FIG.1

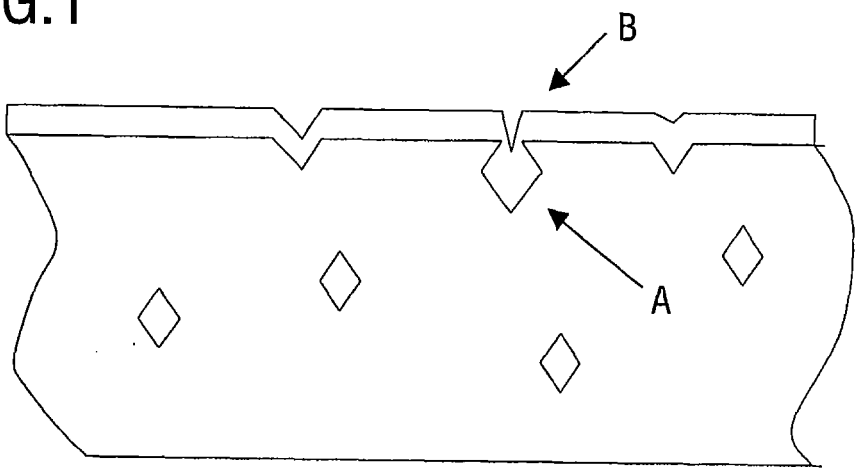
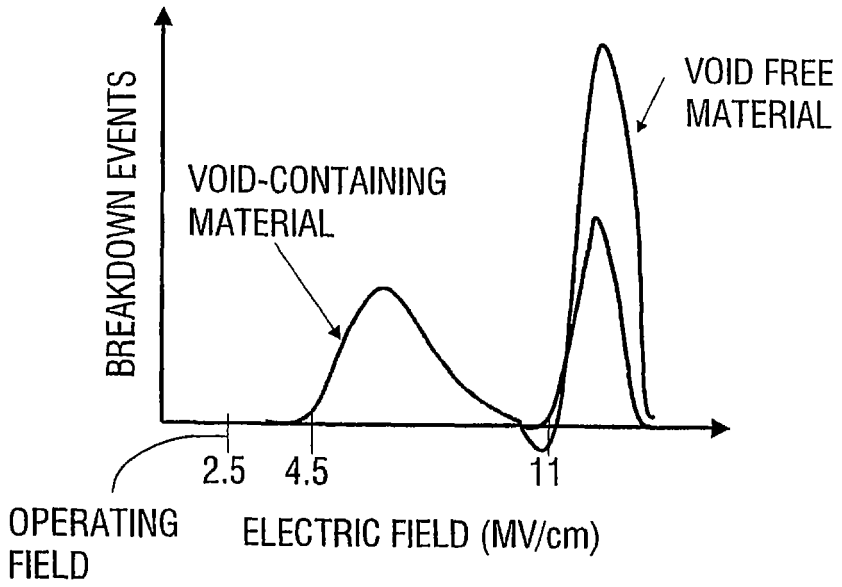


