIG. 5

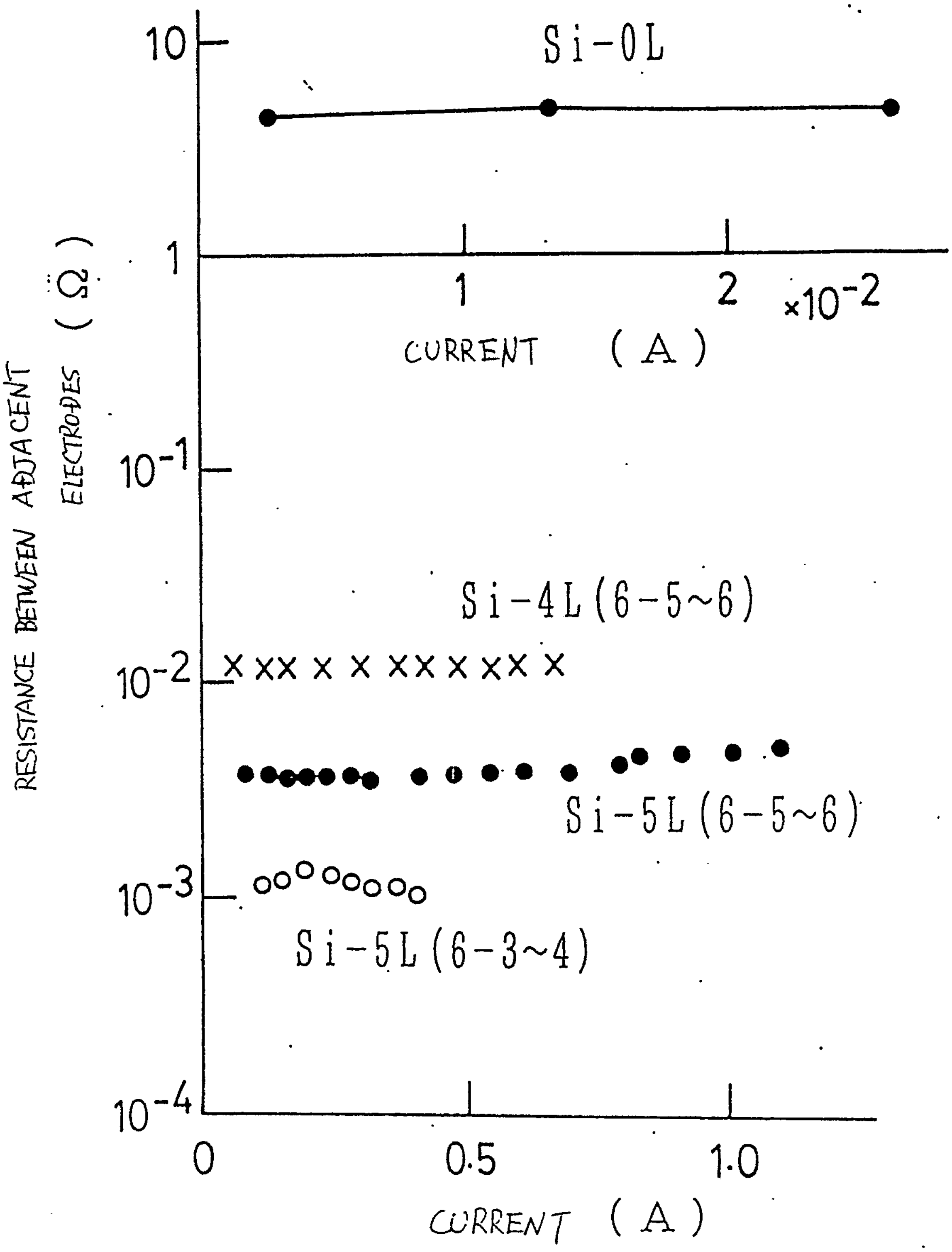
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
RESISTANCE BETWEEN ADJACENT ELECTRODES (Ω)
Si-0L
1
2
×10^{-2}
CURRENT (A)
Si-4L(6-5~6)
Si-5L(6-5~6)
Si-5L(6-3~4)
0
0.5
1.0
CURRENT (A)

