COMMISSION OF THE EUROPEAN COMMUNITIES

Energy

A desk calculator controlled measuring system for the determination of the differential capacitance of semiconductor-liquid junctions

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A desk calculator controlled measuring system for the determination of the differential capacitance of semiconductor-liquid junctions

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1. Introduction

An important parameter of a semiconductor-electrolyte junction is its flat band potential U_{fb}. This is the semiconductor electrode potential mesured relative to a reference electrode at which the internal electrical field in the space charge layer disappears and where correspondingly the energy bands become flat (see e.g. [1]). The knowledge of U_{fb} or of its corresponding semiconductor Fermi energy level E_{fb}^{F} *) allows the determination of the energetic position of the band edges at the interface which is known to be independent or only slightly dependent of the electrode polarization.

U_{fb} is of great importance because the kinetics of charge transfer process at semiconductor electrodes depends essentially on the relative energy position of the redox couple and the band edges.

In semiconductor-liquid junction solar cells U_{fb} is of particular importance for efficiency and stability considerations (see e.g. [2]). The question of whether or not photoelectrochemical water decomposition is possible depends essentially on how far U_{fb} is more negative than the reversible hydrogen electrode potential.

So far only an approximate method for the calculation of U_{fb} of metal oxide semiconductors in contact with aqueous electrolytes has been found [3]. To obtain reliable values an experimental determination is indispensable. The most common method is based on the measurement of the differential space charge capacity dC/dU [4-6]. Usually dC/dU is measured by comparing the space charge capacitance of the semiconductor electrode with a known capacity in a bridge circuit. However this is a rather time consuming method and allows only

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*) The electrochemical potential U is related to the energy E which is used in semiconductor physics by

$$U = -e\,(E + 4.5)$$

U is measured versus the normal hydrogen electrode (NHE).

the measurement in steady state conditions. Faster methods based on a potential pulse method [8] and a network analyzer [9] have been developed recently. In this work a new fast measuring system is presented which is controlled by a process calculator and which is based on the measurement of the phase shift and amplitude of a small ac-voltage.

Principles

The determination of the flat band potential V_{fb} is based on the Mott-Schottky relation for the space charge capacity C and the electrode potential U (see e.g. [10]).

$$1/C^2 = (1/\varepsilon \varepsilon_o \cdot N_d e) \cdot (U-U_{fb} - kT/e) \qquad (1)$$

ε and ε_o are the dielectric constants of the semiconductor and the vacuum respectively. N_d is the donor density and the other constants have their usual meaning.

Extrapolation of measured values of $1/C^2$ to zero gives $U(1/C^2 \rightarrow 0) = U_{fb}$. Additionally N_d can be determined from the slope $d(1/C^2)/dU$. Equ. (1) is completely valid only for ideally polarizable electrodes. This condition is for semiconductor electrodes usually satisfied in the dark and by using indifferent electrolyte solutions under anodic for n-type and cathodic bias for p-type materials.

The determination of C requires the knowledge of the total equivalent electrical circuit of the electro-chemical cell which is composed of the semiconductor electrode, the electrolyte and the counter electrode. It contains capacitors due to the double layers of the semiconductor and the counterelectrode, due to surface states and the space charge layer and it contains resistances due to the bulk electrolyte and the bulk semiconductor. However this complicated and often incompletely known circuit can be approximated at frequencies which are large in comparison to reciprocal relaxation times of surface states ($> 10^4 s^{-1}$) by the simple circuit consisting only of the space charge capacity C and one resistor r in serie [5].

Therefore at frequencies in the order of 10^4Hz and higher conventional capacity measurement techniques can be used for the investigation of the space charge capacity of a semiconductor electrode in an electrochemical cell.

Measurement method

The space charge capacity C is determined by a measurement of the phase shift α and the amplitudes U_A and U_B of an ac-voltage which is superimposed on a dc voltage as shown in fig. 1a. From the vector diagram of Fig. 1b the following relation can be derived:

$$\frac{1}{E\,G} = \frac{R\cos\alpha}{\frac{\sin(\alpha+\beta)}{2} - \sin\beta} \qquad (2)$$

$$\beta = \operatorname{arctg}\left[\operatorname{ctg}\alpha - L/\sin\alpha\right] \qquad (3)$$

$$\tau = \frac{\tan\beta}{EG} \qquad (4)$$

E is the ac-frequency and $L = |Z_{cell}| \,/\, |Z_{tot}|$. This ratio is obtained from the ratio of the ac amplitudes U_B and U_A.

In fig. 2 the measurement system is shown which includes as central part the desk calculator (HP 9825 A) by which most of the peripheral instruments are controlled, the calculation of the data is performed and tables and plots by the printer (HP 9871) are generated. The ac- and dc- voltages are applied through the external inputs of the potentiostat (PAR 373). The dc-voltage is obtained from a digital to analog converting power supply (HP 59303 A). The ac-amplitudes U_A and U_B are measured at the points A and B respectively in the ac-voltage mode of the digital multimeter (HP 3455 A) and the phase shift is measured by a universal counter (HP 5328). To trigger the counter for start and stop the zero passage of the sine waves at A and B respectively are monitored. In order to avoid reading errors also the variable external resistance R and the ac-frequency E are mea-

sured by the multimeter in the R-mode and the universal counter respectively. For a rapid connection of the measurement instruments to their respective circuits a relay actuator (HP 59306 A) also is used. A schematic diagram of the relay actuator and the instruments which are switched by it is shown in fig. 3 which contains also a table of the relay state during the specific instrument operations. The symbol A stands for a connection of the terminal C with A whereas B is used for the opposite state. The step numbers correspond to the order in which they are programmed to be passed.
Step 1 and 2 are only once passed whereas steps 3 to 5 are repeated for each electrode potential setting.