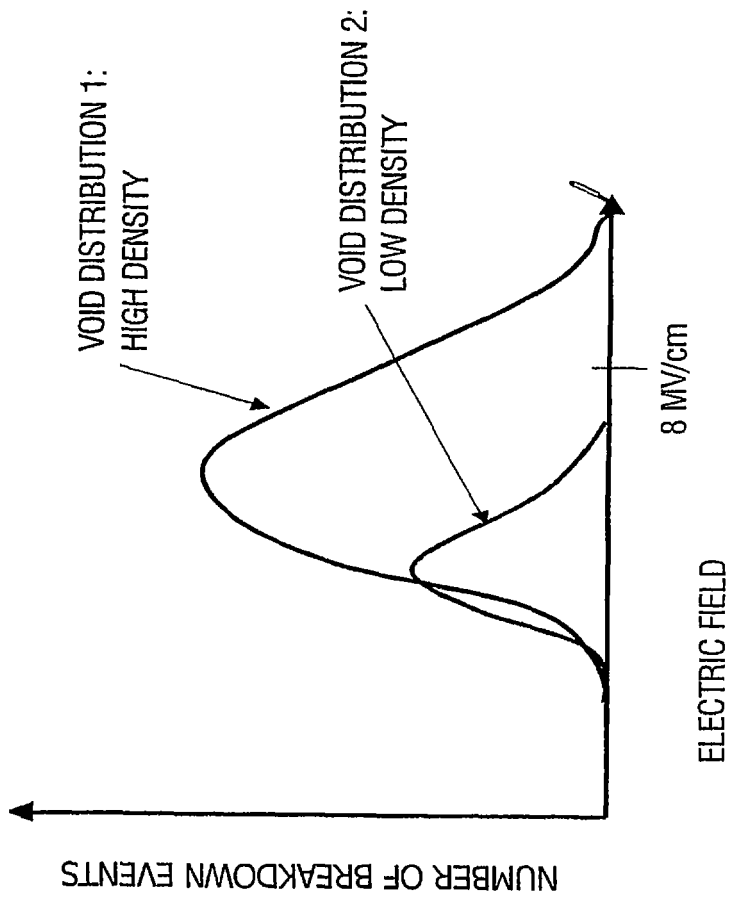
FIG. 2

G00002



163163

FIG. 3


VOID DISTRIBUTION 1:
HIGH DENSITY
VOID DISTRIBUTION 2:
LOW DENSITY
8 MV/cm
ELECTRIC FIELD
NUMBER OF BREAKDOWN EVENTS

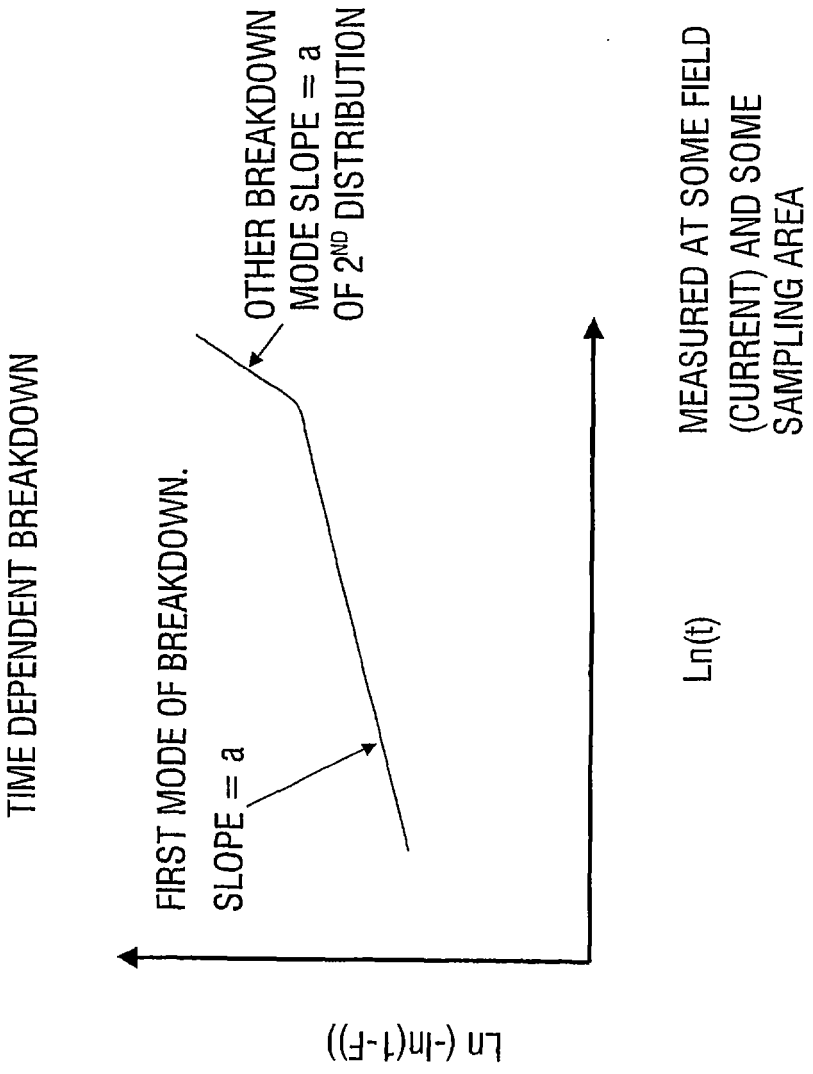

TIME DEPENDENT BREAKDOWN
FIRST MODE OF BREAKDOWN.
SLOPE = a
OTHER BREAKDOWN
MODE SLOPE = a
OF 2ND DISTRIBUTION
Ln (-ln(1-F))
Ln(t)
MEASURED AT SOME FIELD
(CURRENT) AND SOME
SAMPLING AREA

FIG. 4

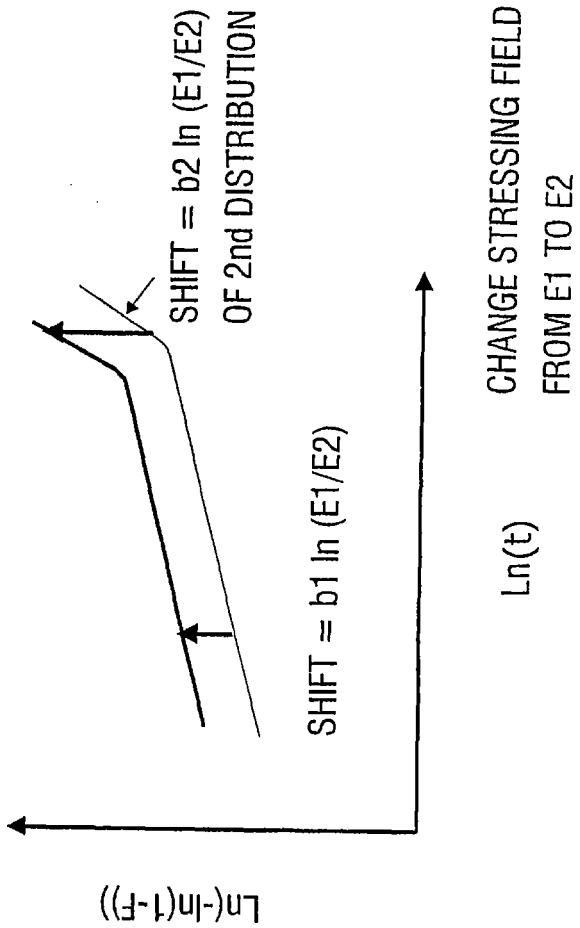

Ln(-ln(1-F))
Ln(t)
SHIFT = b1 ln (E1/E2)
SHIFT = b2 ln (E1/E2)
OF 2nd DISTRIBUTION
CHANGE STRESSING FIELD
FROM E1 TO E2

FIG. 5

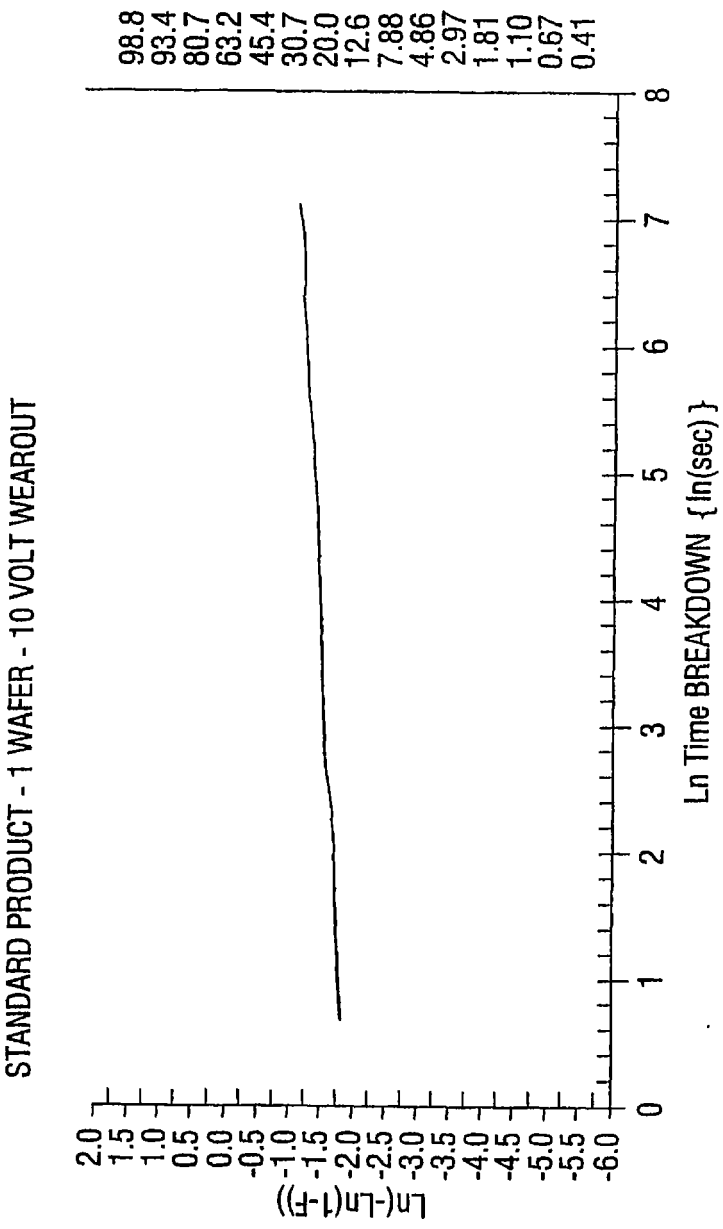

STANDARD PRODUCT - 1 WAFER - 10 VOLT WEAROUT
Ln(-Ln(1-F))
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
-4.5
-5.0
-5.5
-6.0
0
1
2
3
4
5
6
7
8
Ln Time BREAKDOWN {ln(sec)}
98.8
93.4
80.7
63.2
45.4
30.7
20.0
12.6
7.88
4.86
2.97
1.81
1.10
0.67
0.41

