The Temperature Dependence of the Electrical Resistivity of N-Type SiGe

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JPL

SiGe Integration Meeting
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Waltham, MA

The Temperature Dependence of the Electrical Resistivity of N-Type SiGe

Questions about the Qualitative behavior of the Resistivity of N-Type SiGe:

- Near room temperature, should the resistivity increase linearly with temperature or not?
- Why does the resistivity usually (but not always) decrease with increasing temperature above about 700 °C?
- Can phosphorus go in and out of solution fast enough for the carrier concentration to change significantly DURING a measurement?

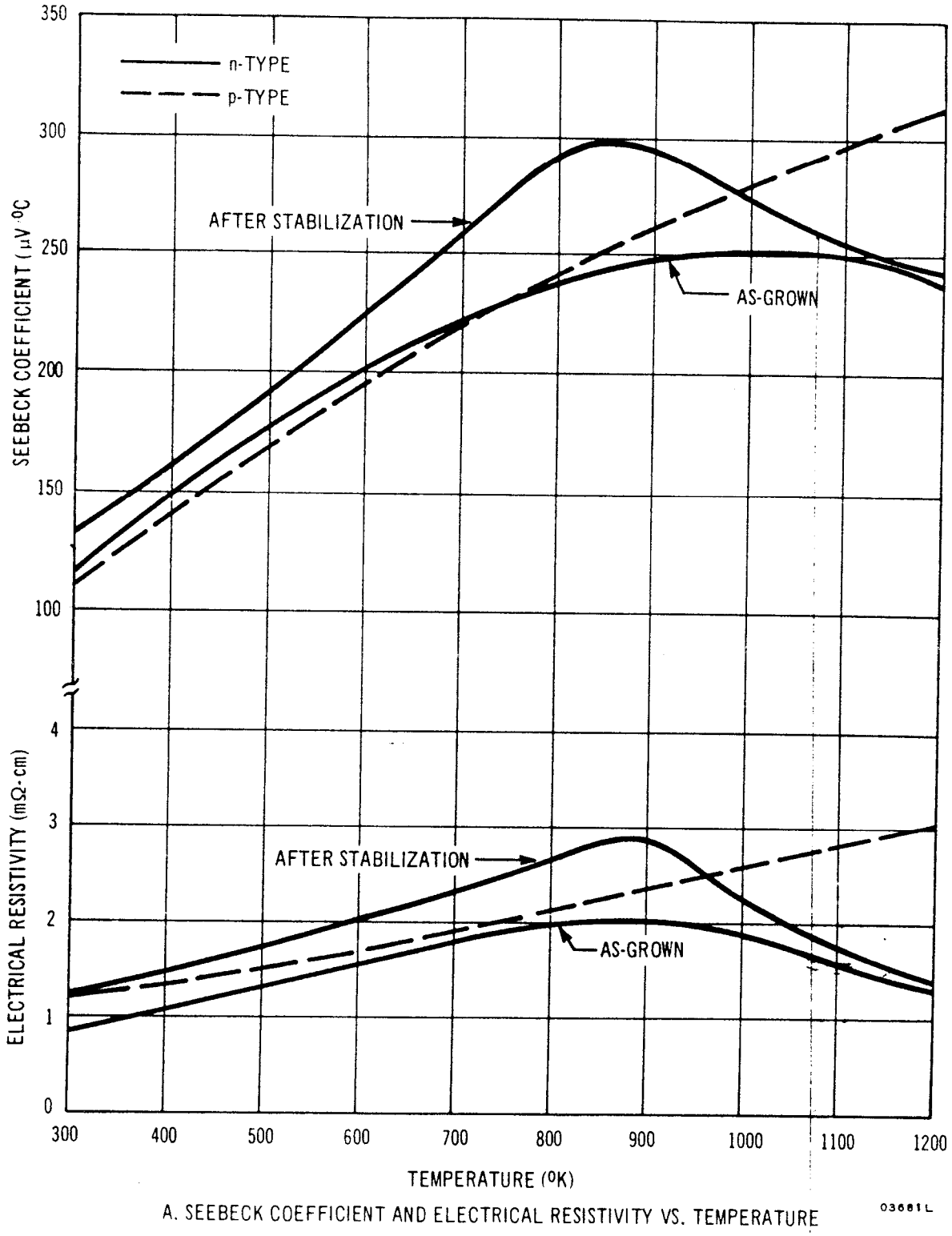
The Temperature Dependence of the Electrical Resistivity of N-Type SiGe

- $\rho = 1/\sigma = 1/(e\ n\ \mu)$;
  (We will ignore the variation of Mobility with doping level)

- Temperature dependence of the resistivity (Actually, $1/\mu$)

Scattering Mechanism	Strongly Degenerate ("High" Doping)	Strongly Nondegenerate ("Low" Doping)
Acoustic phonons	T	$T^{3/2}$
Ionized Impurities	independent of T	$T^{-3/2}$