Program description

The calculator program which controls the measurement sequence, proceeds the data and generates tables and plots, is written in the HPL-language. The address codes and the meaning of the used program code sets are listed in Table 1. The program itself is listed in annex 1; it consists essentially of 5 parts:

1) line 0 to 42: This part serves for the input of data and its tabulation by the printer. The input data

- "date", "electrode", electrolyte", and "remarks" are optional and are to characterize the electrode under measurement
- dielectric constant, X [6], and electrode surface, S will be used for the calculation of the space charge capacity per unit surface area and of the charge carrier density according to (1)
- initial and final potential V [2] and V [3] define the boundaries of the electrode potential range, whereas N is the number of intervals in which this range is subdivided and measurements are performed. V [1] is the electrode potential which is applied after the measurement sequence has been performed. X [1] is the time between two measuring points

- the ac-frequency, E, and the external resistance, R, are measured by program control
- K [6] is a control parameter; if the value 2 is entered, the measurement sequence which starts from the initial potential V [2] to the final potential V [3] is complemented by a second serie from V [3] to V [2]. At V [3] only one measurement will be performed.

2) line 43 to 62: By this part the particular operations for the program code setting, potential setting, measuring of phase shift and amplitude are controlled.

3) line 63 to 107: The measuring data determined in part 2) are processed according to the relations (2), (3) and (4) in order to obtain the capacitance and resistance values. Finally a last square fit is performed to obtain the values for the flat band potential and the charge carrier density. It is supposed that the $1/C^2$-U dependence is linear. The program part 2) to 3) can be repeated up to 5 times according as x[2] is set equal to 1 or not. The generation of a table is optional and is controlled by the parameter x[4] ("1" for the affirmative case).

4) line 107 to 166: This part controls the generation of the Mott-Schottky plot. A normalization of the $1/C^2$-scale is performed such that the maximum $1/C^2$-value is printed at least at 50% of the length of the y-axis. Also the potential scale is normalized; the boundaries are given by the integer values of the initial and final potential. If more than one measuring series have been performed the plot symbols are different for each serie.

5) line 167 to 246: Here the subroutines are stored, which are standard subroutines for the plotting program with the exception of the subroutine "time".

Results

The described system was tested by measurements on CdS and Fe_2O_3 semiconductor electrodes. Table 2 shows the results as obtained with a single crystalline CdS/1m Na_2SO_4 electrode in the tabulated form as generated by the calculator. Fig. 4 is the corresponding Mott-Schottky plot as generated by the calculator. As time period x [1] of two consecutive measuring points 1 s has been chosen. The minimum time is determined essentially by the ac-voltage measurement and is about 0.2 s. The obtained $1/C^2$ versus U plot is linear in the voltage range $-0.5 < U < 0.2$. By the least square fit method a flat band potential $U_{fb} = -0.76V(SCE)$ and a charge carrier density of $N_o = 2.4 \cdot 10^{16}$ cm-3 is obtained. Both values are in good agreement with earlier measurement [12] and with the specifications of the crystal respectively.

The measurements on Fe_2O_3 have been performed in the measuring mode corresponding to a K [6] value setting of 2 which effects a measurement sequence from the initial to the final and back to the initial potential. The electrode has been prepared by reactive sputtering of Fe_2O_3 powder in an O_2 atmosphere of 10^{-2} Torr on an iron substrate. The electrolyte was an aqueous solution 1 m NaOH Fig. 5 shows the calculator generated Mott-Schottky plot. It is interesting to note the small difference between the measuring points obtained during the anodic and cathodic "sweep". These differences are probably caused by small changes of the surface composition causing slight changes also of capacity values. These differences are the more pronounced the faster the sweep rate is analogously to voltametric measurements. For potential values $U < -0.5$ V (SCE) Fe_3O_4 is known to be the stable phase [11]. The deviation from the linearity are large for $U > -0.5$ V (SCE); however, from the measured values in the lower electrode potential part a linear extrapolation is possible by which for the flat band potential a value of $U_{fb} = -0.82$ V (SCE) is obtained in comparison to - 0.73 V (SCE) for sintered polycristalline Fe_2O_3-electrodes [7].

Conclusions

A new system for capacity measurements which is controlled by a process calculator has been assembled. The system allows a rapid generation of a Mott-Schottky plot. It can be used in an analogous mode as in voltametry measurements to monitor changes of the surface state between an anodic and cathodic sweep.

Table 1

Instrument	Address	program code	operation
multimeter HP 3455A	722	R2F4AOHOM3T3	resistance meas.
		R3F2AOHOM3T3	fast ac-voltage m.
universal counter HP 5328 A	725	PF4G6T	frequency meas.
		PF : G4R	phase shift meas.
relay actuator 59303 A	716	"Aa" or "Ba"(a=relay N)	relay state
digital analog converter HP 59303 A	719	"EO"	range setting
	718	V (V = potential)	potential setting
Printer HP 9871	701	-	-