FIG. 6

FIG. 7

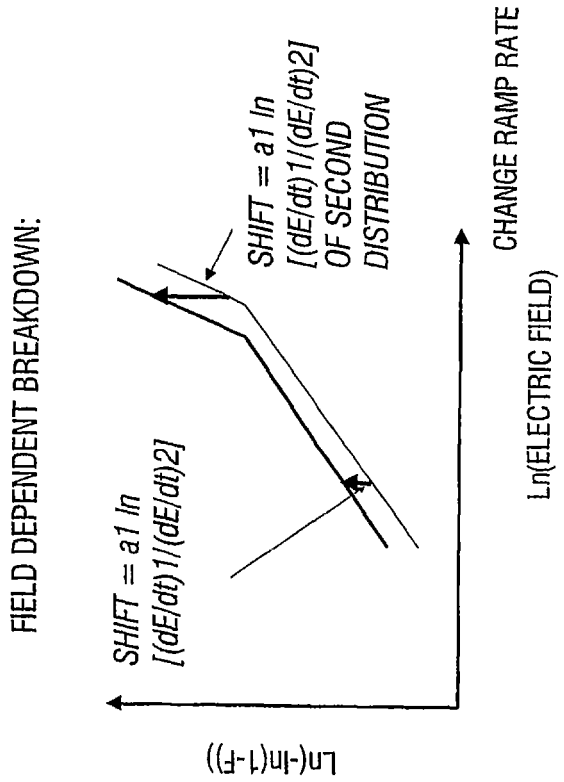
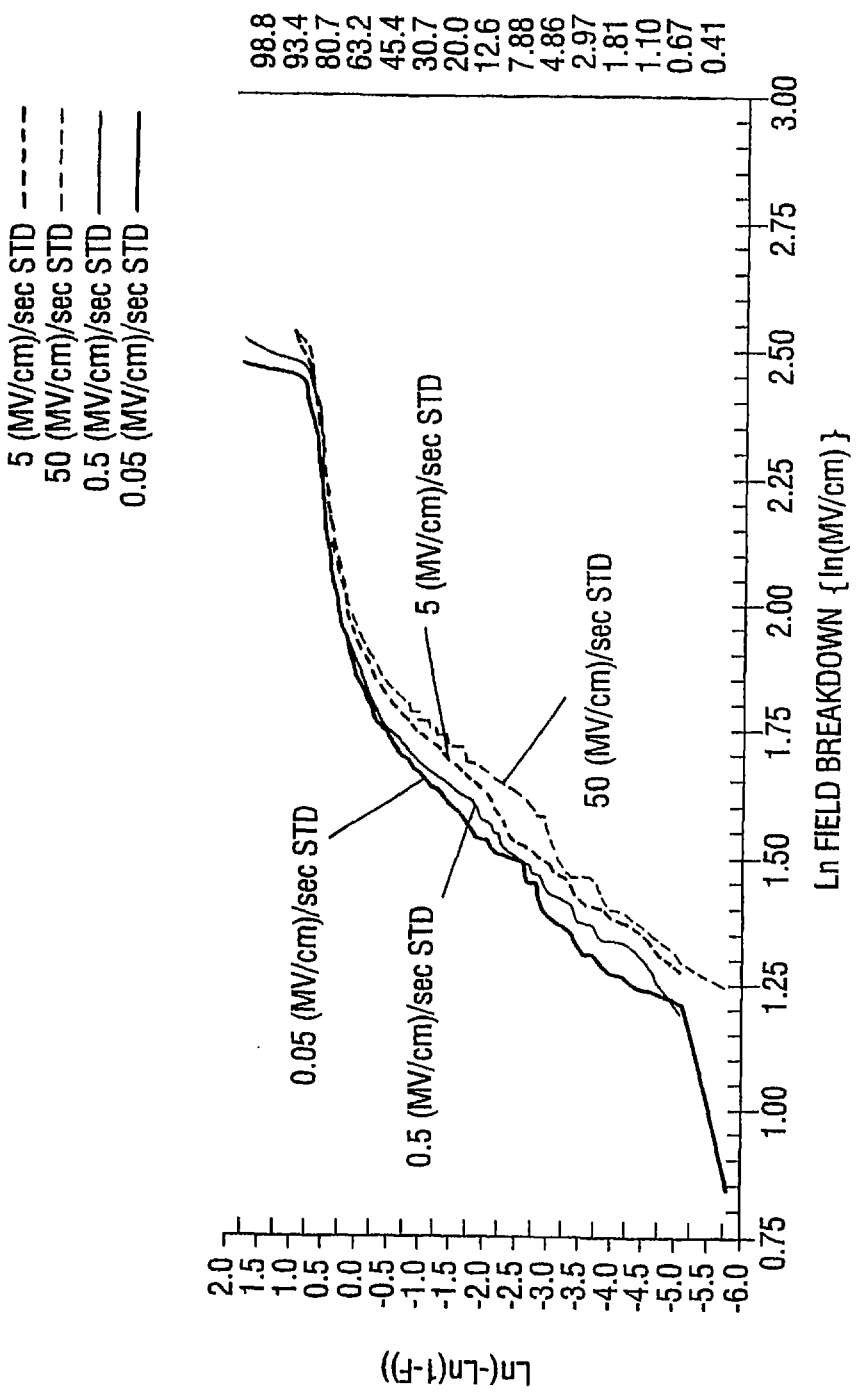

FIELD DEPENDENT BREAKDOWN:
SHIFT = a1 ln [(dE/dt)1/(dE/dt)2]
SHIFT = a1 ln [(dE/dt)1/(dE/dt)2] OF SECOND DISTRIBUTION
Ln(-ln(1-F))
Ln(ELECTRIC FIELD)
CHANGE RAMP RATE

FIG. 8


5 (MV/cm)/sec STD
50 (MV/cm)/sec STD
0.5 (MV/cm)/sec STD
0.05 (MV/cm)/sec STD
98.8
93.4
80.7
63.2
45.4
30.7
20.0
12.6
7.88
4.86
2.97
1.81
1.10
0.67
0.41
0.05 (MV/cm)/sec STD
0.5 (MV/cm)/sec STD
5 (MV/cm)/sec STD
50 (MV/cm)/sec STD
Ln FIELD BREAKDOWN {ln(MV/cm)}
Ln(-Ln(1-F))

