The Application of the Continuous Anodic Oxidation Technique for the Evaluation of State-of-the-Art Front-End Structures

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Outline

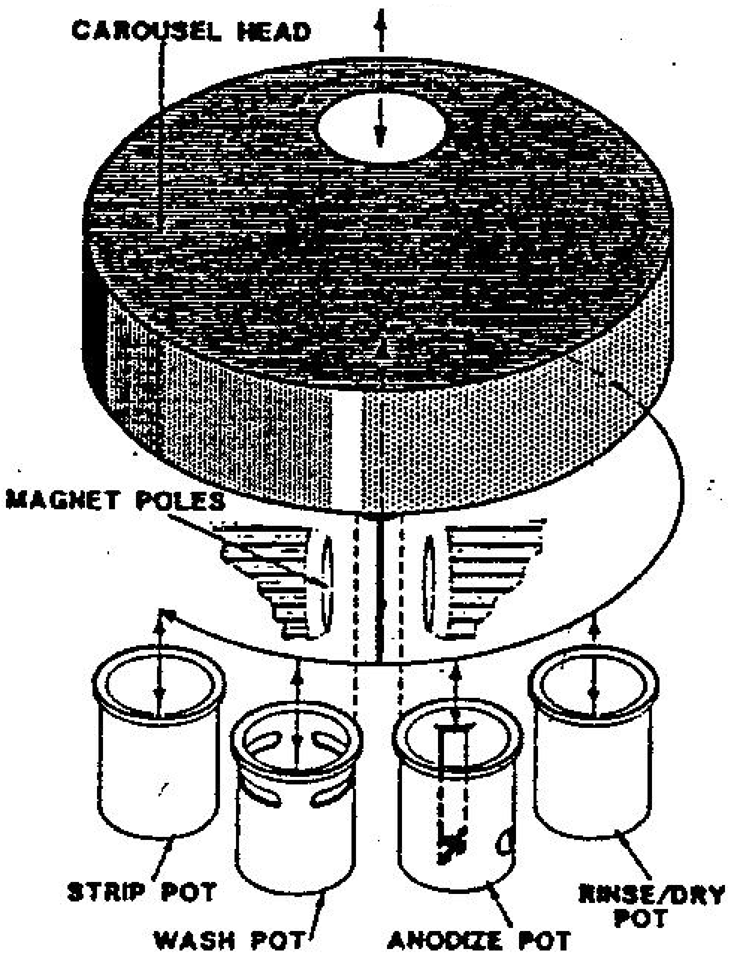
- Introduction
- A.S.T.M. Algorithm
- Defect Scattering Contribution to Mobility
- Hall Scattering Factor
- Comparison of CAOT DHE with SIMS and SRP
- Application of CAOT DHE for Doped Polysilicon Films
- Differentiation of Scattering Defects
- Conclusions

Doping Techniques and Thermal Treatments

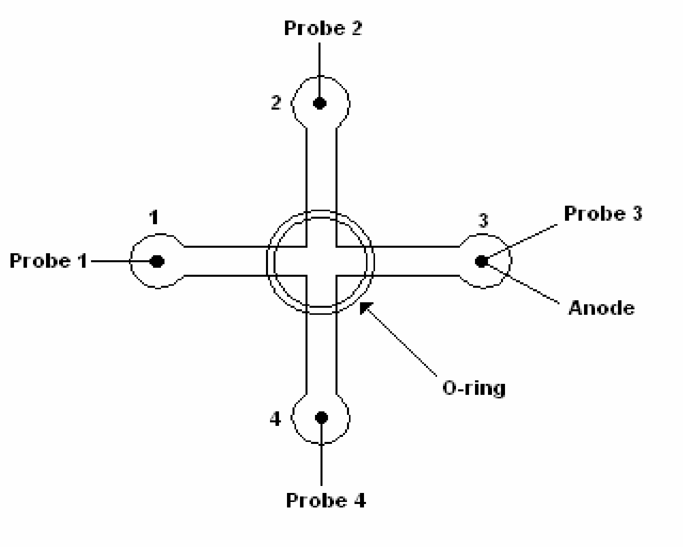
- Doping Techniques
  - Ion Implantation
  - Plasma Imersion
  - Cluster
  - Molecular
- Thermal Treatments
  - RTA
  - SPER
  - LSA (Laser Spike Anneal)
  - Flash (Arc-lamp fRTP or Xe-lamp FLA (flash lamp anneal))
  - DSA (Dynamic Surface Anneal)
  - Combinations

HL5900 Stripping Hall System

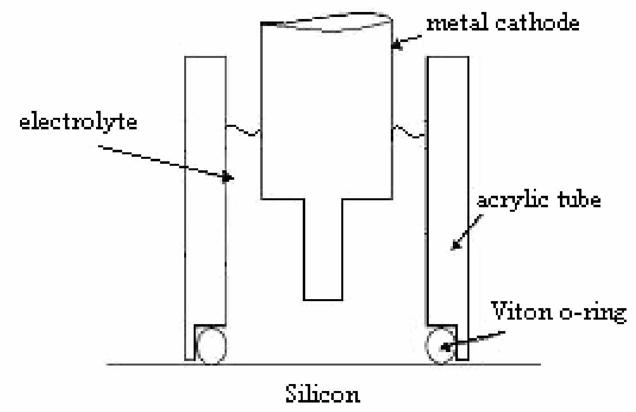
(BIORAD MICROSCIENCE)