FIG. 6

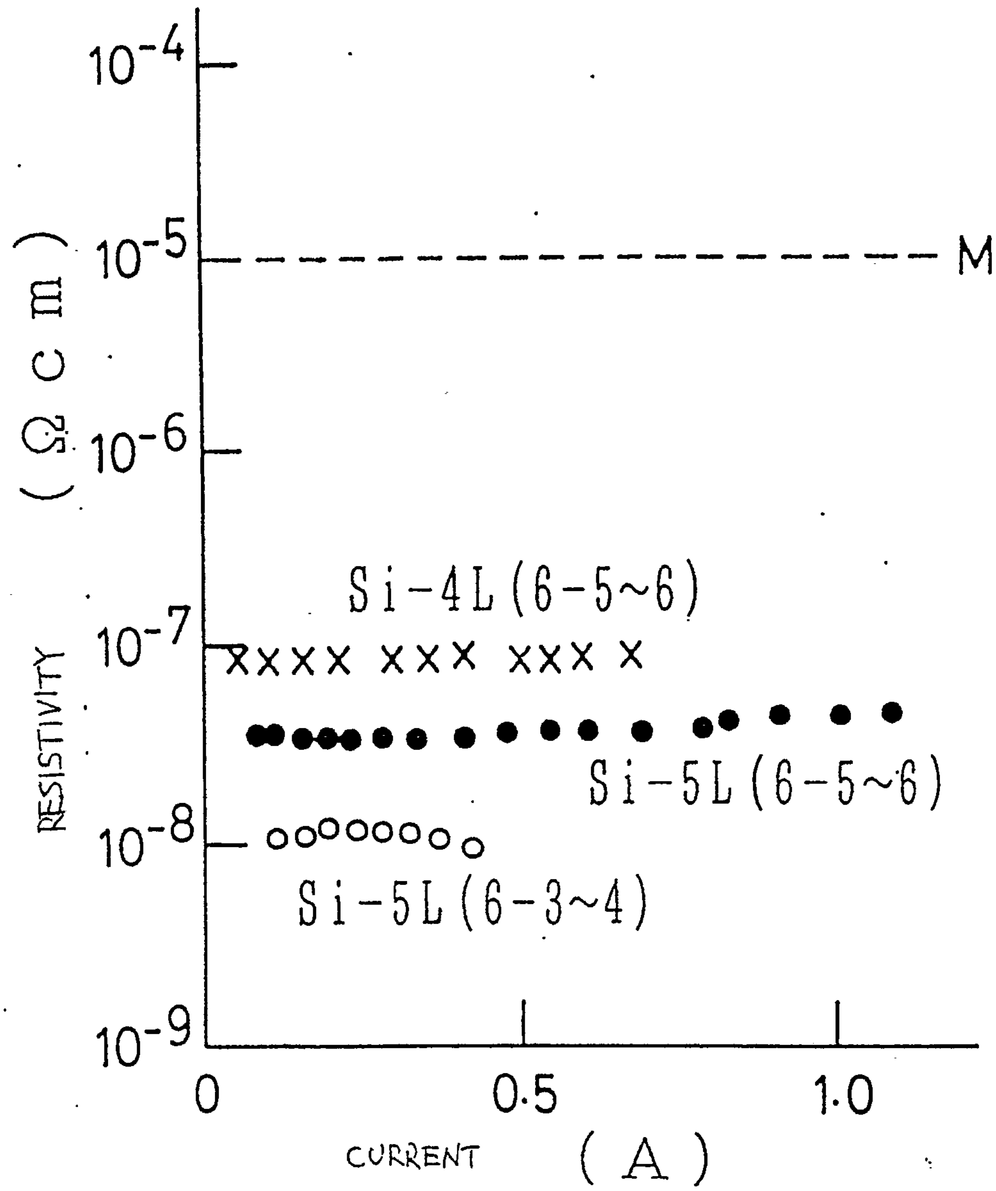
RESISTIVITY (Ω cm)
10-4
10-5
10-6
10-7
10-8
10-9
M
Si-4L(6-5~6)
Si-5L(6-5~6)
Si-5L(6-3~4)
0
0.5
1.0
CURRENT (A)