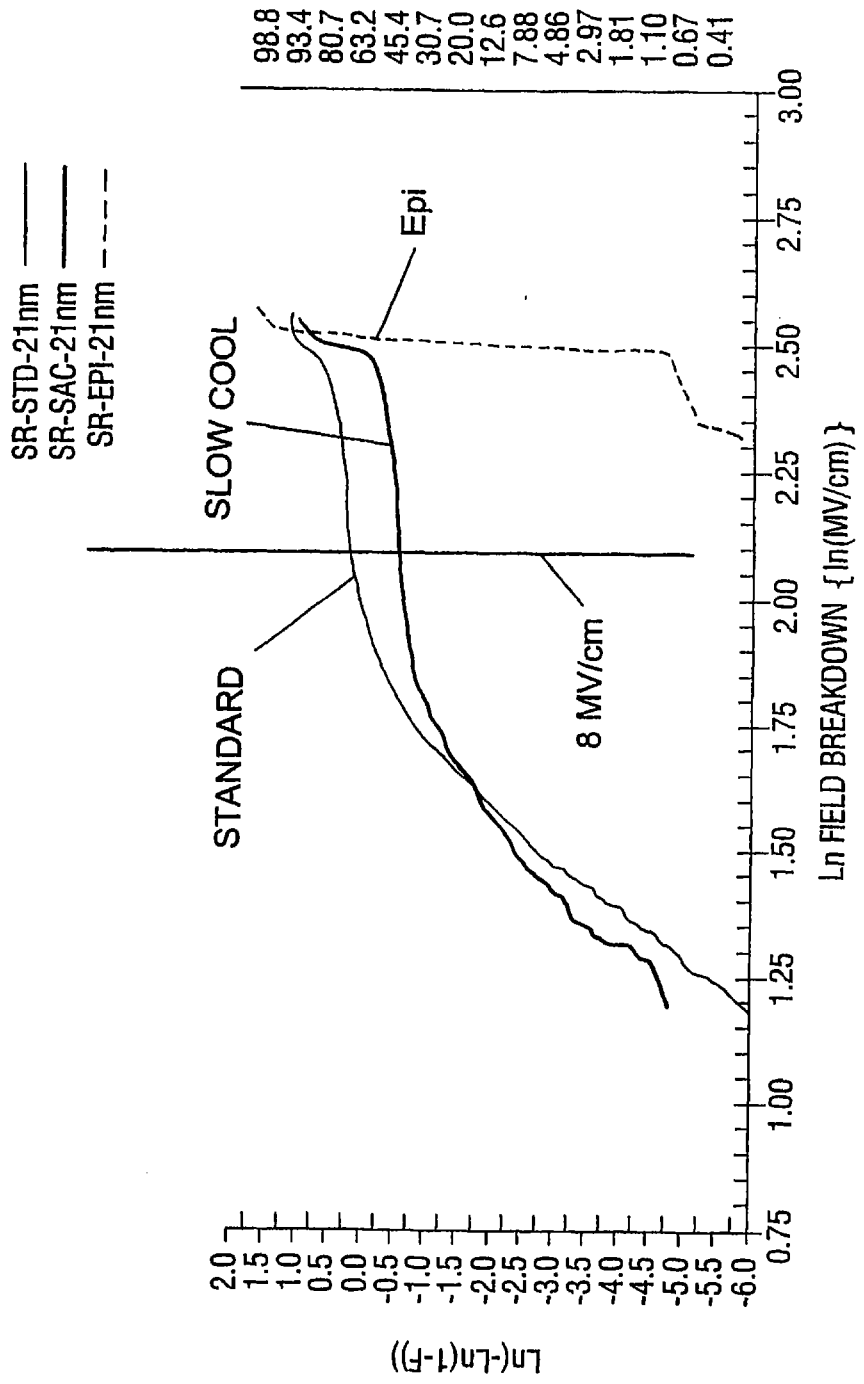

SR-STD-21nm
SR-SAC-21nm
SR-EPI-21nm
SLOW COOL
STANDARD
Epi
8 MV/cm
98.8
93.4
80.7
63.2
45.4
30.7
20.0
12.6
7.88
4.86
2.97
1.81
1.10
0.67
0.41
Ln FIELD BREAKDOWN {ln(MV/cm)}
Ln(-Ln(1-F))

FIG. 9

FIG. 10

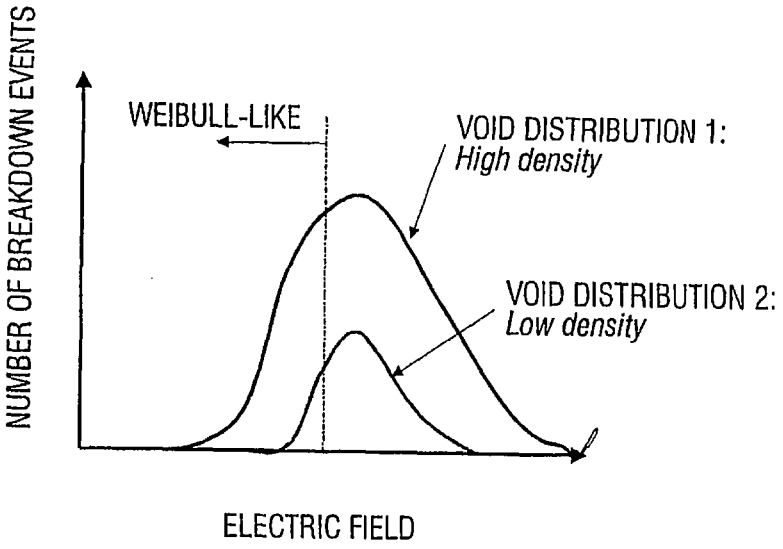

NUMBER OF BREAKDOWN EVENTS
WEIBULL-LIKE
VOID DISTRIBUTION 1:
High density
VOID DISTRIBUTION 2:
Low density
ELECTRIC FIELD

FIG. 11

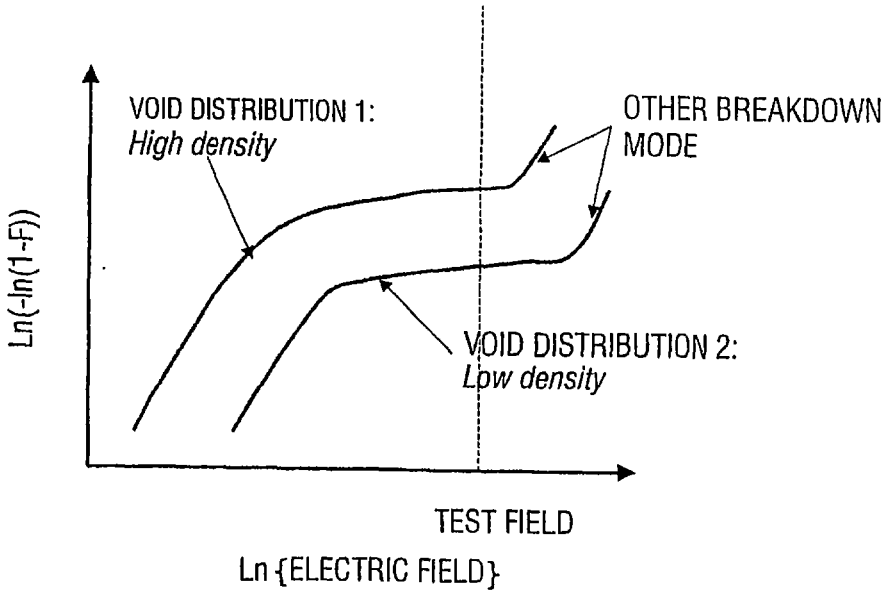

VOID DISTRIBUTION 1:
High density
OTHER BREAKDOWN
MODE
VOID DISTRIBUTION 2:
Low density
Ln(-ln(1-F))
TEST FIELD
Ln {ELECTRIC FIELD}