CAOT Set-Up

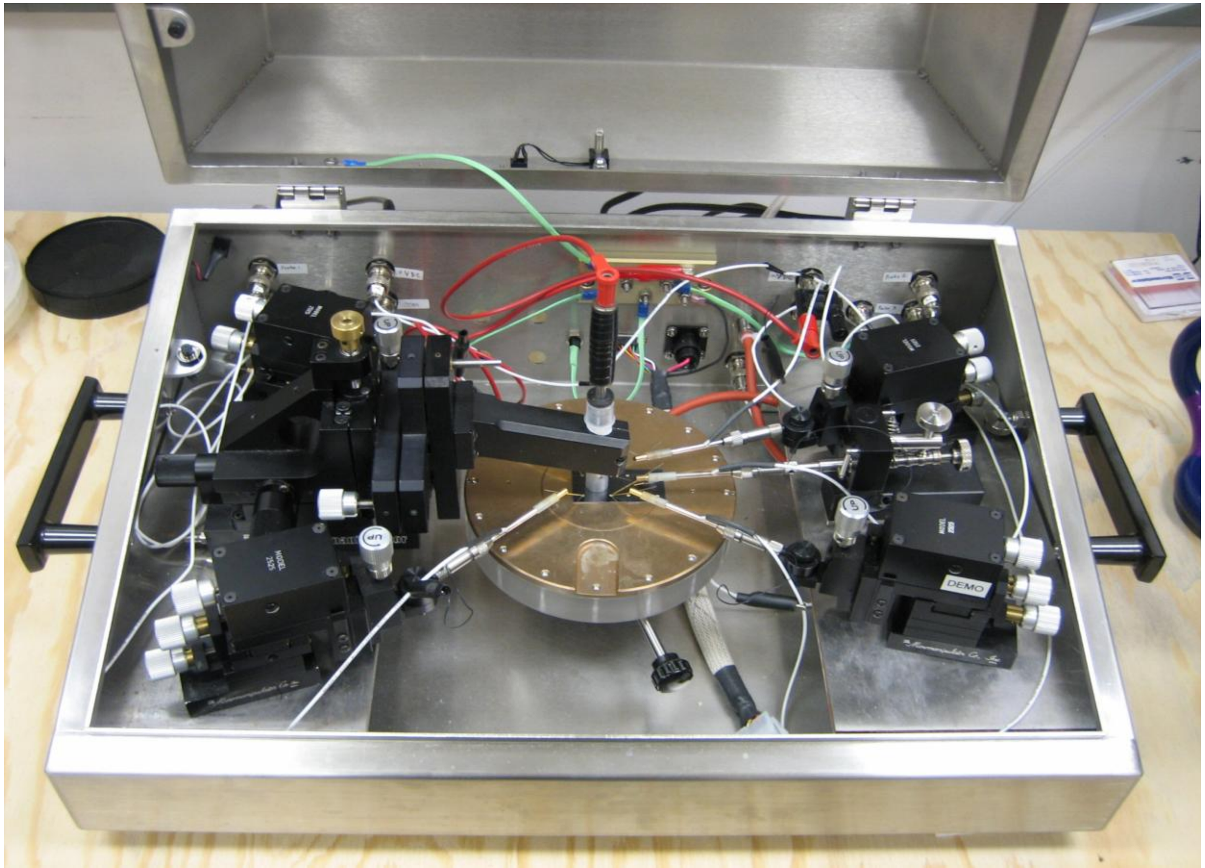


Probe 2
2
1
Probe 1
3
Probe 3
Anode
O-ring
4
Probe 4

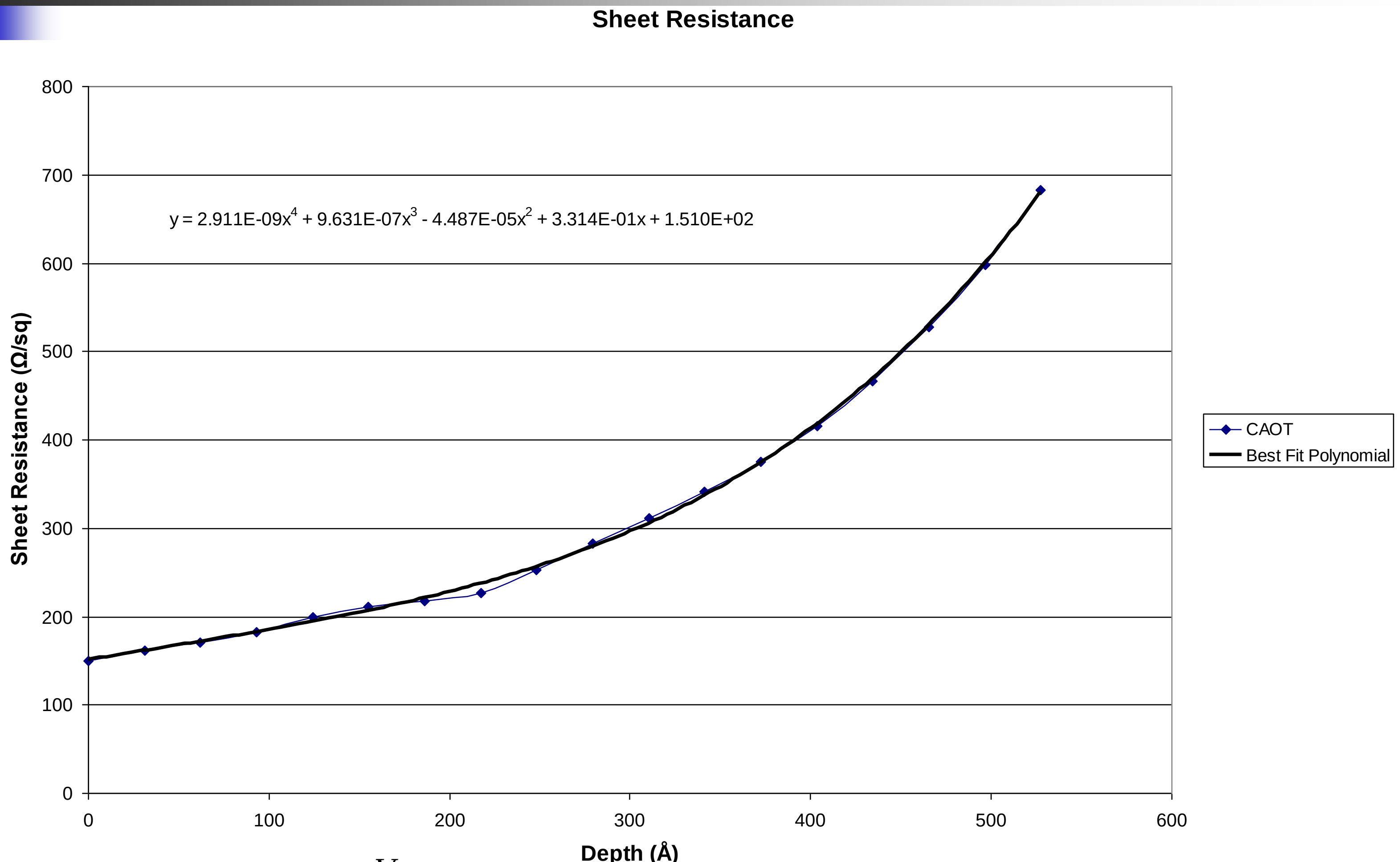


metal cathode
electrolyte
acrylic tube
Viton o-ring
Silicon

CAOT Probing Station

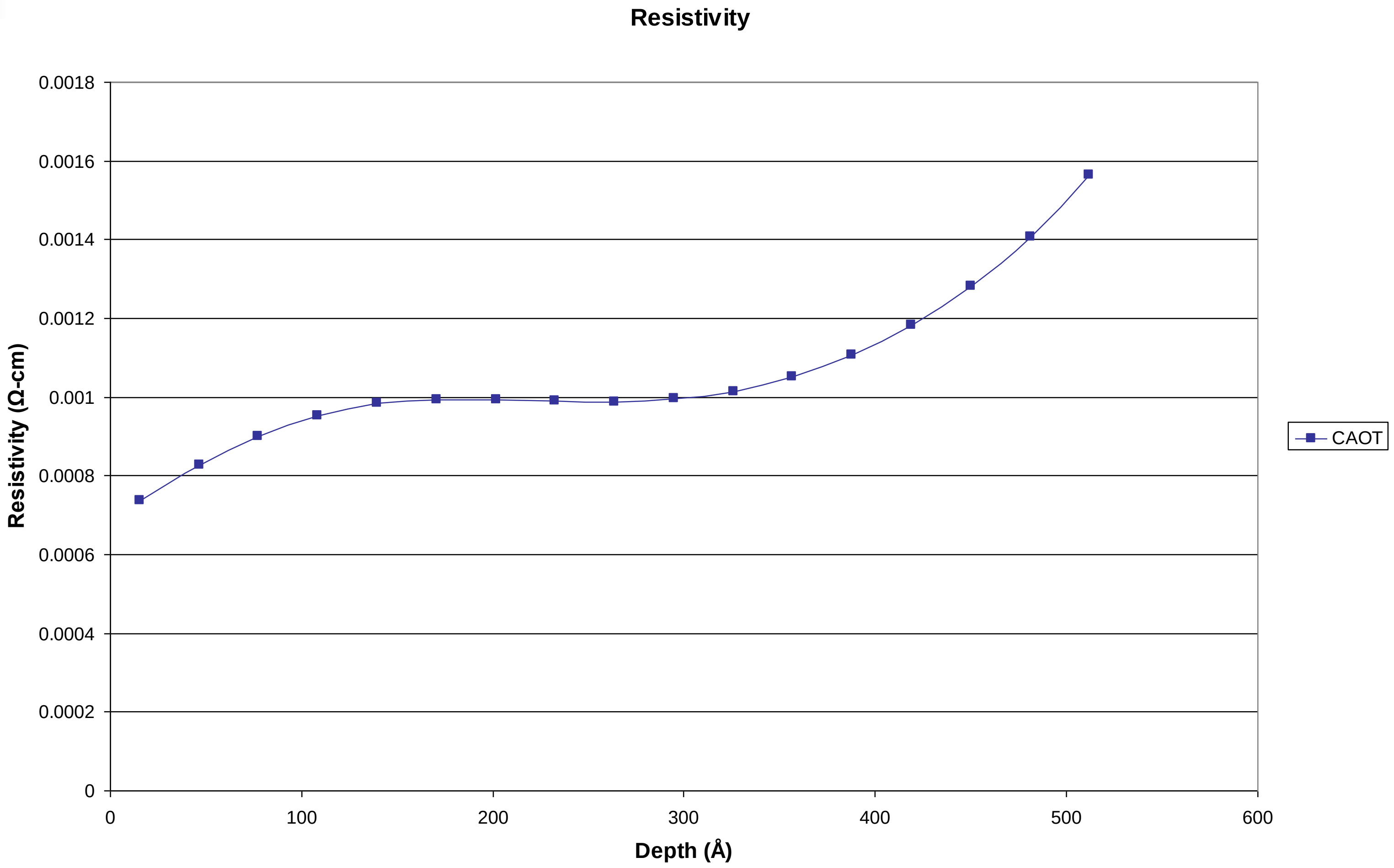


Sheet Resistance



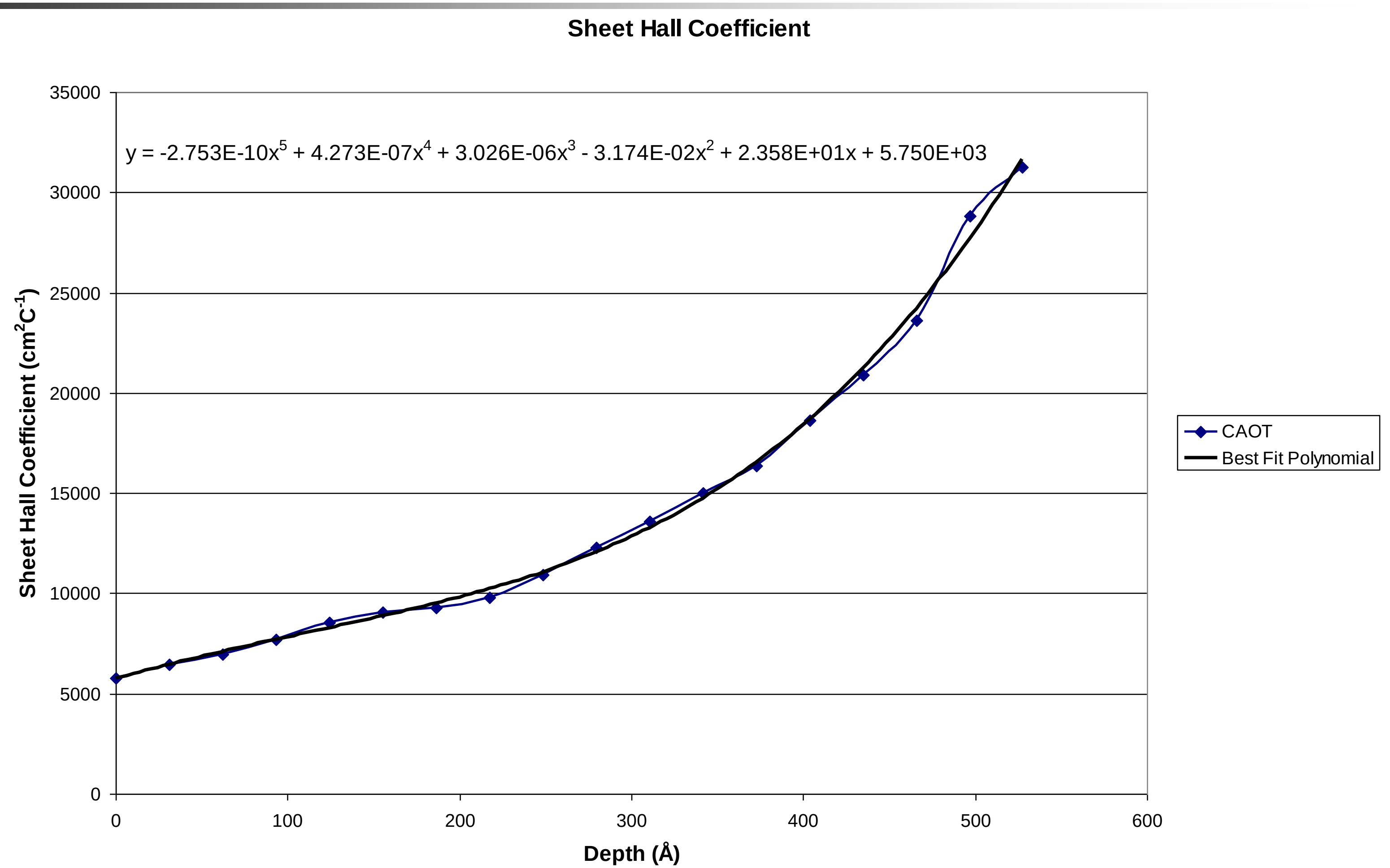
Direct Measurements $$R_S = \frac{V}{I} \cdot \frac{\pi}{\ln 2}$$