Table II

```
SPACE CHARGE CAPACITY EVALUATION FROM HP 9825 CONTROLLED PHASE SHIFT MEASUREMENTS
=================================================================================

                                                                           25/09/1978
                                                                  CdS, single crystal
                                                                         .5 m Na2SO4
                                                                                 test
                                            electrode surface [cm2] S =          1.50
                                             dielectric constant X[6] =         10.00
                                                      frequency [kHz] E =       48.83
                                          external resistance [Ohm] R =         82.10
                                             initial potential [V] V[2] =        0.10
                                               final potential [V] V[3] =       -0.60
                                             standby potential [V] V[1] =       -0.50
                                                   number of intervals N =      28.00
                         time between two measuring points [s], X[1] =          1.00


measurement No  1

Ux[V]      delay[ns]     delay[degr]     VO[V]     Vx[V]     Vx/VO     r[Ohm]      C[F/cm2]    1/c2[cm4/F2]

 0.100      2212.378        38.890       0.150     0.070     0.468     24.312     4.417E-08      5.126E 14
 0.075      2222.331        39.065       0.153     0.071     0.462     24.044     4.508E-08      4.920E 14
 0.050      2234.649        39.282       0.156     0.071     0.456     23.716     4.608E-08      4.710E 14
 0.025      2239.401        39.365       0.158     0.071     0.450     23.562     4.695E-08      4.537E 14
 0.000      2243.393        39.435       0.161     0.071     0.444     23.408     4.799E-08      4.342E 14
-0.025      2251.174        39.572       0.163     0.072     0.439     23.181     4.882E-08      4.196E 14
-0.050      2255.571        39.649       0.165     0.072     0.435     23.030     4.958E-08      4.069E 14
-0.075      2256.945        39.674       0.168     0.072     0.428     22.906     5.071E-08      3.888E 14
-0.100      2260.264        39.732       0.171     0.072     0.425     22.775     5.141E-08      3.784E 14
-0.125      2262.140        39.765       0.173     0.072     0.418     22.607     5.277E-08      3.592E 14
-0.150      2265.132        39.817       0.176     0.073     0.413     22.457     5.366E-08      3.473E 14
-0.175      2263.038        39.781       0.179     0.073     0.408     22.392     5.465E-08      3.348E 14
-0.200      2263.137        39.792       0.182     0.073     0.403     22.258     5.583E-08      3.208E 14
-0.225      2261.099        39.747       0.185     0.074     0.397     22.154     5.705E-08      3.072E 14
-0.250      2265.689        39.827       0.188     0.074     0.392     21.947     5.807E-08      2.966E 14
-0.275      2261.253        39.749       0.193     0.074     0.385     21.827     5.969E-08      2.807E 14
-0.300      2255.926        39.656       0.196     0.074     0.380     21.749     6.105E-08      2.683E 14
-0.325      2248.641        39.528       0.201     0.075     0.371     21.585     6.325E-08      2.500E 14
-0.350      2242.433        39.418       0.205     0.075     0.366     21.472     6.486E-08      2.377E 14
-0.375      2234.724        39.283       0.211     0.075     0.357     21.248     6.743E-08      2.199E 14
-0.400      2224.765        39.108       0.215     0.076     0.353     21.248     6.859E-08      2.125E 14
-0.425      2208.553        38.823       0.222     0.076     0.343     21.048     7.185E-08      1.937E 14
-0.450      2194.148        38.570       0.227     0.077     0.337     20.961     7.404E-08      1.824E 14
-0.475      2169.868        38.143       0.236     0.077     0.327     20.794     7.782E-08      1.651E 14
-0.500      2150.153        37.796       0.242     0.077     0.319     20.672     8.075E-08      1.534E 14
-0.525      2113.776        37.157       0.253     0.078     0.308     20.451     8.609E-08      1.349E 14
-0.550      2081.592        36.591       0.261     0.078     0.300     20.376     8.994E-08      1.236E 14
-0.575      2024.786        35.593       0.274     0.079     0.287     20.120     9.769E-08      1.048E 14
-0.600      1978.769        34.784       0.284     0.078     0.276     19.858     1.046E-07      9.148E 13


                                             charge carrier density [cm-3]  =        2.436E 16
                                               flat band potential Ufb [V]  =            -0.76
```

References

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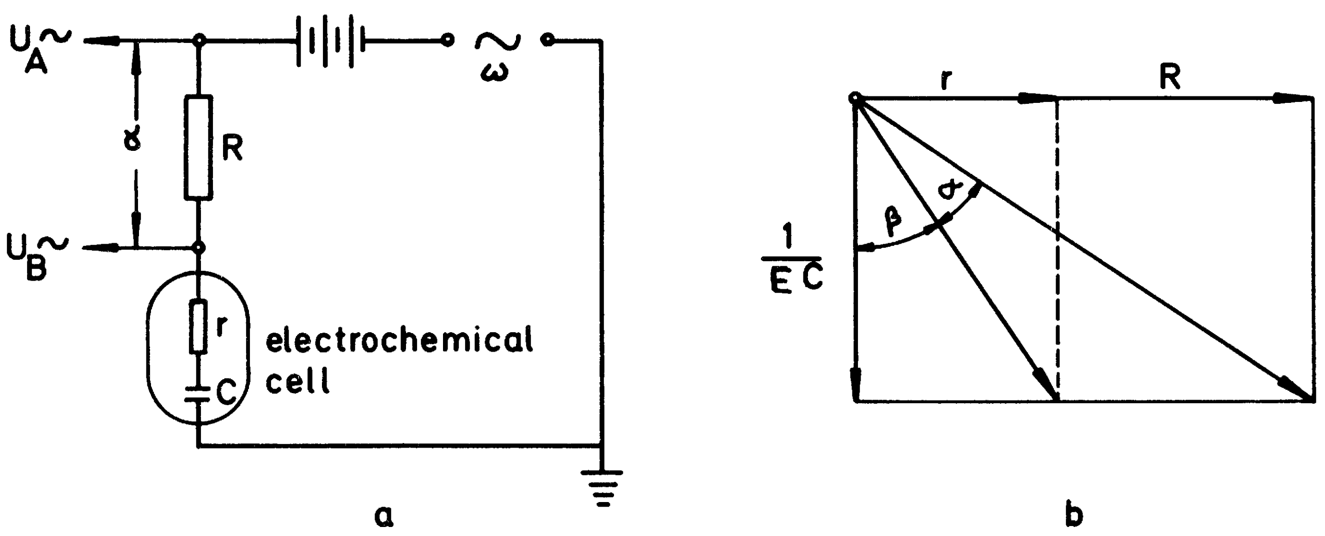