FIG. 12

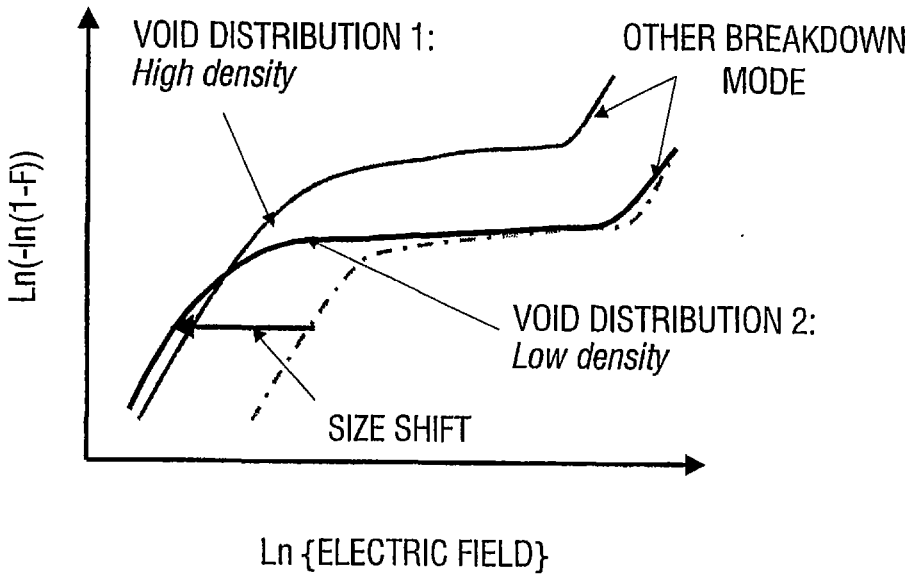
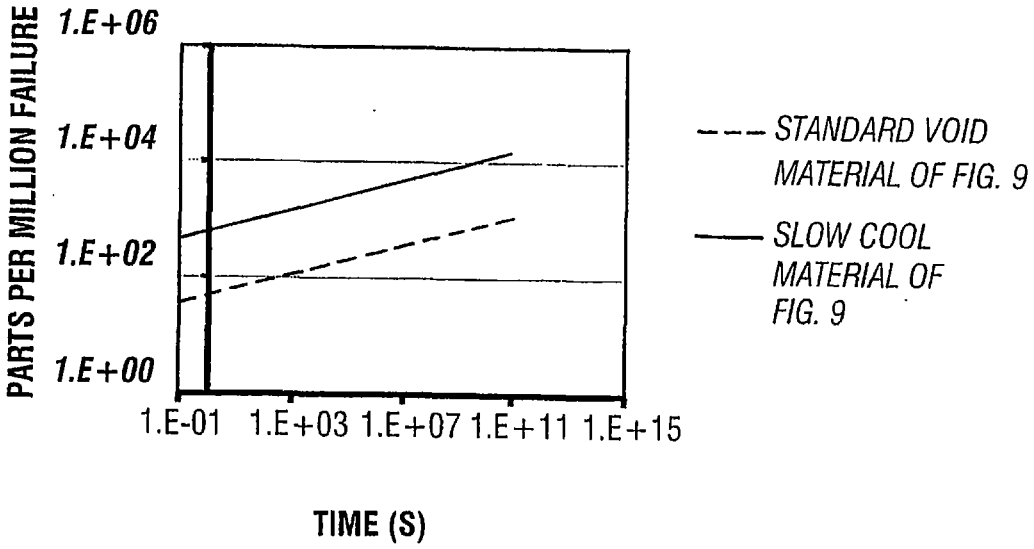

VOID DISTRIBUTION 1:
High density
OTHER BREAKDOWN MODE
VOID DISTRIBUTION 2:
Low density
SIZE SHIFT
Ln(-ln(1-F))
Ln {ELECTRIC FIELD}

FIG. 13


PARTS PER MILLION FAILURE
1.E+06
1.E+04
1.E+02
1.E+00
1.E-01
1.E+03
1.E+07
1.E+11
1.E+15
TIME (S)
STANDARD VOID MATERIAL OF FIG. 9
SLOW COOL MATERIAL OF FIG. 9

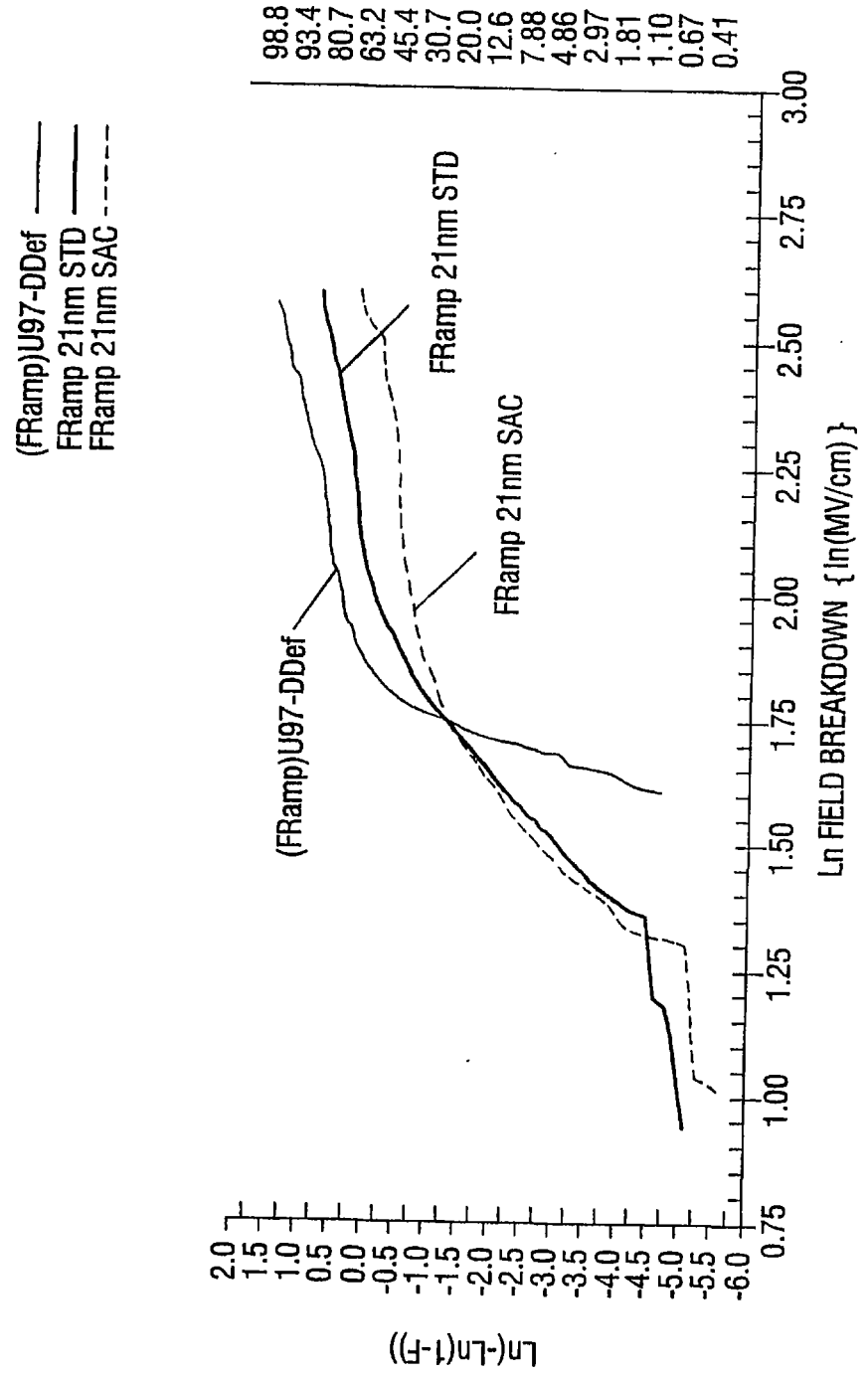

(FRamp)U97-DDef
FRamp 21nm STD
FRamp 21nm SAC
98.8
93.4
80.7
63.2
45.4
30.7
20.0
12.6
7.88
4.86
2.97
1.81
1.10
0.67
0.41
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
-4.5
-5.0
-5.5
-6.0
0.75
1.00
1.25
1.50
1.75
2.00
2.25
2.50
2.75
3.00
Ln(-Ln(1-F))
Ln FIELD BREAKDOWN {ln(MV/cm)}