FIG. 7

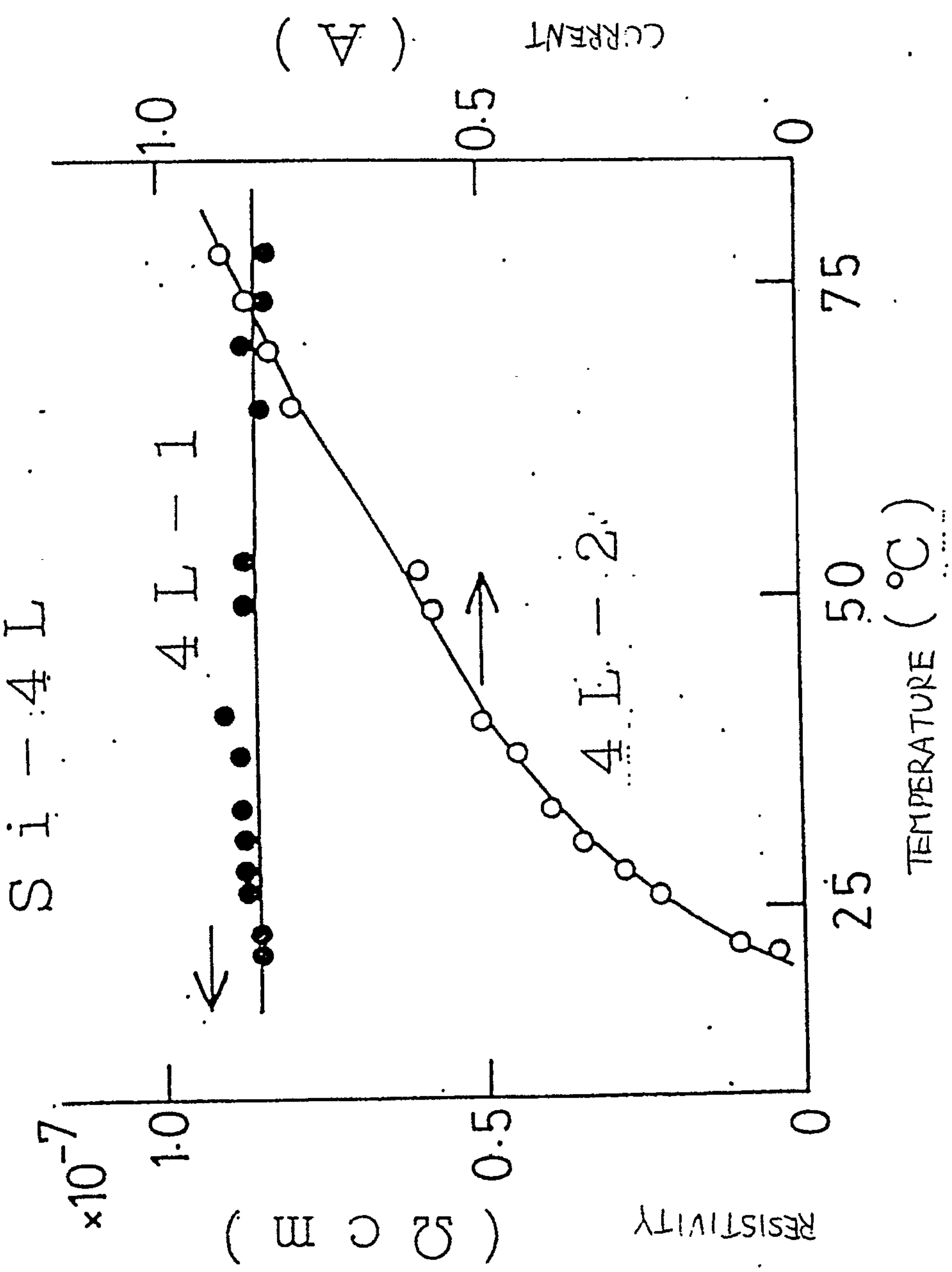
Si - 4L
4L - 1
4L - 2
CURRENT
(A)
1.0
0.5
0
RESISTIVITY
(Ω cm)
×10^-7
1.0
0.5
0
TEMPERATURE (°C)
25
50
75