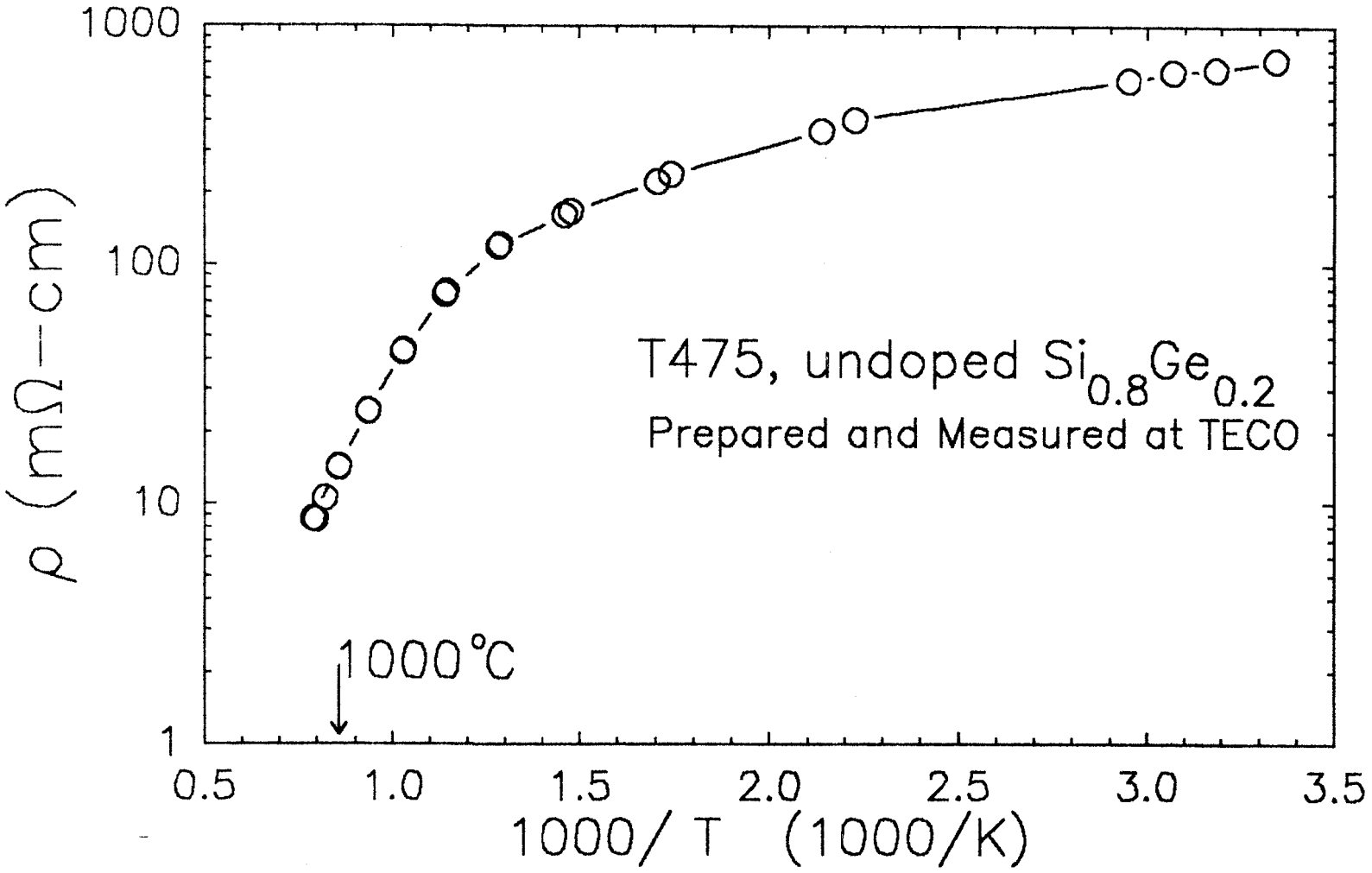
- At low doping, Si & Ge are Dominated by $T^{3/2}$ due to phonons
- Metals are dominated by T
- Heavily doped SiGe is something between these, plus impurity terms



A. SEEBECK COEFFICIENT AND ELECTRICAL RESISTIVITY VS. TEMPERATURE

Figure 6. 80.0 At. % SiGe, Thermoelectric Properties (Sheet 1 of 2)

RCA Topical Report for 1/68 to 11/69


1000
100
10
1
ρ (mΩ-cm)
T475, undoped $Si_{0.8}Ge_{0.2}$
Prepared and Measured at TECO
1000°C
0.5
1.0
1.5
2.0
2.5
3.0
3.5
1000/ T (1000/K)