FIG. 14

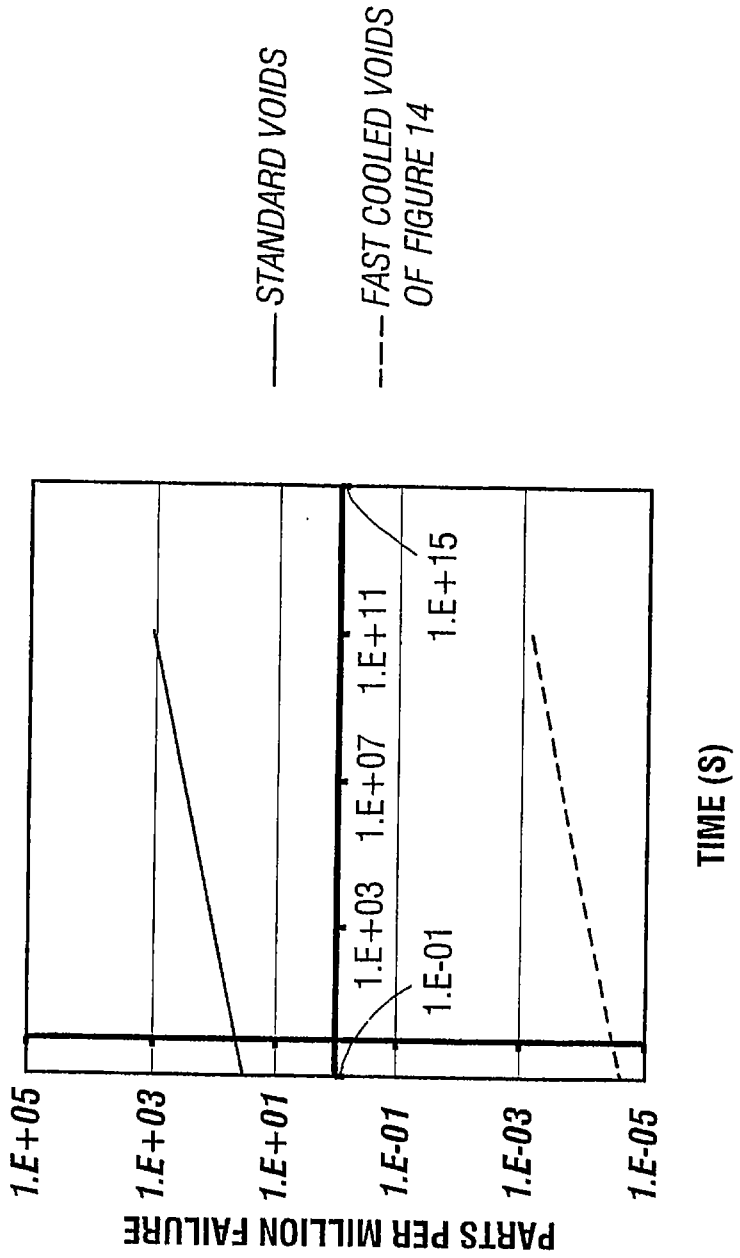

STANDARD VOIDS
FAST COOLED VOIDS OF FIGURE 14
PARTS PER MILLION FAILURE
1.E+05
1.E+03
1.E+01
1.E-01
1.E-03
1.E-05
1.E+03
1.E+07
1.E+11
1.E+15
1.E-01
TIME (S)

FIG. 15

FIG. 16

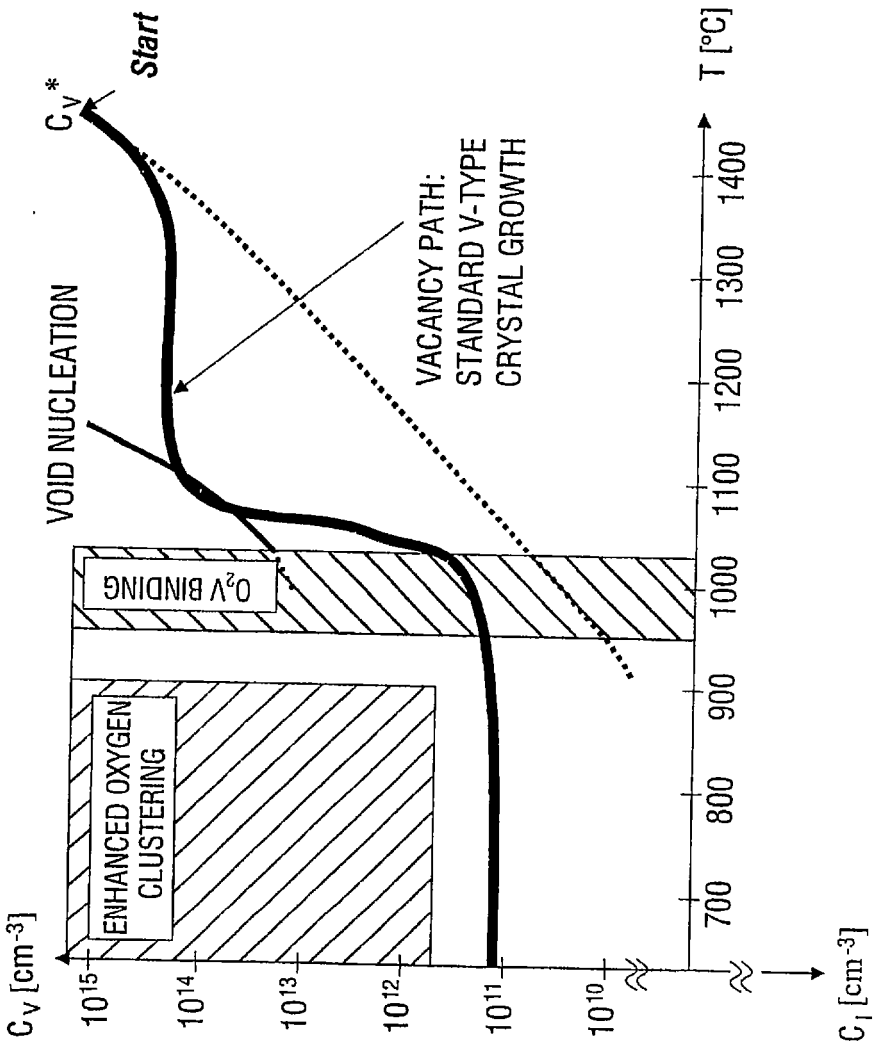

Start
C_V^*
VOID NUCLEATION
VACANCY PATH:
STANDARD V-TYPE
CRYSTAL GROWTH
O_2V BINDING
ENHANCED OXYGEN
CLUSTERING
C_V [cm^{-3}]
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
700
800
900
1000
1100
1200
1300
1400
T [°C]
C_I [cm^{-3}]