Fig. 1 : a) schematic diagram of the cell circuit and
b) of its corresponding vector representation

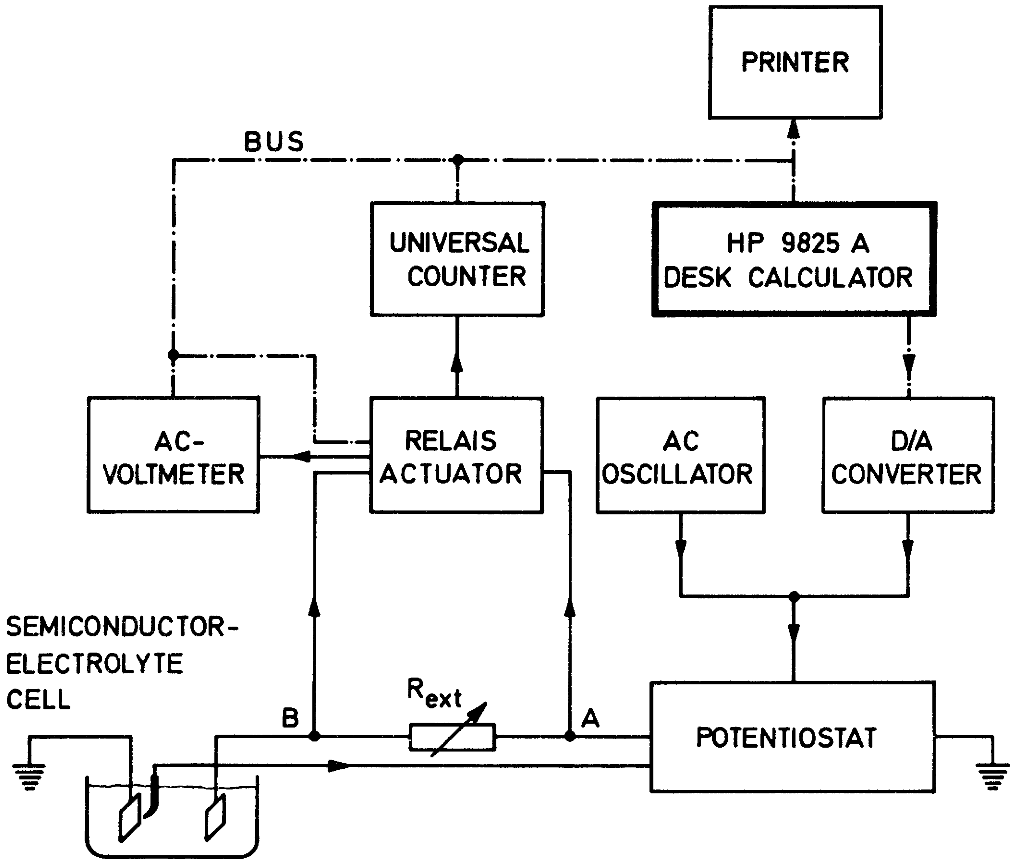
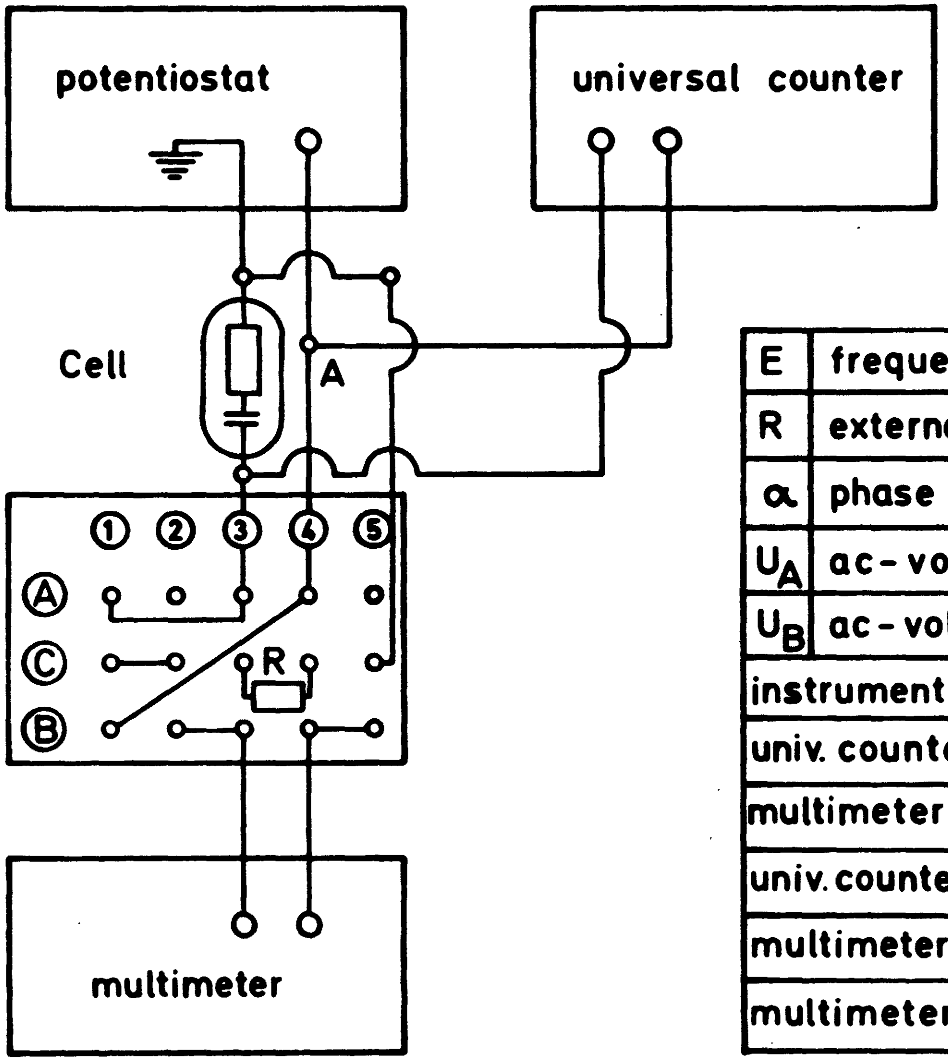