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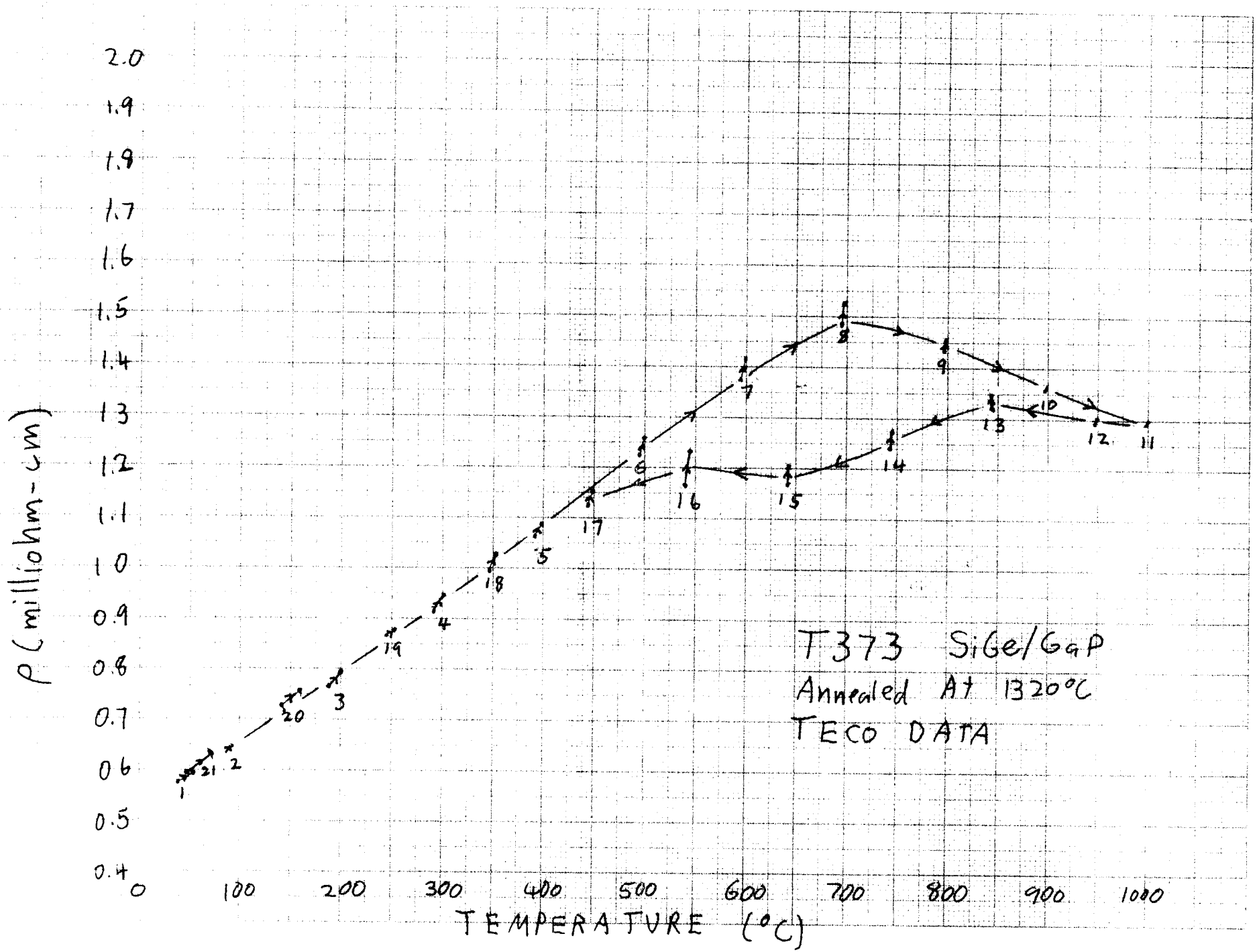
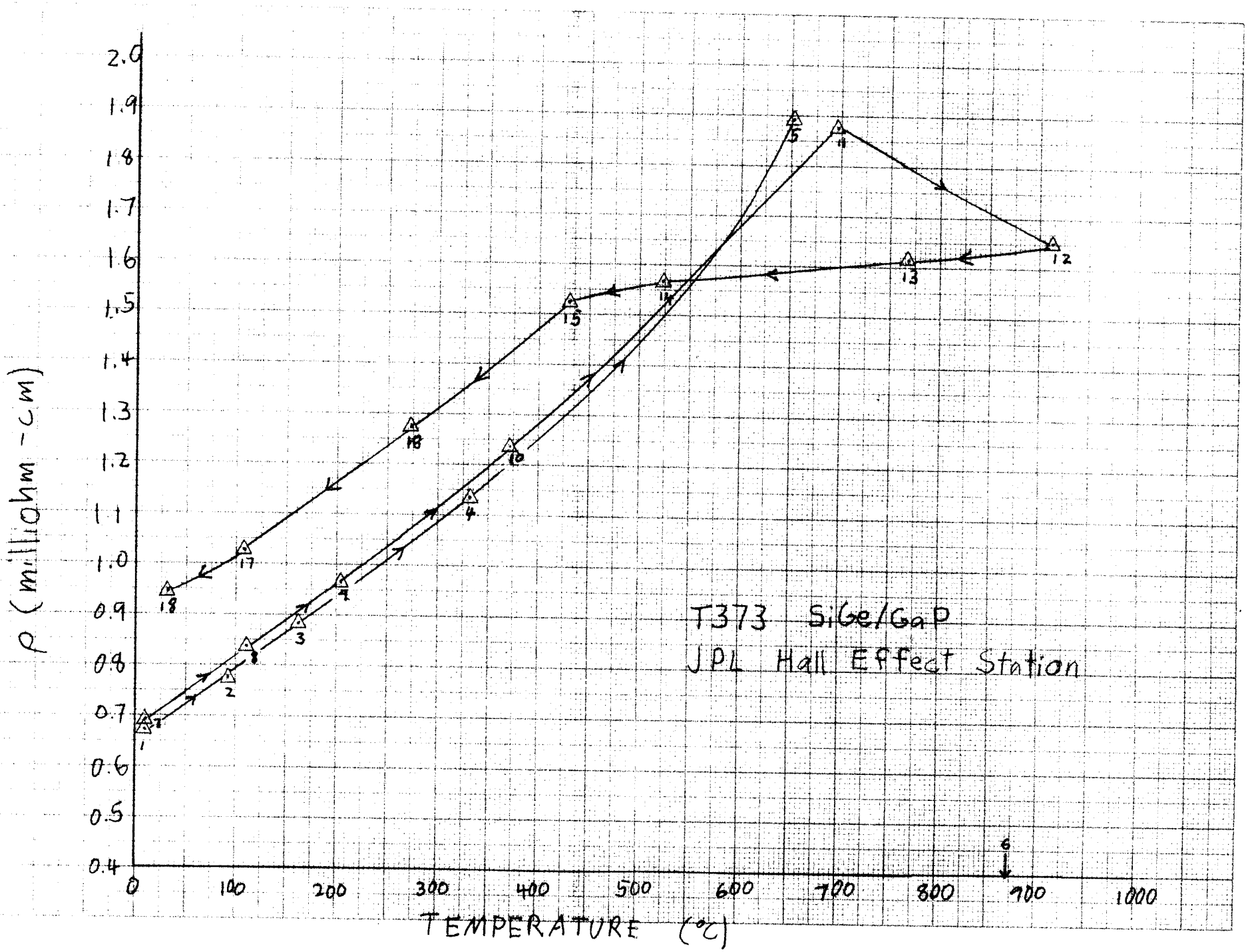
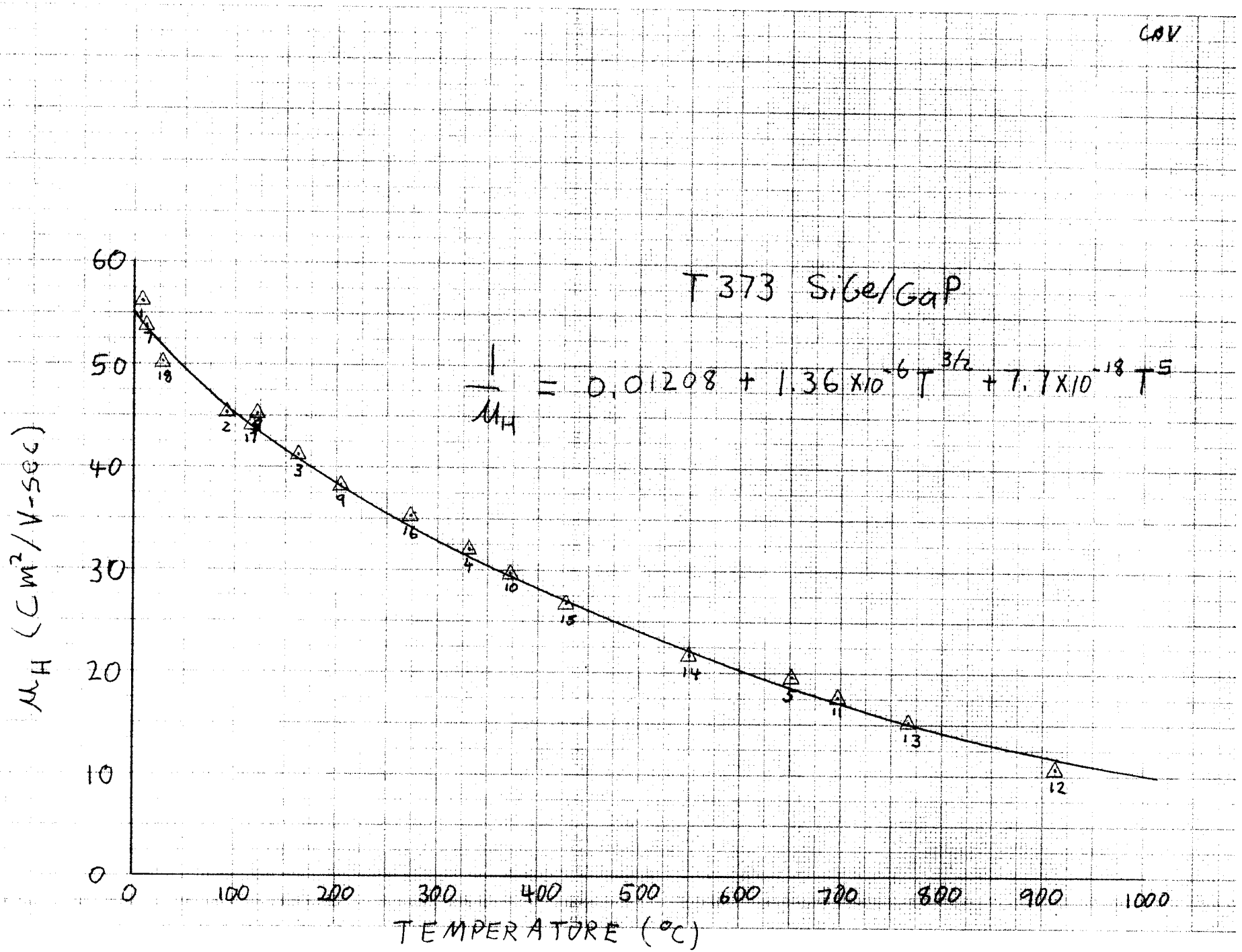