FIG. 17

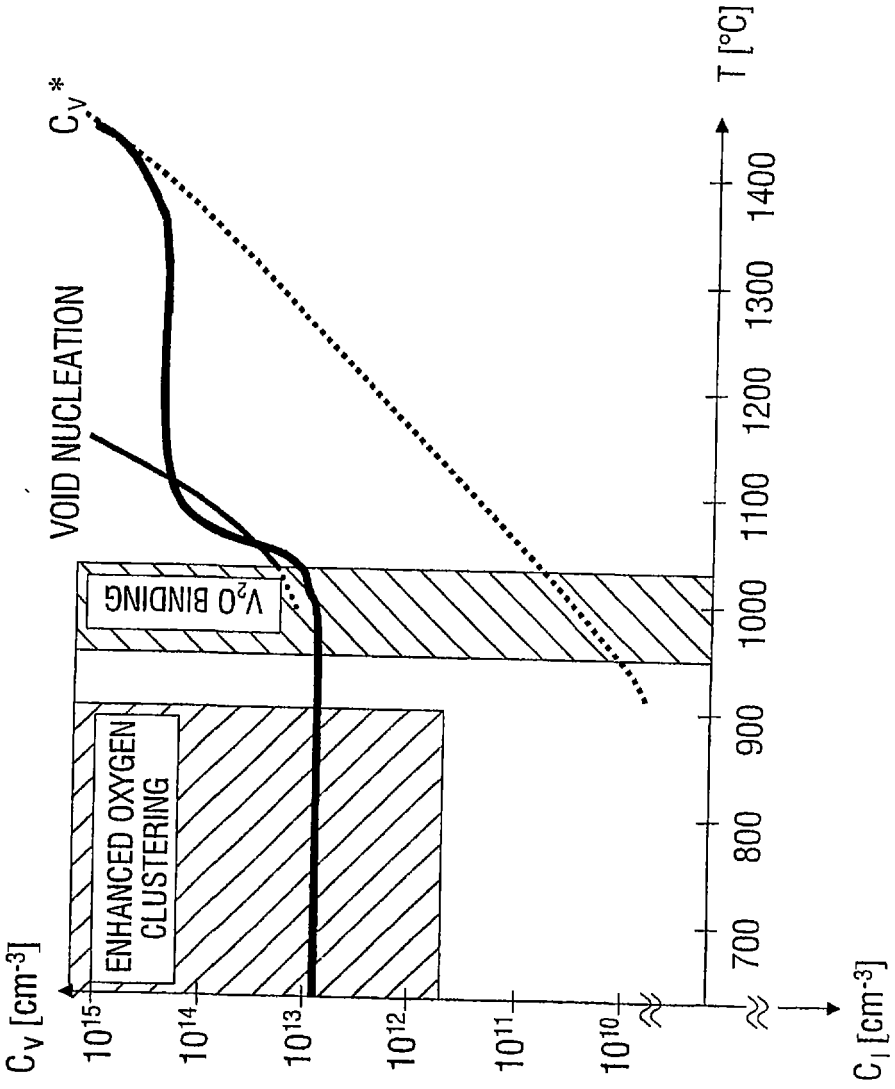

C_V*
VOID NUCLEATION
V_2O BINDING
ENHANCED OXYGEN CLUSTERING
C_V [cm^{-3}]
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
T [°C]
700
800
900
1000
1100
1200
1300
1400
C_I [cm^{-3}]

FIG. 18

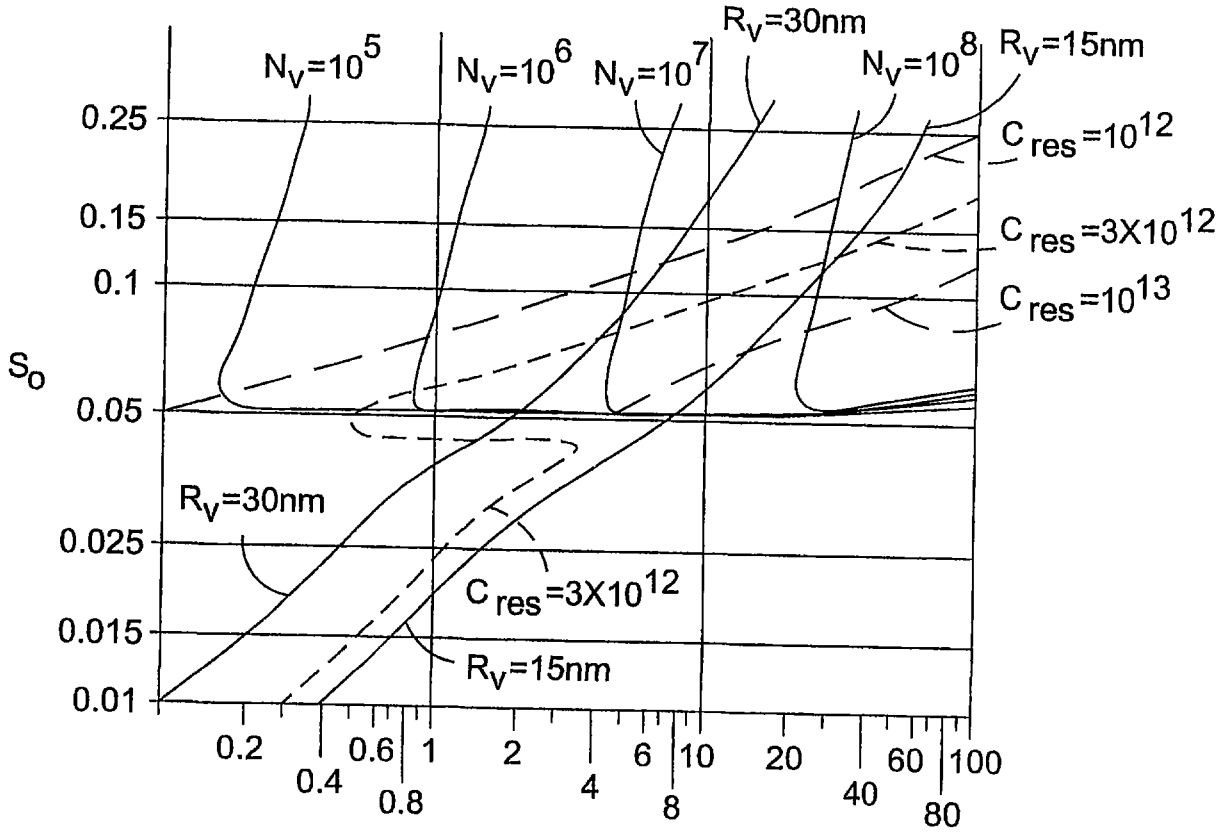

$N_V=10^5$
$N_V=10^6$
$N_V=10^7$
$N_V=10^8$
R_V=30nm
R_V=15nm
$C_{res}=10^{12}$
$C_{res}=3X10^{12}$
$C_{res}=10^{13}$
S_o
0.25
0.15
0.1
0.05
0.025
0.015
0.01
R_V=30nm
$C_{res}=3X10^{12}$
R_V=15nm
0.2
0.4
0.6
0.8
1
2
4
6
8
10
20
40
60
80
100
COOLING RATE