Fig. 2 : block diagram of the measurement system



E	frequency
R	external resistance
α	phase shift
U_A	ac-voltage at A
U_B	ac-voltage at B

instrument	Step N	meas.	relay state				
univ. counter	1	E	A	A	A	A	A
multimeter	2	R	A	A	B	B	A
univ. counter	3	α	A	A	A	A	A
multimeter	4	U_A	B	B	A	A	B
multimeter	5	U_B	A	B	A	A	B

Fig. 3 : schematic diagram of the relay actuator and its peripheral instruments. The inserted table gives the relay state corresponding to the operation which is performed during the different steps.

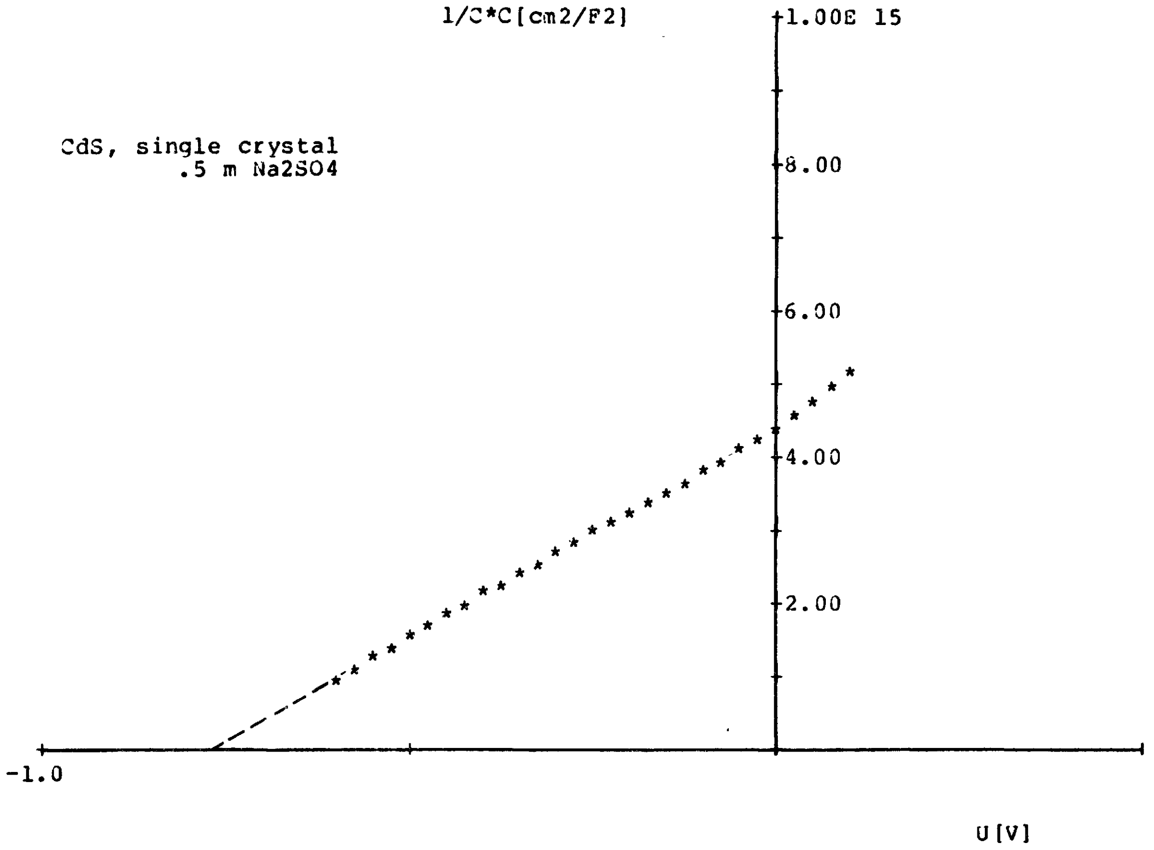


Fig. 4 : Mott-Schottky plot of a CdS/1m Na_2SO_4 electrode as printed according to the program