ρ (milliohm-cm)
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0
100
200
300
400
500
600
700
800
900
1000
TEMPERATURE (°C)
T373 SiGe/GaP
Annealed At 1320°C
TECO DATA


ρ (milliohm - cm)
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0
100
200
300
400
500
600
700
800
900
1000
TEMPERATURE (°C)
T373 SiGe/GaP
JPL Hall Effect Station


GAV
T373 Si,Ge/GaP
$\frac{1}{\mu_H} = 0.01208 + 1.36 \times 10^{-6} T^{3/2} + 1.7 \times 10^{-18} T^5$
μ_H (cm^2/V-sec)
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
800
900
1000
TEMPERATURE (°C)
19
7
2
17
3
9
16
4
10
15
14
5
11
13
12

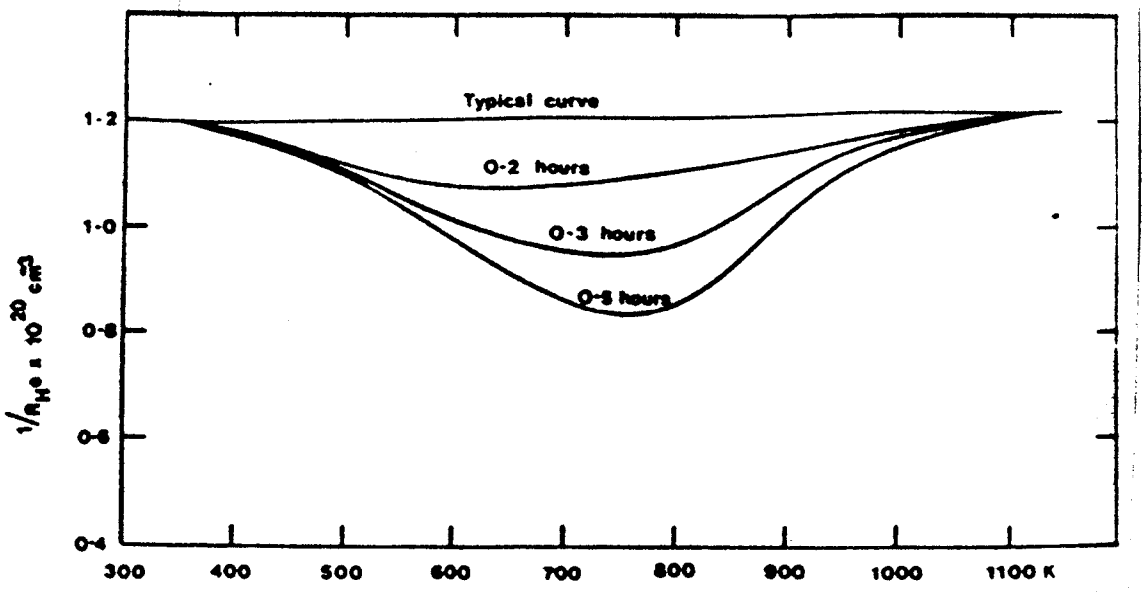


Fig. 2. Effect of short-term heat treatment on carrier concentration.