Resistivity



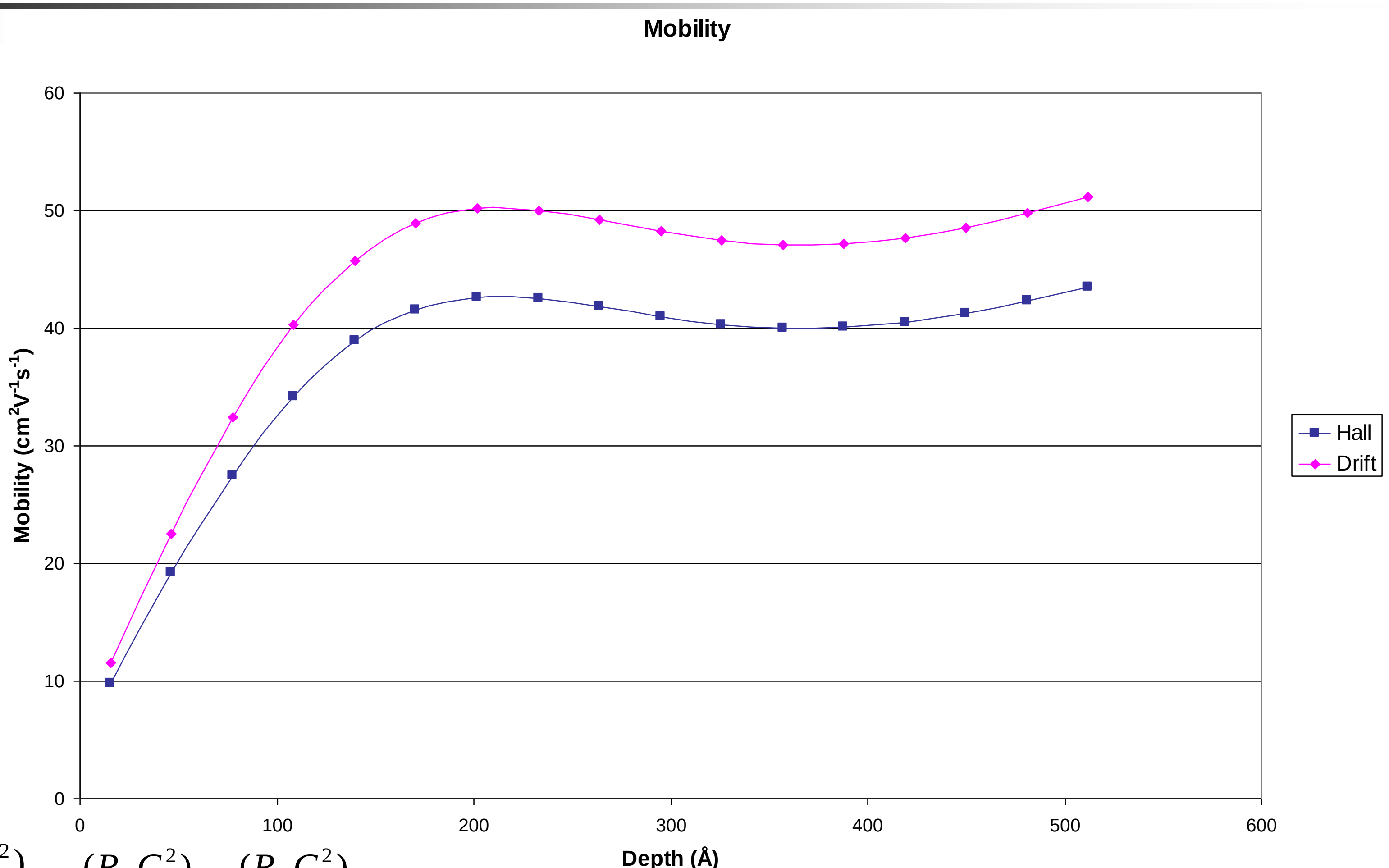
$$\rho = \Delta x \Delta R_s$$

Sheet Hall Coefficient



Direct Measurements $R_{HS} = \frac{V}{I \cdot B}$

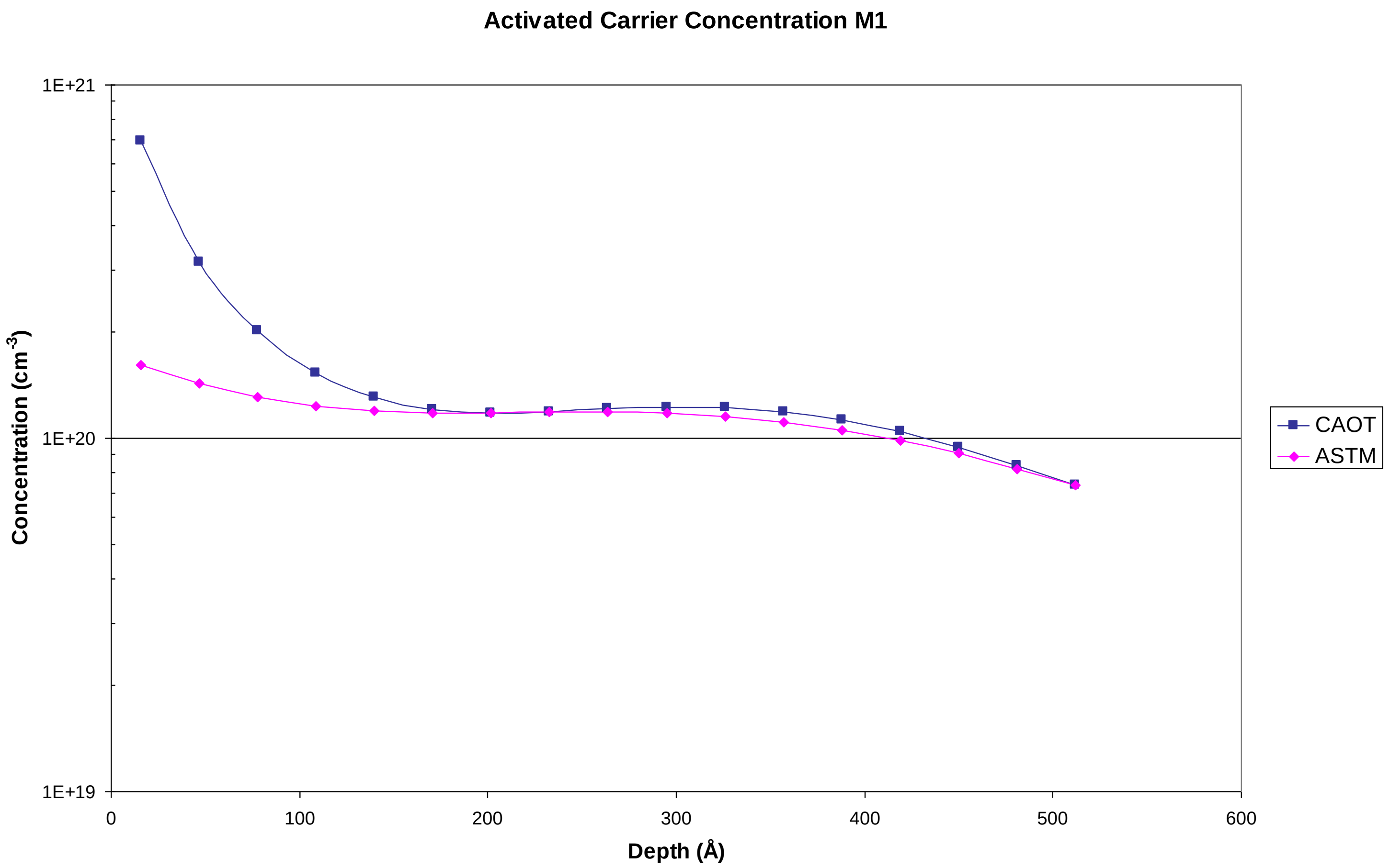
Mobility



$$\mu_{Drift} = \frac{\mu_H}{r_H}$$

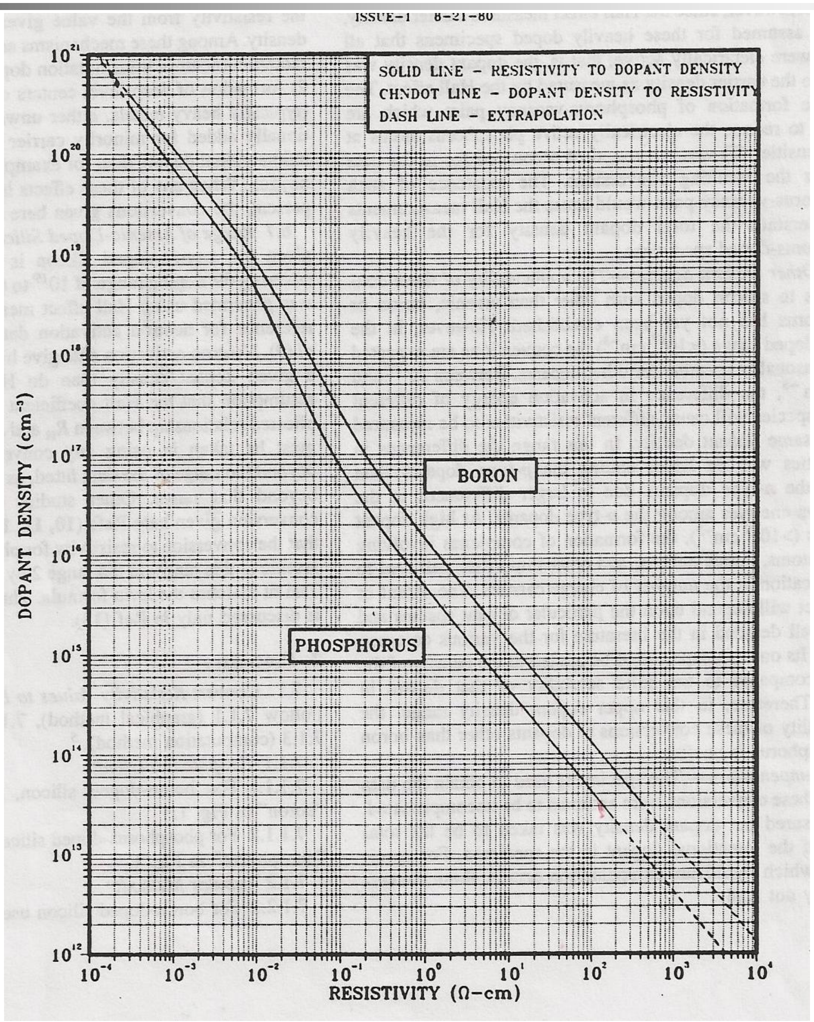
$$\mu_H = \frac{\Delta(R_H G^2)_n}{\Delta(G)_n} = \frac{(R_H G^2)_n - (R_H G^2)_{n+1}}{(G)_n - (G)_{n+1}}$$

Concentration



$$n = \frac{1}{\rho \, \mu \, q}$$

Conversion Between Resistivity and Dopant Density



Designation: F 723 – 99

Standard Practice for Conversion Between Resistivity and Dopant Density for Boron-Doped, Phosphorus-Doped, and Arsenic-Doped Silicon [1]