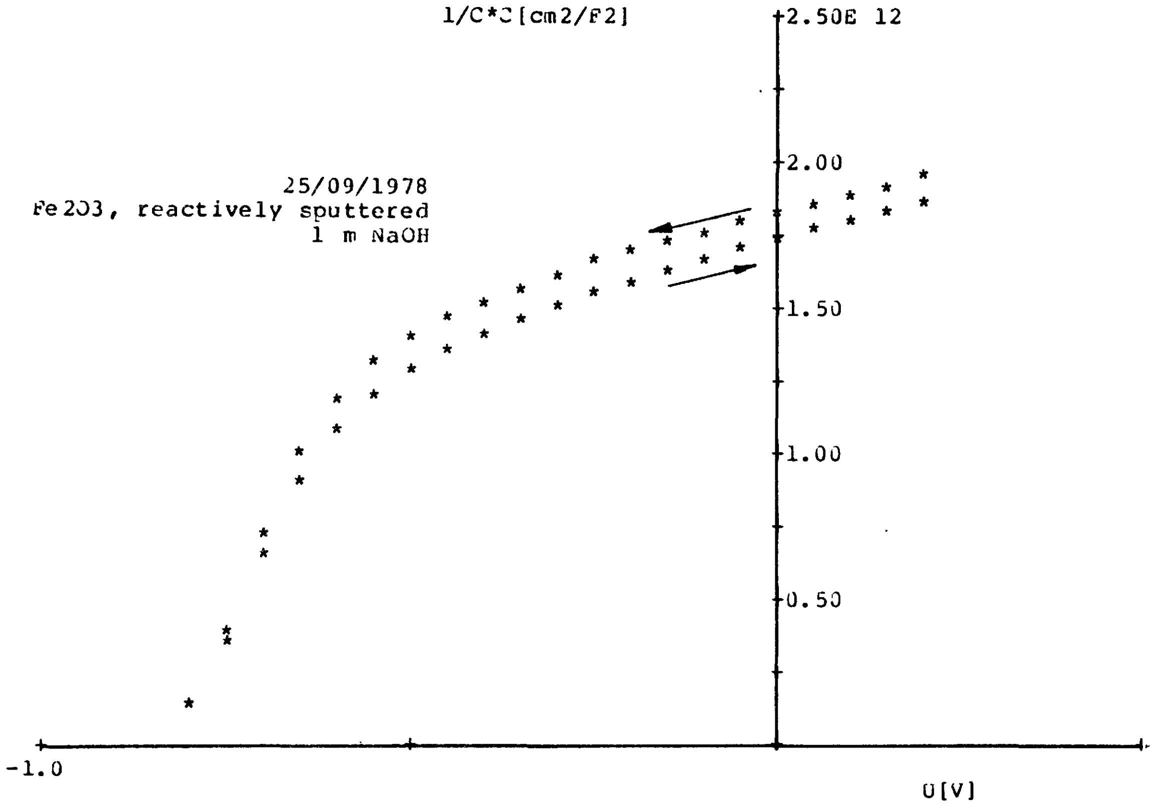


Fig. 5 : Mott-Schottky plot as obtained for a α-Fe_2O_3/1m NaOH electrode

ANNEX: Progam List

```
0: dim X[10],V[10],K[10]
1: rem 716
2: wrt 716,"A1","A2","A3","A4","A5"
3: fmt 3/,25x,"SPACE CHARGE CAPACITY EVALUATION ",z;wrt 701
4: fmt "FROM HP 9825 CONTROLLED PHASE SHIFT MEASUREMENTS";wrt 701
5: fmt 25x,81"=",2/;wrt 701
6: dim A$[12],B$[120],C$[120],D$[120]
7: ent "date [12]",A$
8: ent "electrode ? [120]",B$
9: ent "electrolyte ?",C$
10: ent "remarks ? [120]",D$
11: fmt c120,/,c120,/,c120,/,c120
12: wrt 701,A$,B$,C$,D$
13: ent "dielectric constant ?",X[6]
14: ent "electrode surface [cm2]",S
15: ent "initial potential [V]",V[2]
16: ent "final potential [V]",V[3]
17: ent "standby potential [V]",V[1]
18: ent "number of intervals",N
19: ent "if loop requ. ent K[6]→2",K[6]
20: if K[6]#2;1→K[6]
21: dim S[2N+1],Q[5,2N+1],A[5,2N+1],B[5,2N+1],H[5,2N+1],R[5,2N+1]
22: dim G[5,2N+1]
23: ent "time betw. 2 meas. points [s]",X[1]
24: wrt 725,"PF4G6T"
25: fmt e12.1
26: red 725,E
27: wrt 716,"A1","A2","B3","B4","A5"
28: wrt 722,"R2F4A0H0M3T3";trg 722;fmt ;wait 100
29: red 722,R
30: fmt c112,f8.2
31: wrt 701,"electrode surface [cm2] S = ",S
32: wrt 701,"dielectric constant X[6] = ",X[6]
33: wrt 701,"frequency [kHz] E = ",E
34: wrt 701,"external resistance [Ohm] R = ",R
35: wrt 701,"initial potential [V] V[2] = ",V[2]
36: wrt 701,"final potential [V] V[3] = ",V[3]
37: wrt 701,"standby potential [V] V[1] = ",V[1]
38: wrt 701,"number of intervals N = ",N
39: wrt 701,"time between two measuring points [s], X[1] = ",X[1]
40: X[1]*10→X[1]
41: fmt 3,5/
42: wrt 701.3
43: (V[3]-V[2])/N→D
44: wrt 719,"E0"
45: wrt 722,"R3F2A0H0M3T3"
46: wrt 725,"PF:G5R"
47: fmt 1,f5.2
48: wrt 718.1,V[2];wait 1000
49: 1→Z
50: fmt
51: for J=1 to K[6]*N+1
52: if J>N;jmp 2
53: V[2]+(J-1)*D→S[J];jmp 2
54: V[3]-(J-N-1)*D→S[J]
```

```
55: wrt 718.1,S[J];cll 'time'(X[1])
56: wrt 716,"A1","A2","A3","A4","A5"
57: wrt 725,"T";fmt f11.3;red 725,H[Z,J]
58: wrt 716,"B1","B2","A3","A4","B5"
59: trg 722;fmt ;red 722,A[Z,J]
60: wrt 716,"A1","B2","A3","A4","B5"
61: trg 722;fmt ;red 722,B[Z,J]
62: next J
63: for J=1 to K[6]*N+1
64: H[Z,J]*1e-9*E*1e3*360→G[Z,J]
65: B[Z,J]/A[Z,J]→L
66: atn(1/tan(G[Z,J])-L/sin(G[Z,J]))→W
67: R*cos(W)/(sin(W+G[Z,J])/L-sin(W))→P
68: P*tan(W)→R[Z,J]
69: S^2(P*2π*E*1000)^2→Q[Z,J]
70: next J
71: wrt 718.1,V[1]
72: fmt 2/,10x,"measurement No",2x,z;wrt 701
73: fmt f1.0,z;wrt 701,Z
74: ent "if print required, ent 1",X[4]
75: if X[4]#1;jmp 12
76: fmt 2/,10x,"Ux[V]",6x,"delay[ns]",4x,"delay[degr]",5x,"VO[V]",z;wrt 701
77: fmt 5x,"Vx[V]",5x,"Vx/VO",4x,"r[Ohm]",7x,"C[F/cm2]",z;wrt 701
78: fmt 3x,"1/c2[cm4/F2]",2/;wrt 701
79: for J=1 to K[6]*N+1
80: fmt 2,3f15.3,z
81: fmt 3,4f10.3,z
82: fmt 4,2e15.3
83: wrt 701.2,S[J],H[Z,J],G[Z,J]
84: wrt 701.3,A[Z,J],B[Z,J],B[Z,J]/A[Z,J],R[Z,J]
85: wrt 701.4,1/√Q[Z,J],Q[Z,J]
86: next J
87: fmt 3/;wrt 701
88: 0→H
89: 0→T
90: 0→U
91: 0→W
92: 0→V
93: for J=1 to N+1
94: H+S[J]*S[J]→H
95: T+S[J]*Q[Z,J]→T
96: U+S[J]→U
97: V+Q[Z,J]→V
98: next J
99: (H*V-T*U)/((N+1)*H-U*U)→Q
100: (T-Q*U)/H→C
101: 2/(1.602e-19*8.8542e-14*X[6]*C)→W
102: -Q/C→V[4]
103: fmt c100,e15.3