FIG. 19

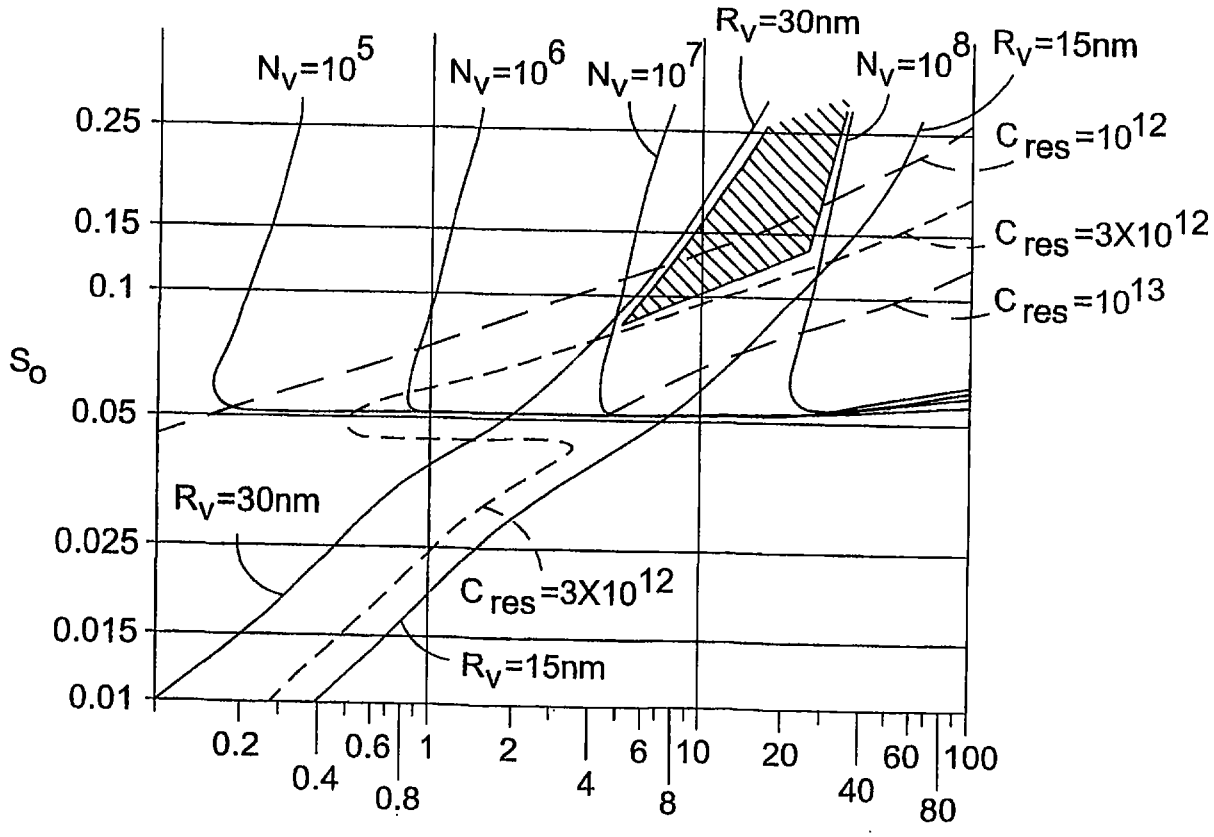
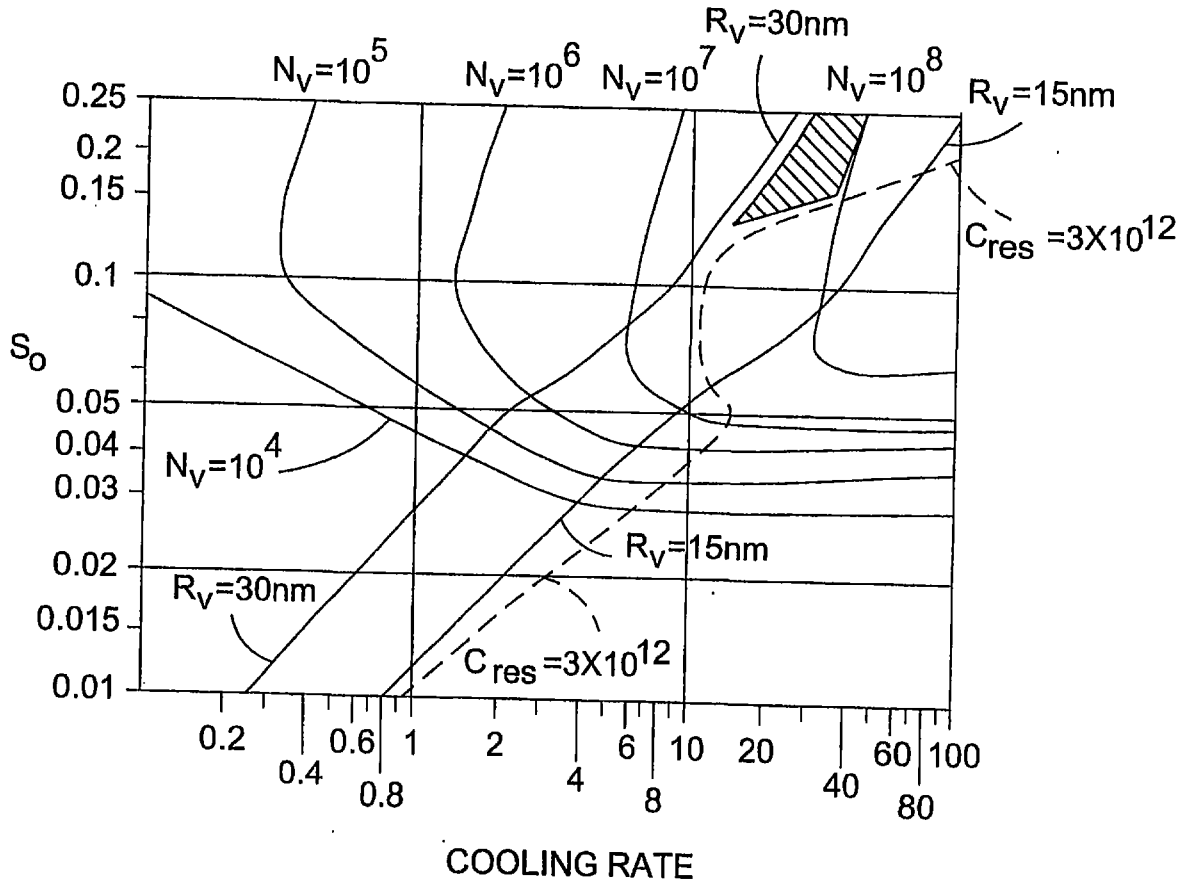

$N_V=10^5$
$N_V=10^6$
$N_V=10^7$
$N_V=10^8$
R_V=30nm
R_V=15nm
$C_{res}=10^{12}$
$C_{res}=3X10^{12}$
$C_{res}=10^{13}$
S_o
0.25
0.15
0.1
0.05
0.025
0.015
0.01
R_V=30nm
$C_{res}=3X10^{12}$
R_V=15nm
0.2
0.4
0.6
0.8
1
2
4
6
8
10
20
40
60
80
100

FIG. 20


R_V=30nm
N_V=10^5
N_V=10^6
N_V=10^7
N_V=10^8
R_V=15nm
C_{res} =3X10^{12}
S_o
0.25
0.2
0.15
0.1
0.05
0.04
0.03
0.02
0.015
0.01
N_V=10^4
R_V=15nm
R_V=30nm
C_{res}=3X10^{12}
0.2
0.4
0.6
0.8
1
2
4
6
8
10
20
40
60
80
100
COOLING RATE