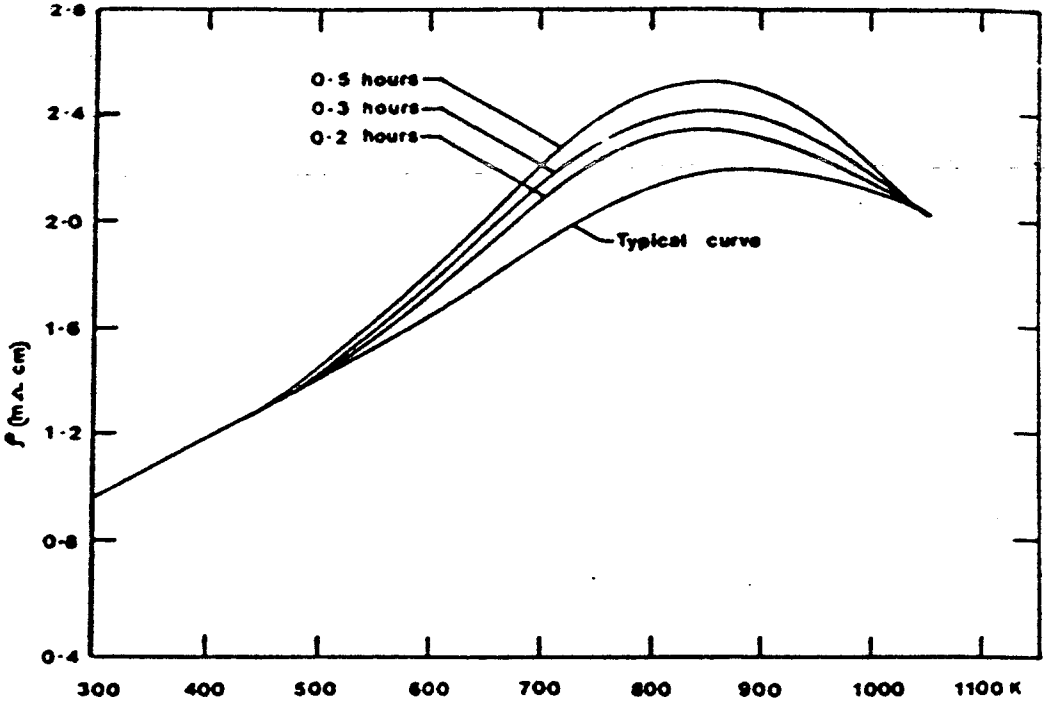


Fig. 4. Effect of short-term heat treatment on electrical resistivity.

V. S. Shukla and D. M. Rowe
Applied Energy 9 (1981) 131-137

Quenched, Zone Leveled Samples

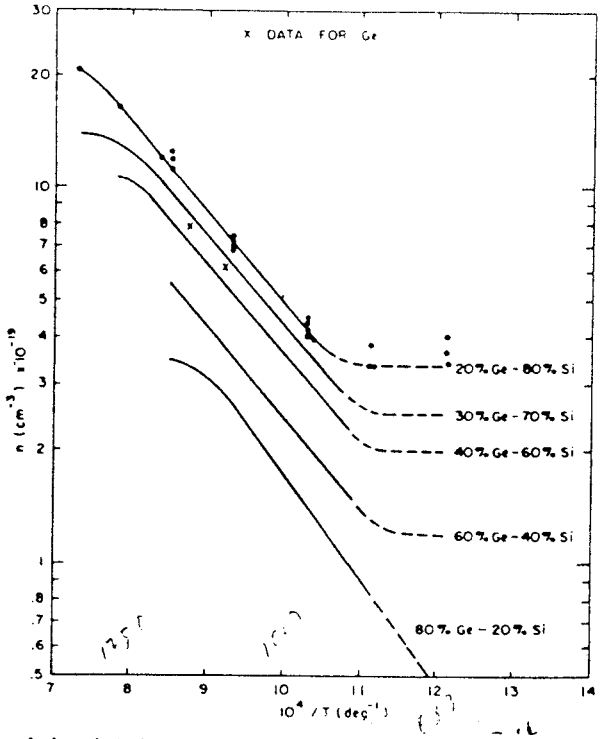
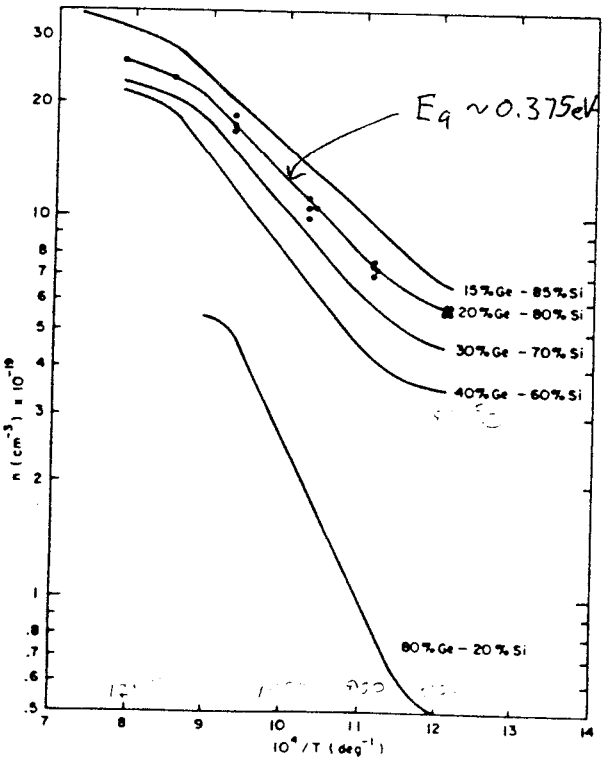


Fig. 24. Variation of solid solubility of arsenic with temperature in Si–Ge alloy compositions