104: wrt 701,"charge carrier density [cm-3]  =",W
105: fmt c100,f15.2
106: wrt 701,"flat band potential Ufb [V] =",V[4]
107: fmt 4/;wrt 701
108: if Z=5;jmp 3
109: ent "for another meas.ent 1",X[2]
```

```
110: if X[2]=1;Z+1→Z;gto 50
111: ent "if plot required, ent 1",X[5]
112: if X[5]#1;gto 166
113: max(Q[*])→r1
114: int(log(r1))+1→r2
115: 1tn^r2→r3
116: if r3/r1<=2;r3→r4;1→r5;jmp 4
117: if r3/r1<=4;r3/2→r4;2→r5;jmp 3
118: if r3/r1<=8;r3/4→r4;4→r5;jmp 2
119: r3/8→r4;8→r5
120: 701→r0
121: cll ´form´(13.2,10,10)
122: cll ´psiz´(5,10,5,2)
123: V[2]→K[1]
124: V[3]→K[2]
125: int(min(S[*]))→r6
126: -int(-max(S[*]))→r7
127: cll ´scl´(r6,r7,0,r4)
128: cll ´xaxis´(0,.5,r6,r7)
129: cll ´yaxis´(0,r4/10,0,r4)
130: cll ´move´(r6,0)
131: cll ´skip´(1)
132: cll ´space´(-2)
133: fmt f4.1;wrt 701,r6
134: cll ´move´(r7,0)
135: cll ´skip´(1)
136: cll ´space´(-2)
137: fmt f4.1;wrt 701,r7
138: 2→I;fmt f4.2
139: cll ´move´(0,I*r4/10)
140: cll ´space´(1)
141: wrt 701,I/r5;I+2→I;if I<8.5;gto -2
142: cll ´move´(0,10*r4/10)
143: cll ´space´(1)
144: fmt e8.2
145: wrt 701,r3/r5
146: cll ´move´(r6/4-.2,10*r4/10)
147: wrt 701,"1/C*C[cm2/F2]"
148: cll ´move´(r7*3/4,1.5)
149: cll ´skip´(3)
150: cll ´space´(-3)
151: wrt 701,"U[V]"
152: for I=1 to Z
153: if I=1;42→C
154: if I=2;43→C
155: if I=3;111→C
156: if I=4;120→C
157: if I=5;46→C
158: for J=1 to K[6]*N+1
159: cll ´plt´(S[J],Q[I,J],C)
160: next J
161: cll ´move´(-1,0)
162: cll ´skip´(I+3)
163: fmt z;wtb 701,C;fmt f4.0,z;wrt 701,I;fmt ,". measurement";wrt 701
164: cll ´move´(0,0)
165: next I
166: end
*9879
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167: "time":for M=1 to p1
168: wait 100
169: next M
170: ret
171: "move":
172: wtb r0,27,65,int((p1-X)U/64),int((p1-X)U),int((p2-Y)V/64),int((p2-Y)V)
173: ret
174: "imove":
175: wtb r0,27,82,int(p1U/64),int(p1U),int(p2V/64),int(p2V)
176: ret
177: "plt":
178: wtb r0,27,65,int((p1-X)U/64),int((p1-X)U),int((p2-Y)V/64),int((p2-Y)V)
179: if p3=0;46→p3
180: if p3=46;wtb r0,27,82,0,0,0,6
181: wtb r0,p3;wtb r0,8
182: if p3=46;wtb r0,27,82,0,0,63,-6
183: ret
184: "fplt":
185: wtb r0,27,97,int((p1-X)U/64),int((p1-X)U),int((p2-Y)V/64),int((p2-Y)V)
186: if p3=0;46→p3
187: if p3=46;wtb r0,27,82,0,0,0,6
188: wtb r0,p3;wtb r0,8
189: if p3=46;wtb r0,27,82,0,0,63,-6
190: ret
191: "iplt":
192: wtb r0,27,82,int(p1U/64),int(p1U),int(p2V/64),int(p2V)
193: if p3=0;46→p3
194: if p3=46;wtb r0,27,82,0,0,0,6
195: wtb r0,p3;wtb r0,8
196: if p3=46;wtb r0,27,82,0,0,63,-6
197: ret
198: "fiplt":
199: wtb r0,27,114,int(p1U/64),int(p1U),int(p2V/64),int(p2V)
200: if p3=0;46→p3
201: if p3=46;wtb r0,27,82,0,0,0,6
202: wtb r0,p3;wtb r0,8
203: if p3=46;wtb r0,27,82,0,0,63,-6
204: ret
205: "char":
206: if p2=0;5→p2;0→p3
207: wtb r0,27,46,p1,int(p2/64),p2,p3
208: ret
209: "psiz":
210: p1→H;p2→W
211: wtb r0,27,79,int(p4*120/64),p4*120,int(p3*96/64),p3*96
212: ret
213: "scl":
214: 120W/(p2-p1)→U
215: 96H/(p4-p3)→V
216: p1→X;p3→Y
217: ret
218: "xaxis":
219: wtb r0,27,46,95,0,5,9
220: if p3=0 and p4=0;X→p3;X+120W/U→p4
221: if p2=0;p4-p3→p2
222: wtb r0,27,65,int((p3-X)U/64),int((p3-X)U),int((p1-Y)V/64),int((p1-Y)V)
223: p3→p5;wtb r0,43;wtb r0,8
```