n-type

$$N = \frac{6.242\times10^{18}}{\rho}\times10^{Z} \quad [cm^{-3}]$$

where

$$Z = \frac{A_0 + A_1 x + A_2 x^2 + A_3 x^3}{1 + B_1 x + B_2 x^2 + B_3 x^3}$$

$x=\log_{10}\rho$

$A_0 = -3.1083$

$A_1 = -3.2626$

$A_2 = -1.2196$

$A_3 = -0.13923$

$B_1 = 1.0265$

$B_2 = 0.38755$

$B_3 = 0.041833$

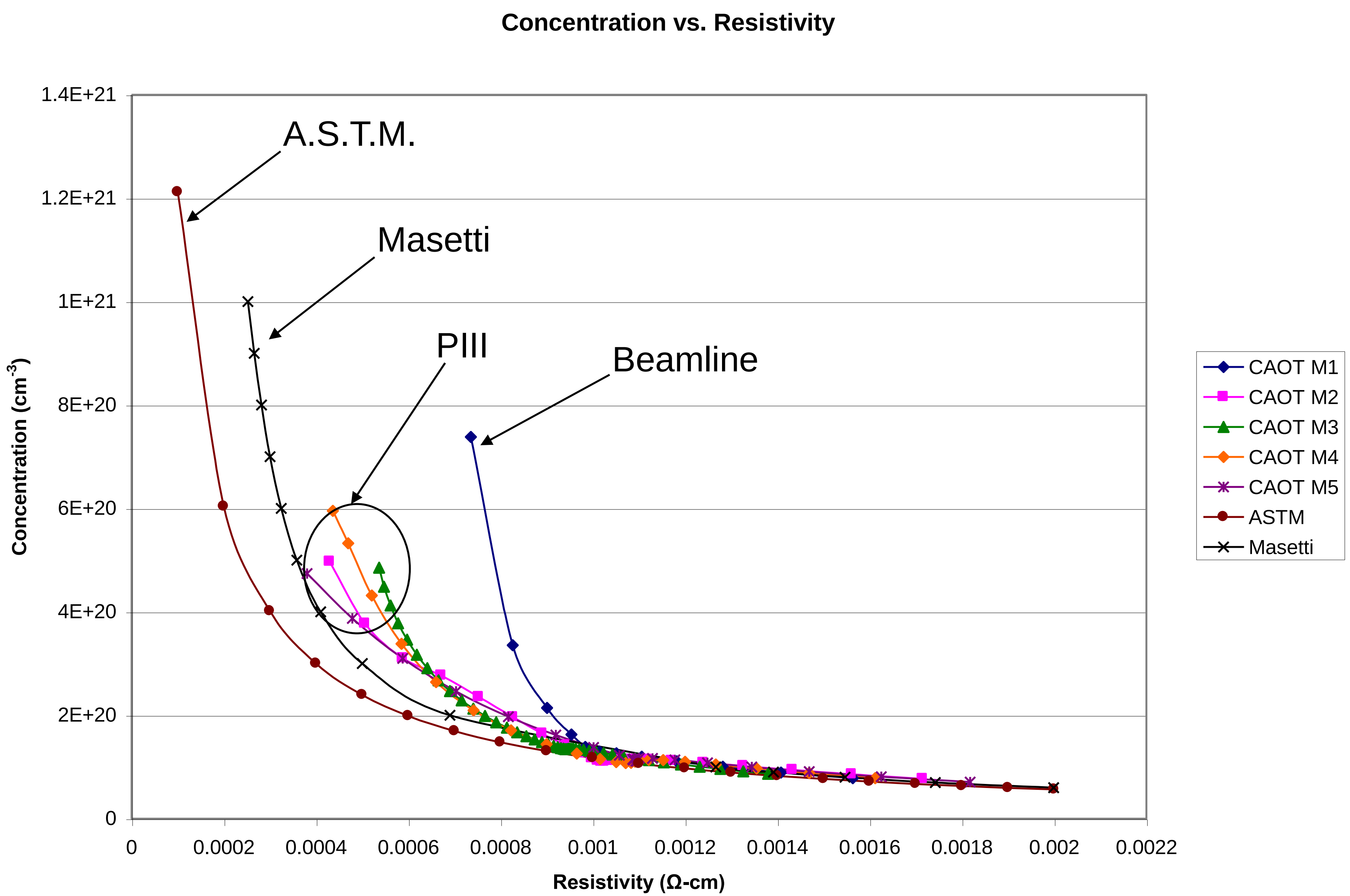
p-type

$$P = \frac{1.330\times10^{16}}{\rho} + \frac{1.082\times10^{17}}{\rho\bullet(1+(54.56\bullet\rho)^{1.105})} \quad [cm^{-3}]$$

Designation: F 672 – 01

Standard Test Method for
Measuring Resistivity Profiles Perpendicular to the Surface of a Silicon Wafer Using a Spreading Resistance Probe [1]