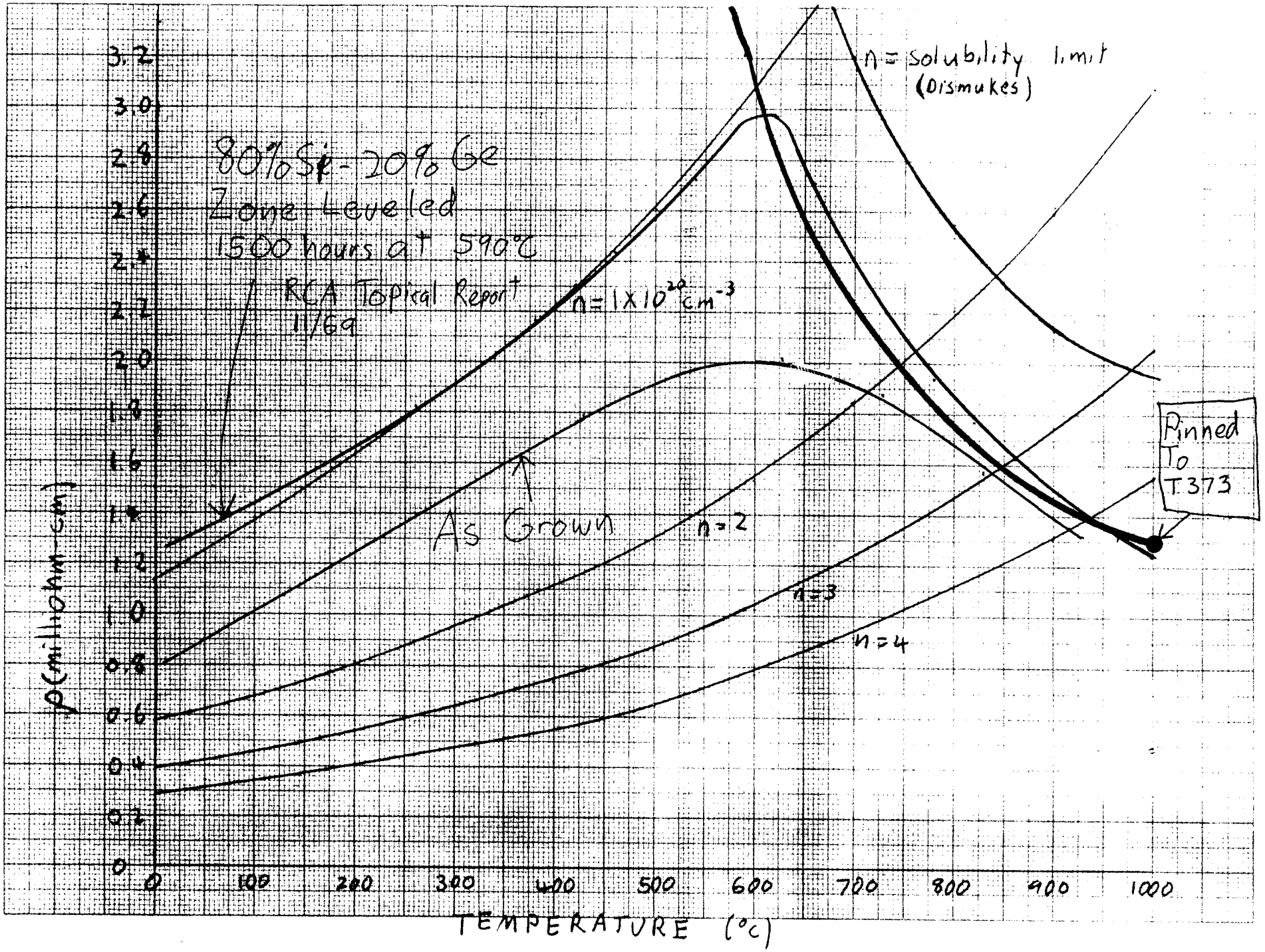


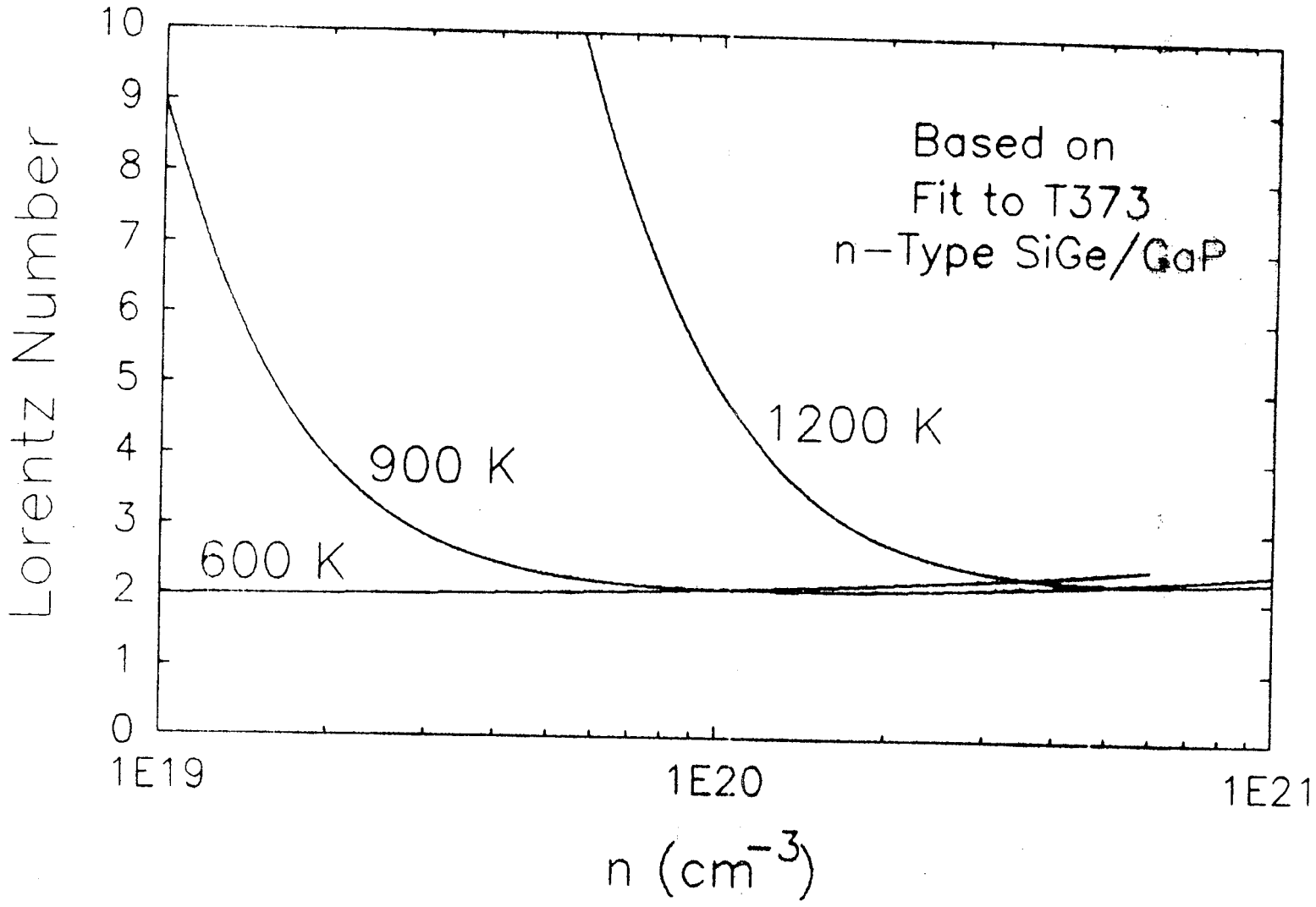
Dismukes 1

$n = Ae^{-Ea/}$

Fig. 25. Variation of the solid solubility of phosphorus with temperature in Si–Ge alloy compositions