FIG. 8

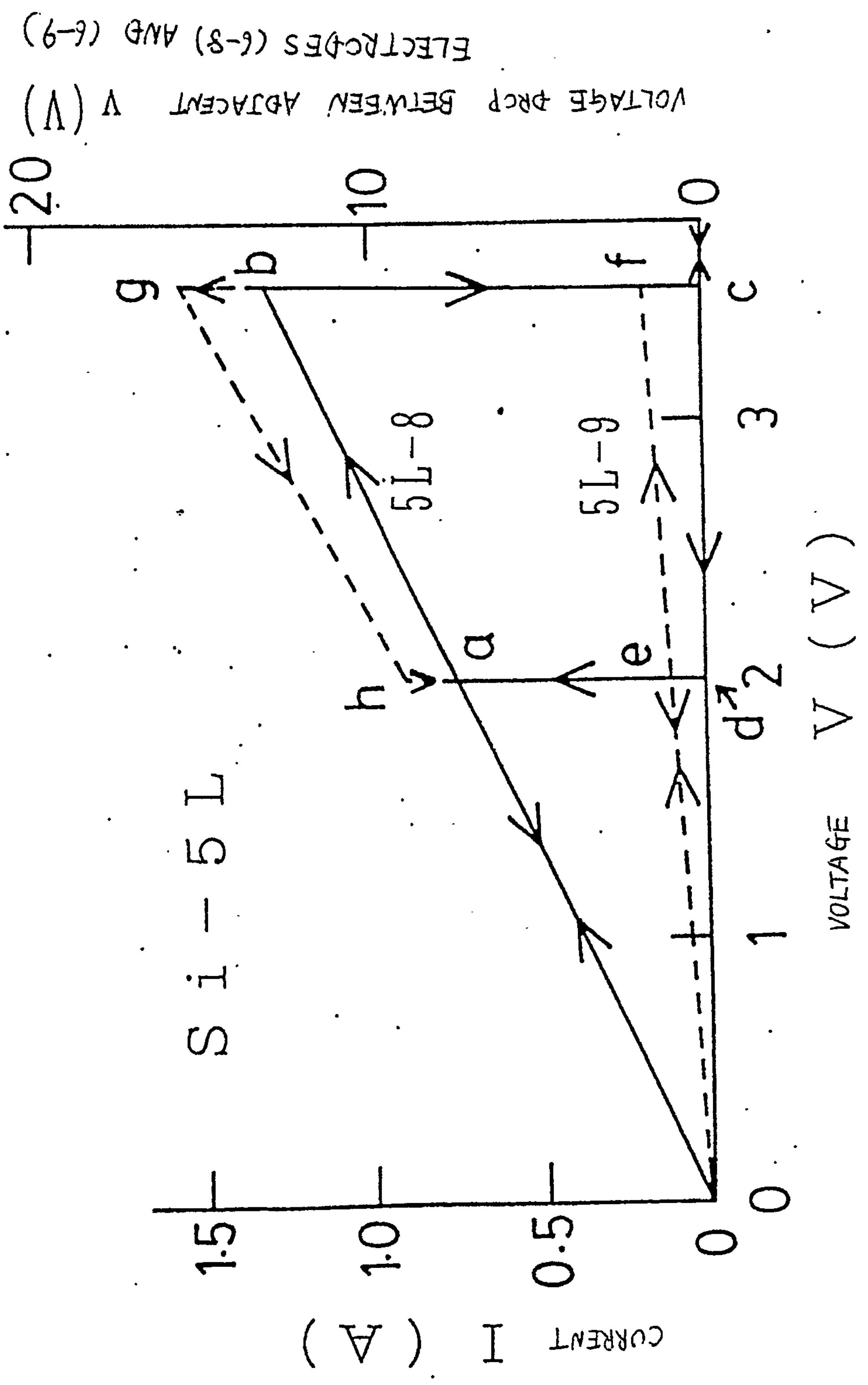
Si - 5L
VOLTAGE DROP BETWEEN ADJACENT V (V)
ELECTRODES (6-8) AND (6-9)
CURRENT I (A)
VOLTAGE V (V)
5L-8
5L-9
a
b
c
d
e
f
g
h
0
0.5
1.0
1.5
1
2
3
10
20

FIG. 9