X3.1.4 The silicon slices in the empirical study from which these conversion relations were derived, had a lowest resistivity value of 0.00086 Ω-cm for boron-doped silicon and 0.00055 Ω-cm for phosphorus-doped silicon. Caution should be taken when applying these conversion relations to resistivities near or below these values.



$$n = \frac{1}{\rho \cdot \mu \cdot q}$$

Defect Scattering Contribution to Mobility

$$\frac{1}{\mu_0} = \frac{1}{\mu_{ph}} + \frac{1}{\mu_{coul}}$$

For carrier concentrations > ~1E20cm-3 we can add the scattering contribution of crystal imperfections and complexes

$$\frac{1}{\mu} = \frac{1}{\mu_{ph}} + \frac{1}{\mu_{coul}} + \frac{1}{\mu_{def}}$$

$$\frac{1}{\mu} = \frac{1}{\mu_0} + \frac{1}{\mu_{def}}$$

$$\mu_{def} = \frac{\mu \cdot \mu_0}{\mu_0 - \mu}$$

μ =measured CAOT DHE mobility $\left(\frac{\mu_H}{r}\right)$

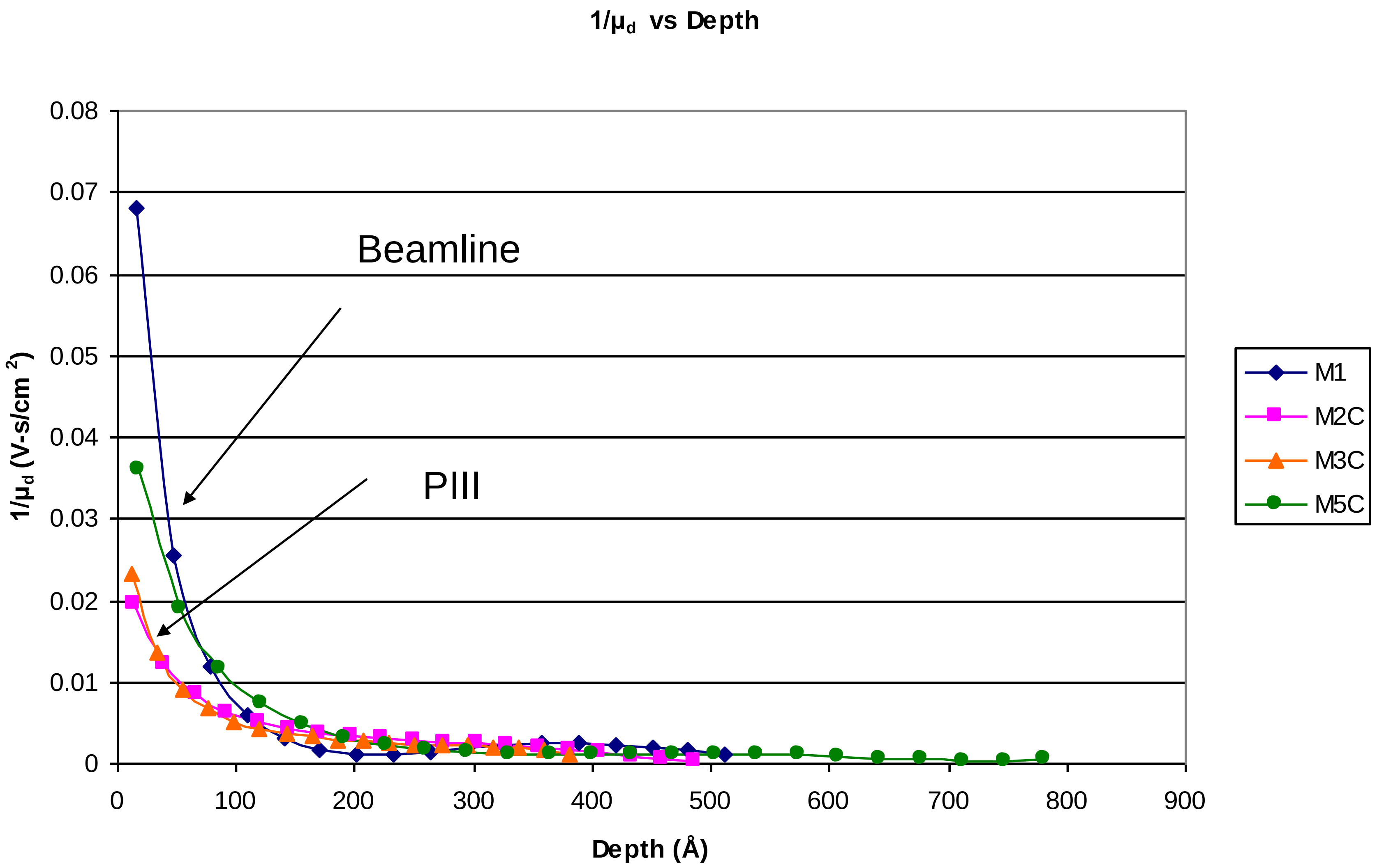
μ_0 =mobility calculated from the A.S.T.M. conversion relation

μ_{def} =scattering component due to crystal imperfections and complexes

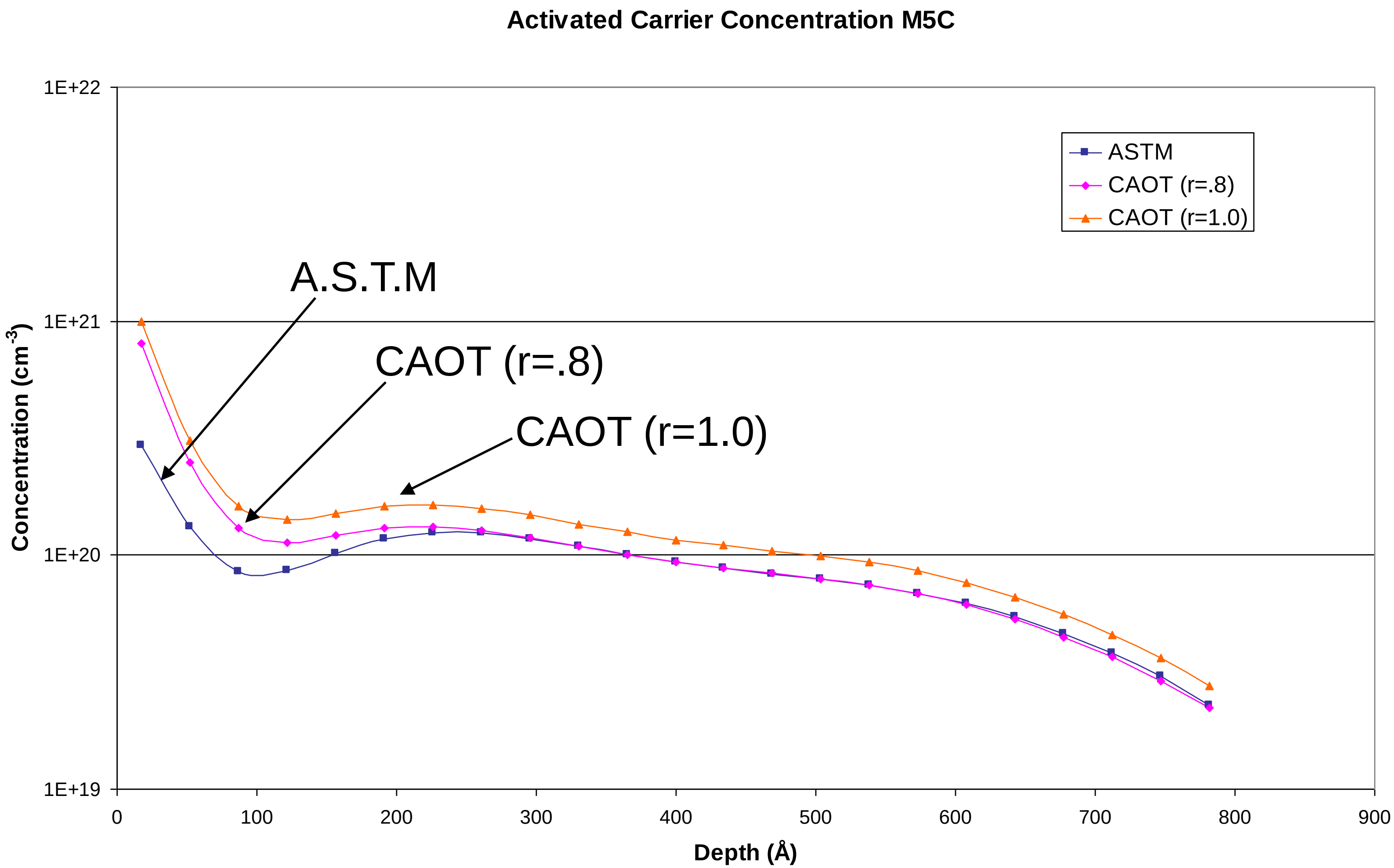
r=Hall scattering factor

Defect Scattering Contribution to Mobility (2)