10/87
CBV

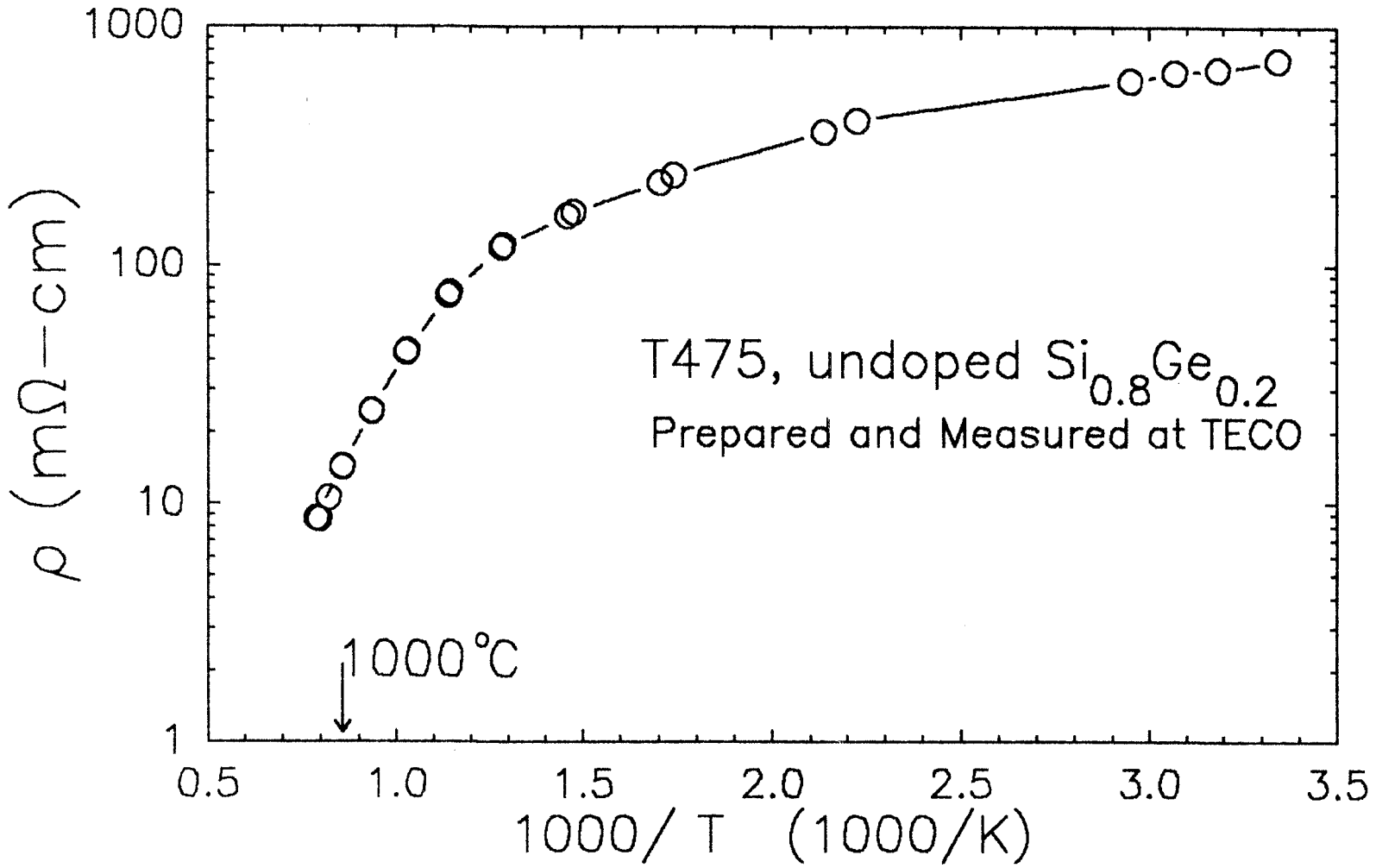

80% Si - 20% Ge
Zone Leveled
1500 hours at 590°C
RCA Topical Report
11/69
n = 1 x 10^20 cm^-3
n = solubility limit
(Dismukes)
As Grown
n = 2
n = 3
n = 4
Pinned
To
T 373
ρ (milliohm-cm)
TEMPERATURE (°C)
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
600
700
800
900
1000


Lorentz Number
10
9
8
7
6
5
4
3
2
1
0
1E19
1E20
1E21
n (cm^{-3})
Based on
Fit to T373
n-Type SiGe/GaP
1200 K
900 K
600 K

The Temperature Dependence of the Electrical Resistivity of N-Type SiGe

Summary:

- The resistivity is expected to increase at a rate between T and $T^{3/2}$ (with constant carrier concentration)
- The actual temperature dependence is closer to $T^{3/2}$ plus a constant
- The decrease in the resistivity above about 700 °C is due to phosphorus going into solution and is not "intrinsic" behavior
- Phosphorus goes in and out of solution fast enough that large changes can be observed in a matter of minutes
- The thermal conductivity is much more sensitive to "intrinsic" thermal excitation of carriers because the heat carried by an electron-hole pair is large. The high temperature increase in the thermal conductivity is "intrinsic" behavior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10
1
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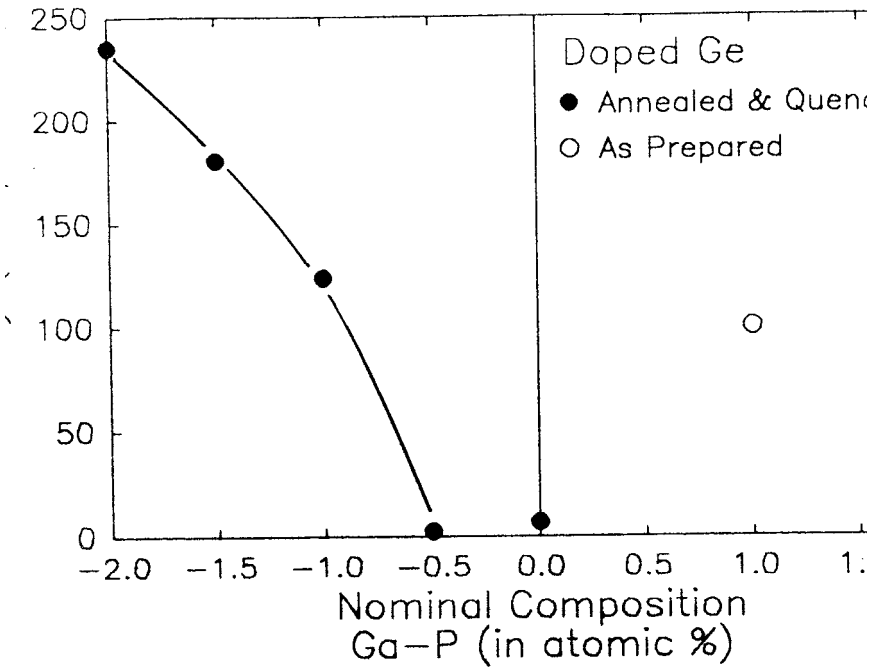
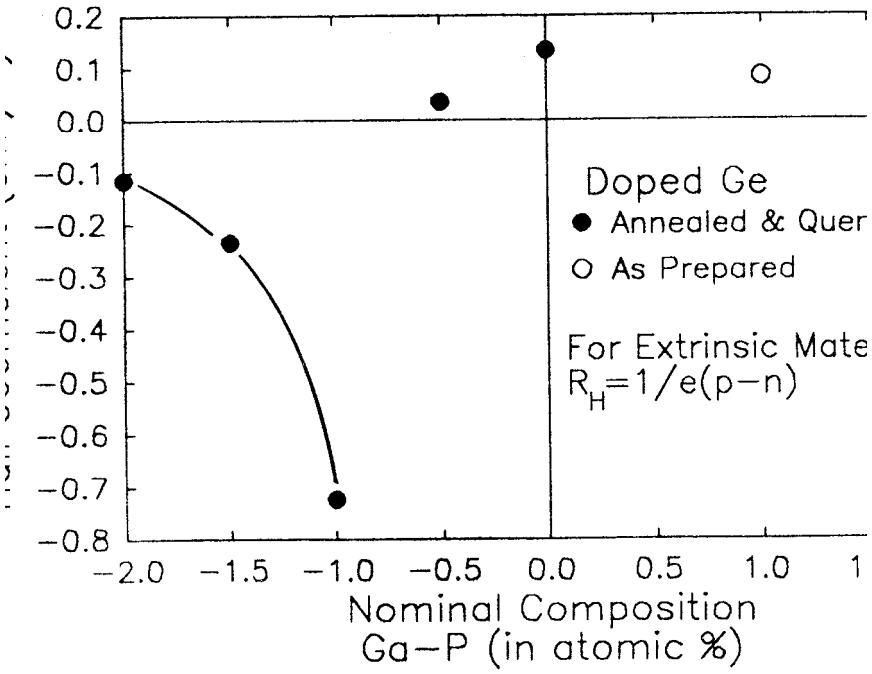
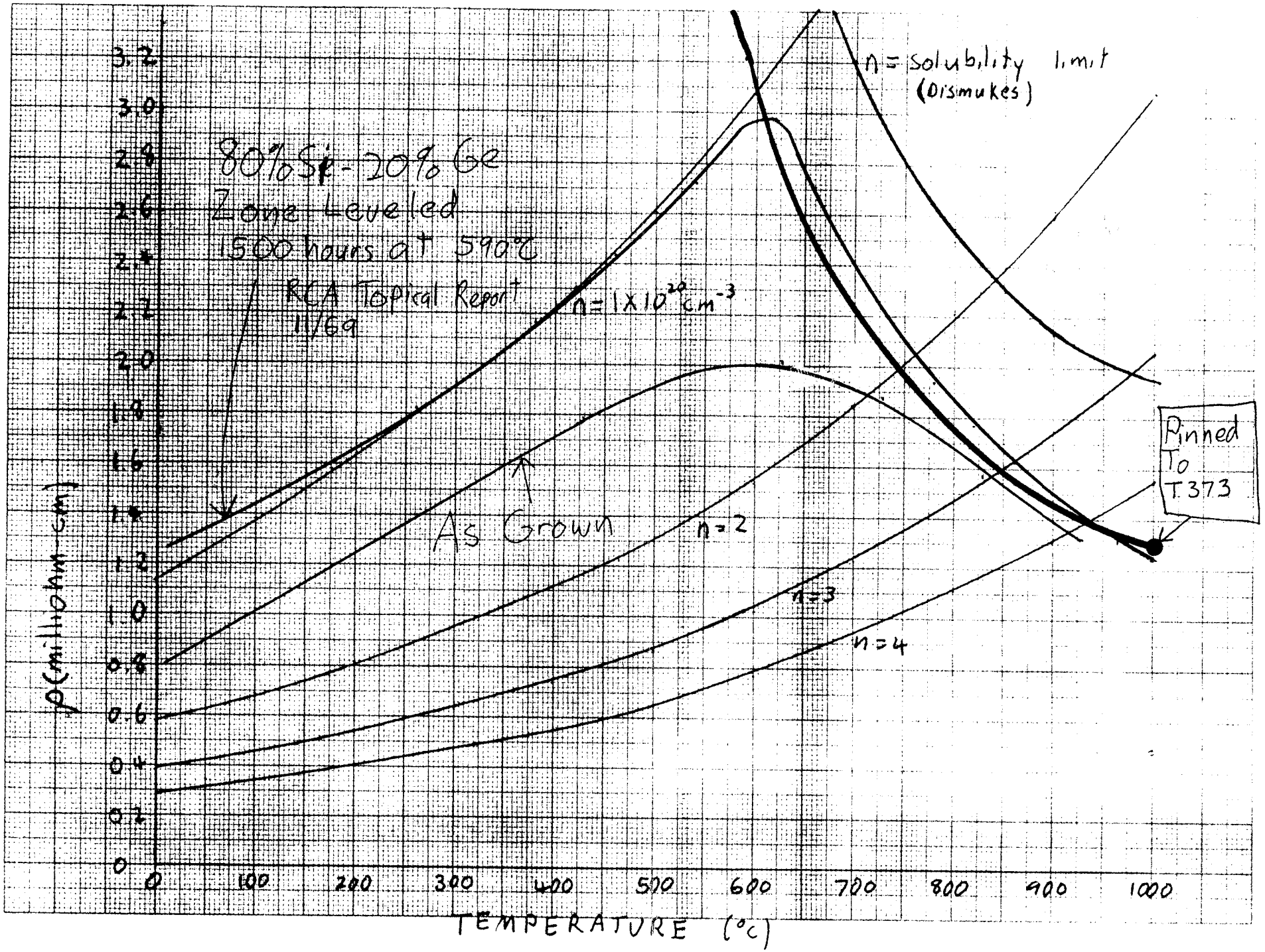

250
200
150
100
50
0
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
Doped Ge
● Annealed & Quen
○ As Prepared
Nominal Composition
Ga−P (in atomic %)


0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
−0.6
−0.7
−0.8
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
Doped Ge
● Annealed & Quer
○ As Prepared
For Extrinsic Mate
$R_H=1/e(p-n)$
Nominal Composition
Ga−P (in atomic %)

10/87
CBV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ρ (milliohm-cm)
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3.2
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2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
600
700
800
900
1000