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224: wtb r0,27,114,int(p2U/64),int(p2U),0,0;wtb r0,43,8;jmp (p5+p2→p5)>=p4
225: ret
226: "yaxis":
227: wtb r0,27,46,124,0,3,0
228: if p3=0 and p4=0;Y→p3;Y+96H/V→p4
229: if p2=0;p4-p3→p2
230: wtb r0,27,65,int((p1-X)U/64),int((p1-X)U),int((p3-Y)V/64),int((p3-Y)V)
231: p3→p5;wtb r0,43;wtb r0,8
232: wtb r0,27,114,0,0,int(p2V/64),int(p2V);wtb r0,43,8;jmp (p5+p2→p5)>=p4
233: ret
234: "space":
235: if p1<0;gto +2
236: wtb r0,32;jmp 2((p1-1→p1)=0)
237: wtb r0,8;jmp (p1+1→p1)=0
238: ret
239: "skip":
240: if p1<0;gto +2
241: wtb r0,10;jmp 2((p1-1→p1)=0)
242: wtb r0,27,10;jmp (p1+1→p1)=0
243: ret
244: "cspc":
245: if p2=0;6→p2
246: wtb r0,27,86,int(96/p2/64),96/p2
247: if p1<0;wtb r0,27,80;ret
248: wtb r0,27,72,int(120/p1/64),120/p1
249: ret
250: "form":
251: wtb r0,27,77
252: wtb r0,27,84
253: if p1=0;13.2→p1;11→p2→p3
254: wtb r0,27,87,int(120*p1/64),120*p1
255: wtb r0,27,76,int(96*p2/64),96*p2
256: wtb r0,27,70,int(96*p3/64),96*p3
257: ret
258: "ptyp":
259: rdb(0)→I;if I=1;ret
260: if I<124;gto +12
261: if I>224 and I<251;I-160→I;gto +15
262: if I>176 and I<182;I-144→I;gto +14
263: if I=182;38→I;gto +13
264: if I=183;64→I;gto +12
265: if I=184;91→I;gto +11
266: if I=185;93→I;gto +10
267: if I=222;92→I;gto +9
268: if I=251;124→I;gto +8
269: if I=191;58→I;gto +7
270: if I=176;39→I;gto +6
271: if I=174 or I=172;I-112→I;gto +5
272: if I>77 and I<88;I-30→I;gto +4
273: if I=88;46→I;gto +3
274: if I=94;wtb r0,14
275: if I=89;44→I
276: wtb r0,I;gto -17
277: "view":
278: wtb r0,27,68,int(p1/64),p1
279: ret
```