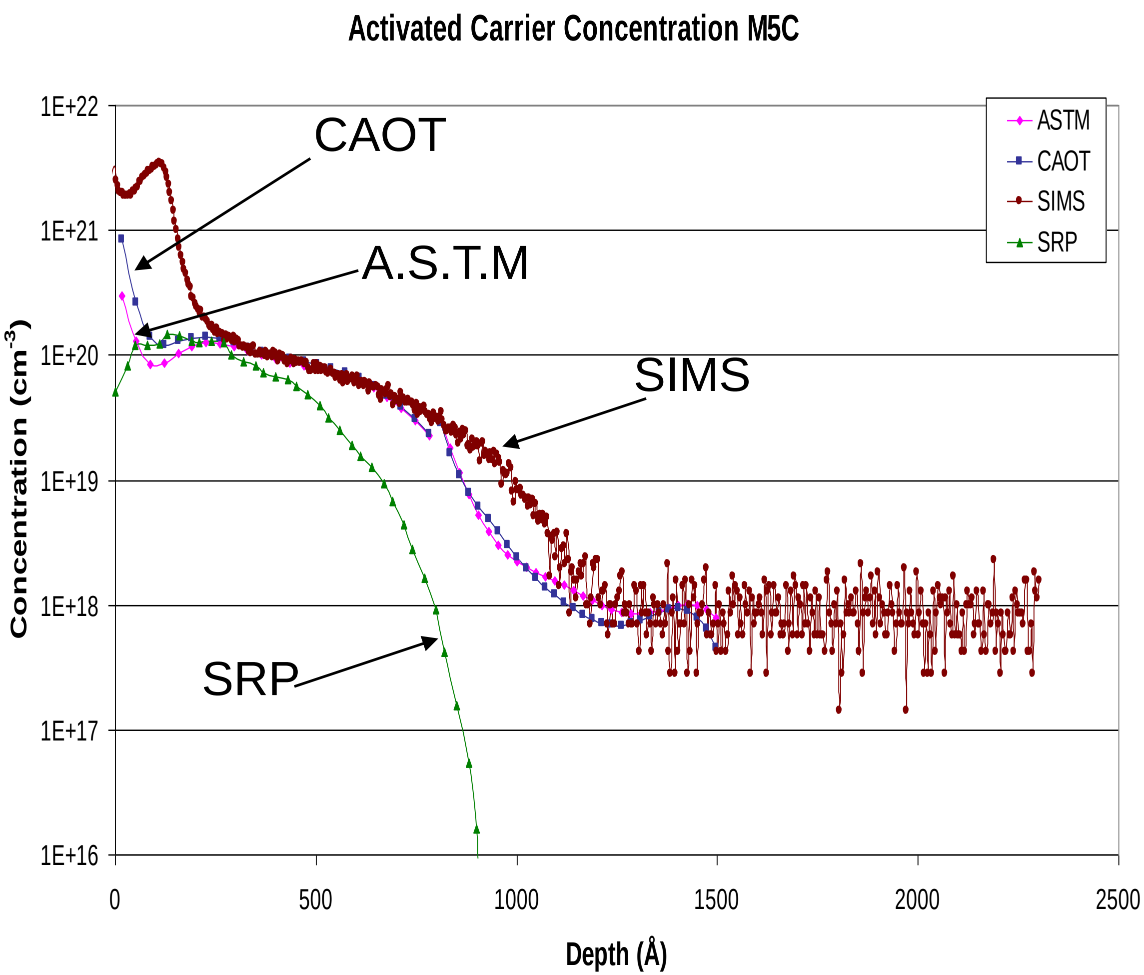
At present, several different doping techniques, such as beamline, PIII, cluster beams, and molecular beams together with various thermal activating processes are being studied as a means to satisfy ultra-shallow junction requirements for the coming generations of devices. In addition we have introduced various thermal treatments. The CAOT permits us to accurately determine the carrier concentration distribution, and the drift mobility characteristics of these competing technologies.


1/μd vs Depth
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1/μd (V-s/cm 2)
Beamline
PIII
0
100
200
300
400
500
600
700
800
900
Depth (Å)
M1
M2C
M3C
M5C

Hall Scattering Factor

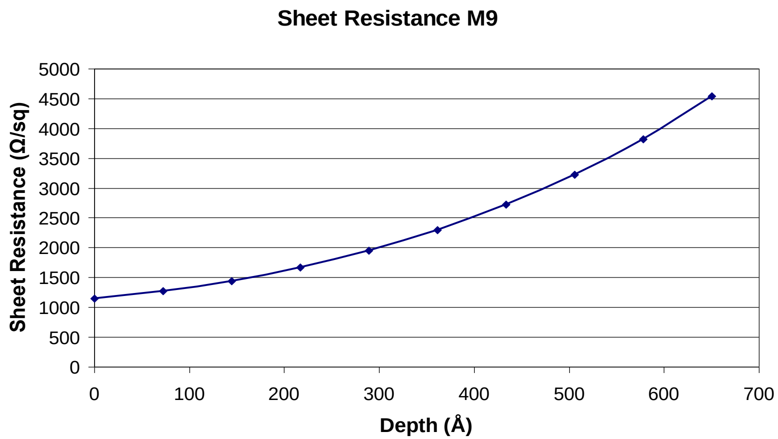


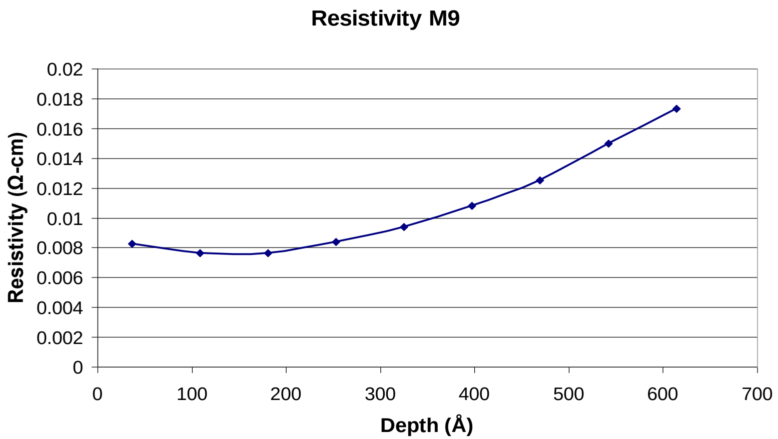
Comparison of CAOT DHE with SIMS and SRP Evaluations



- DHE tracks A.S.T.M. up to 1E20 cm^{-3}.
- SRP carrier concentration too low at surface
- SIMS at surface assumed constant B_{ss}.
- DHE provides correct surface carrier concentration
- Deactivation illustrated at ~100nm

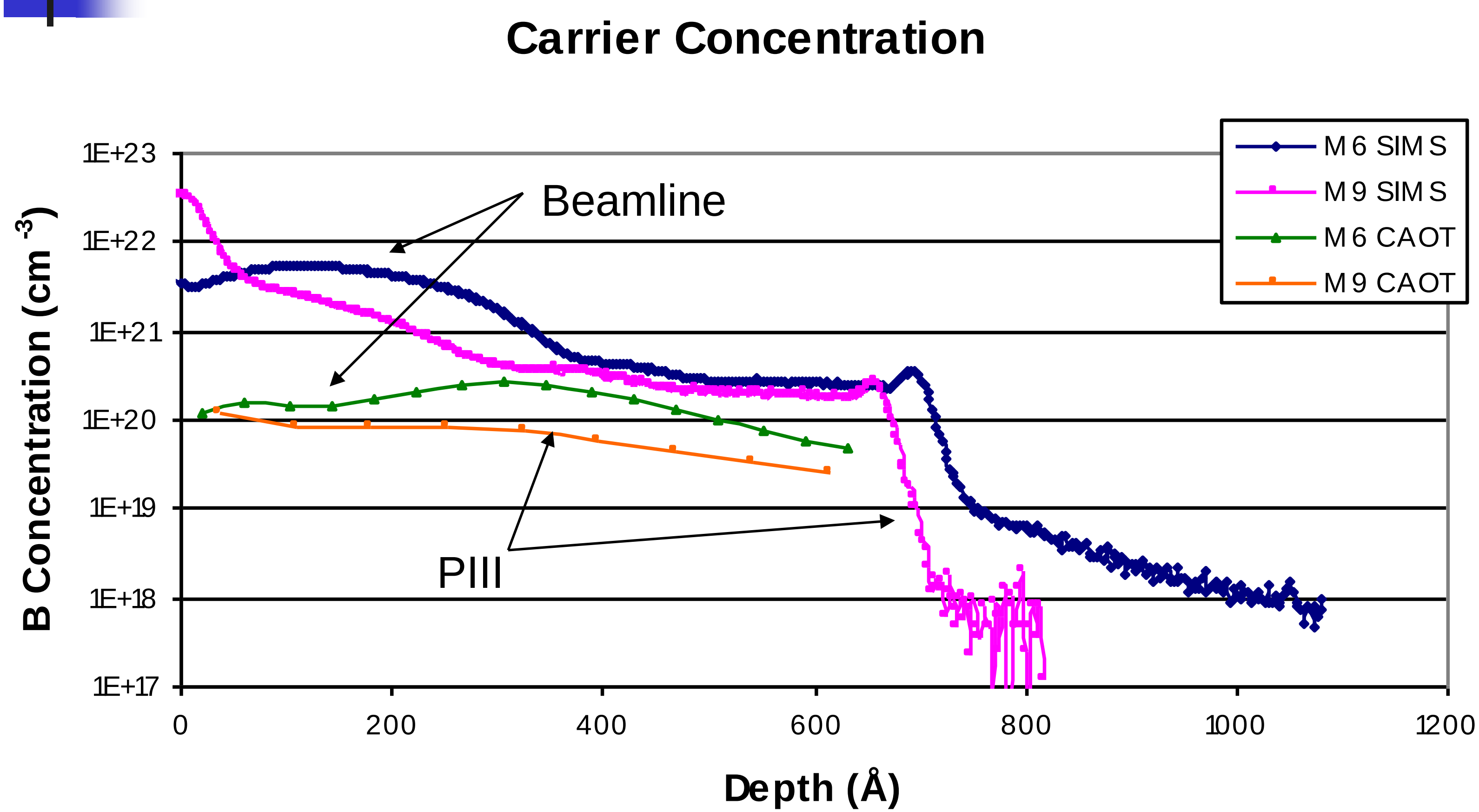
Application of CAOT DHE For Doped Polysilicon Films





Sample	4pp Rs	CAOT vdP Rs	Integrated ρ Rs	Initial Rs_i	Final Rs_f	Rs= $\frac{R_{si} \bullet R_{sf}}{R_{sf} - R_{si}}$
#	(Ω/sq)	**(Ω/sq)**	**(Ω/sq)**	**(Ω/sq)**	**(Ω/sq)**	**(Ω/sq)**
M 6	**648.24**	**642.64**	**686.16**	**642.64**	**10132.09**	**686.16**
M 7	**1409.3**	**1421.78**	**1615.03**	**1421.78**	**10922.99**	**1634.54**
M 9	**1142.8**	**1144.51**	**1641.58**	**1144.51**	**4540.71**	**1530.21**

Application of CAOT DHE For Doped Polysilicon Films (2)



Application of CAOT DHE For Doped Polysilicon Films (3)

Mobility in Doped Polysilicon Films

$$\mu_d = \frac{q\tau_{sc}}{m^*}$$

τ_{sc} = Average scattering time

$$\tau_{sc} = \frac{1}{\sigma_{sc} N_{sc} v_{th}}$$

σ_{sc} = Scattering cross-section

N_{sc} = Scattering centers/unit volume

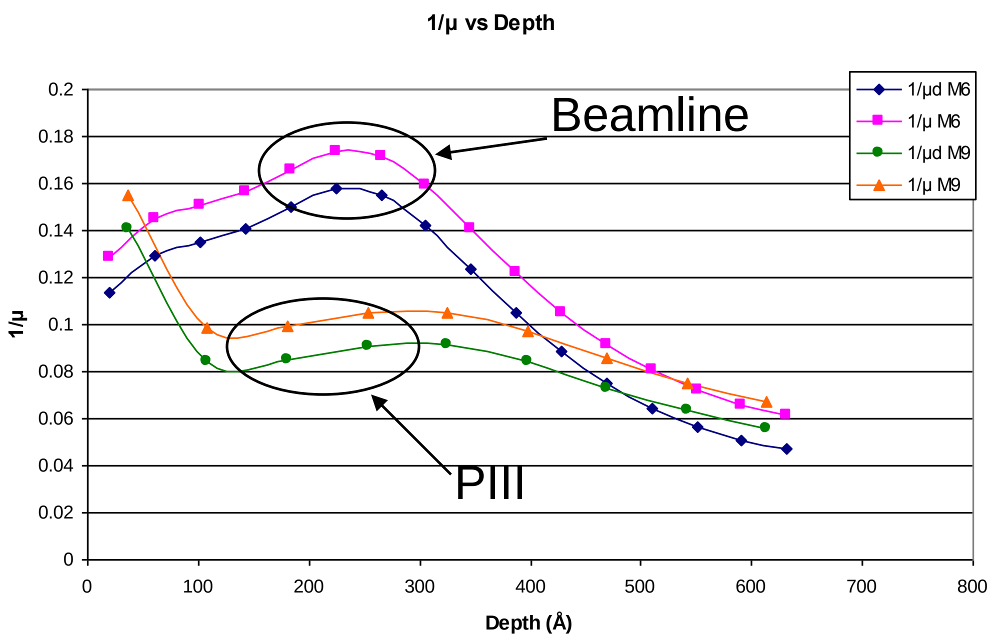
v_{th} = Average thermal velocity

$\frac{1}{\sigma_{sc} N_{sc}}$ = Scattering length

$$\mu_d = K\left(\frac{1}{\sigma_{sc} N_{sc}}\right)$$

Mobility is proportional to average distance that a carrier travels between two collisions, i.e. the average grain diameter for polysilicon.

Application of CAOT DHE For Doped Polysilicon Films (4)



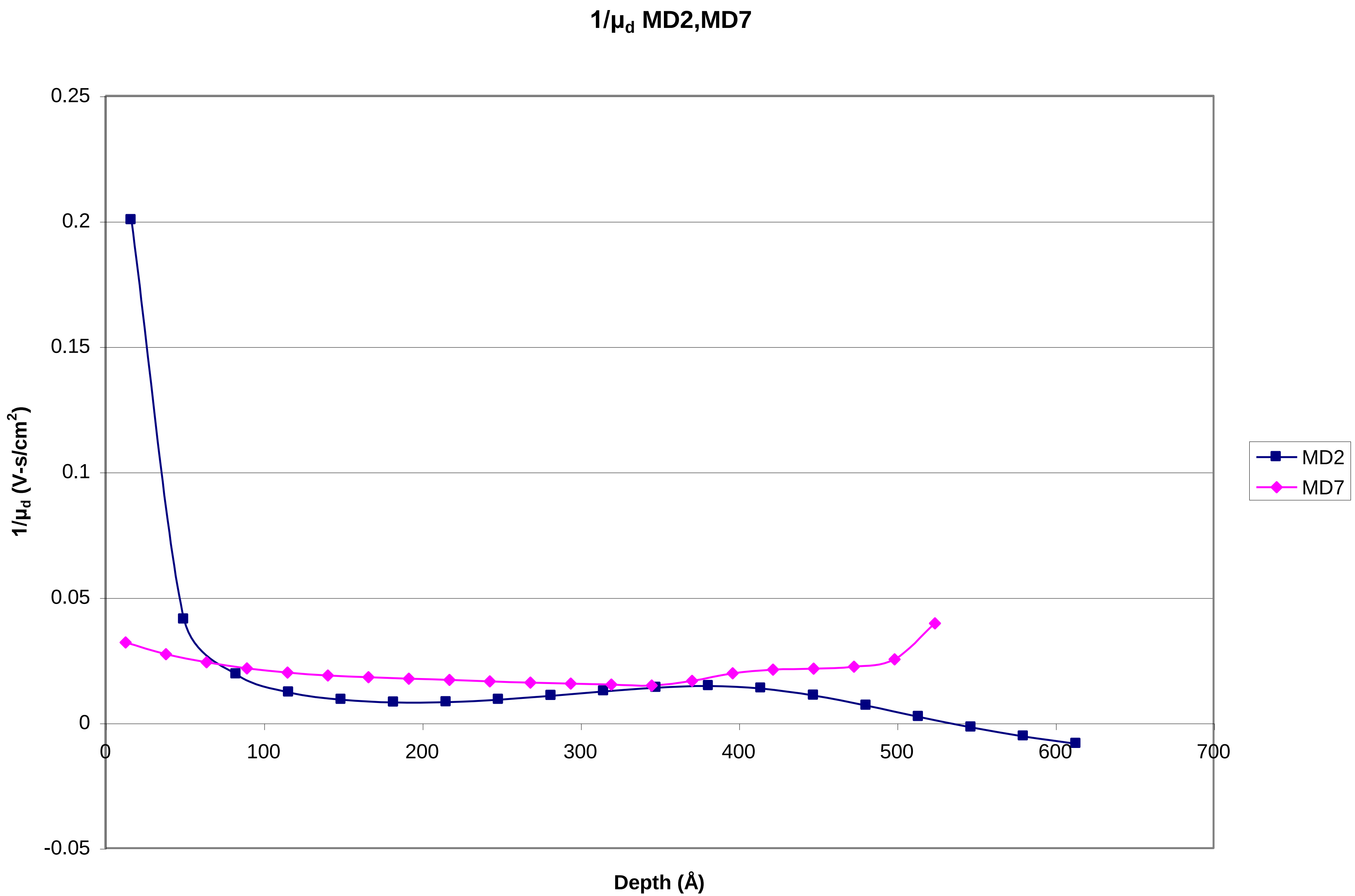
The reciprocal mobility defect component dominates throughout the thickness of the doped polysilicon thickness. Since precipitates do not appear to affect the scattering phenomenon (13), the defect component must be attributed to the grain boundaries. Queirolo (14) has proposed a semi-quantitative relationship between the mean grain size and μ_d .

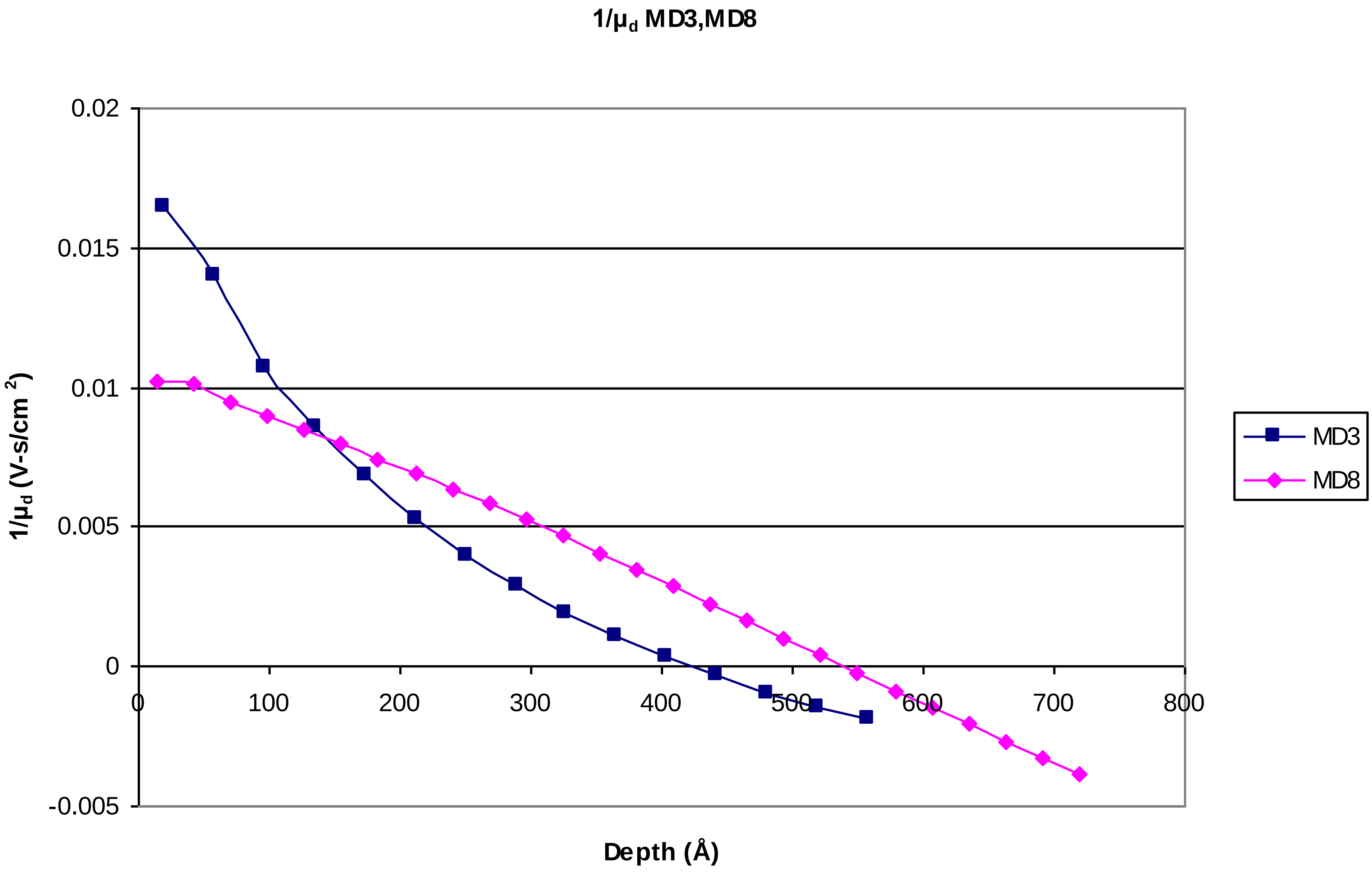
$$\mu_d = KD^{\alpha}$$

where K = 4.5E4 and α = 0.59 are constants
D (cm) = mean grain size.

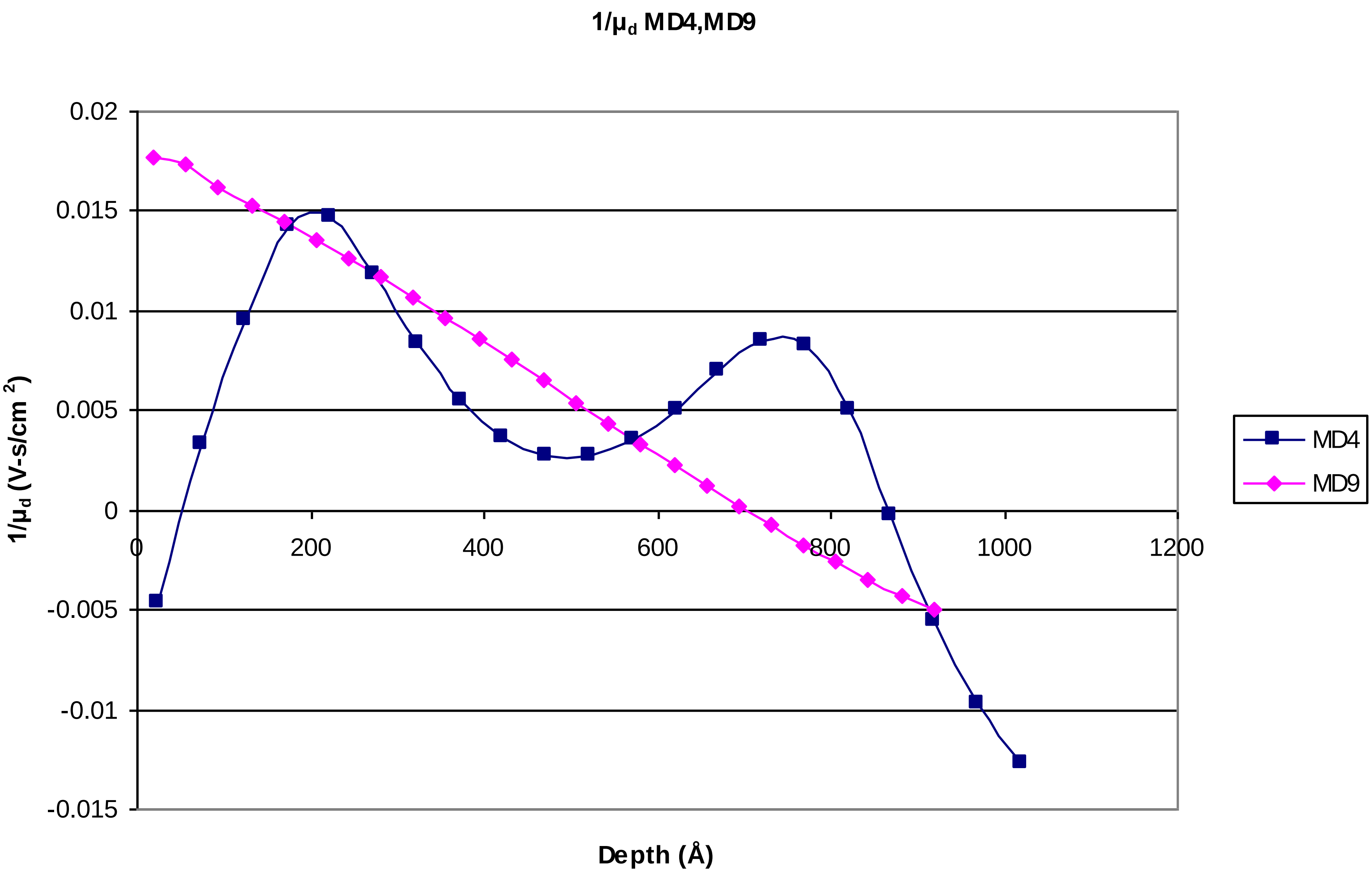
Matrix of Annealed Specimens

Wafer Slot #	Implant Type	Energy (kV)	B Dose (1/cm^2)	Anneals	4PP Rs (Ω/sq)		Rs 1σ (%)	
					600°C/30min	1000°C/20s	680°C/100min	1000°C/20s
MD1	BF2	BF40K4E15		No	NA			
MD2	BF2	BF40K4E15		Anneal1	209.56 (0.470)	NA		
MD3	BF2	BF40K4E15		RTP2	209.86 (0.397)	84.52 (0.516)	NA	
MD4	BF2	BF40K4E15		Anneal3	210.08 (0.272)	84.68 (0.462)	91.4 (0.688)	NA
MD5	BF2	BF40K4E15		RTP4	209.98 (0.445)	84.62 (0.540)	91.5 (0.57)	76.10 (0.748)
MD6	B2H6 PLAD	BH12K2E16		No	NA			
MD7	B2H6 PLAD	BH12K2E16		Anneal1	196.79 (2.650)	NA		
MD8	B2H6 PLAD	BH12K2E16		RTP2	196.82 (2.729)	87.65 (2.344)	NA	
MD9	B2H6 PLAD	BH12K2E16		Anneal3	197.41 (2.807)	87.90 (2.293)	94.41 (2.406)	NA
MD10	B2H6 PLAD	BH12K2E16		RTP4	197.61 (2.577)	87.48 (2.134)	93.87 (3.086)	75.61 (3.086)

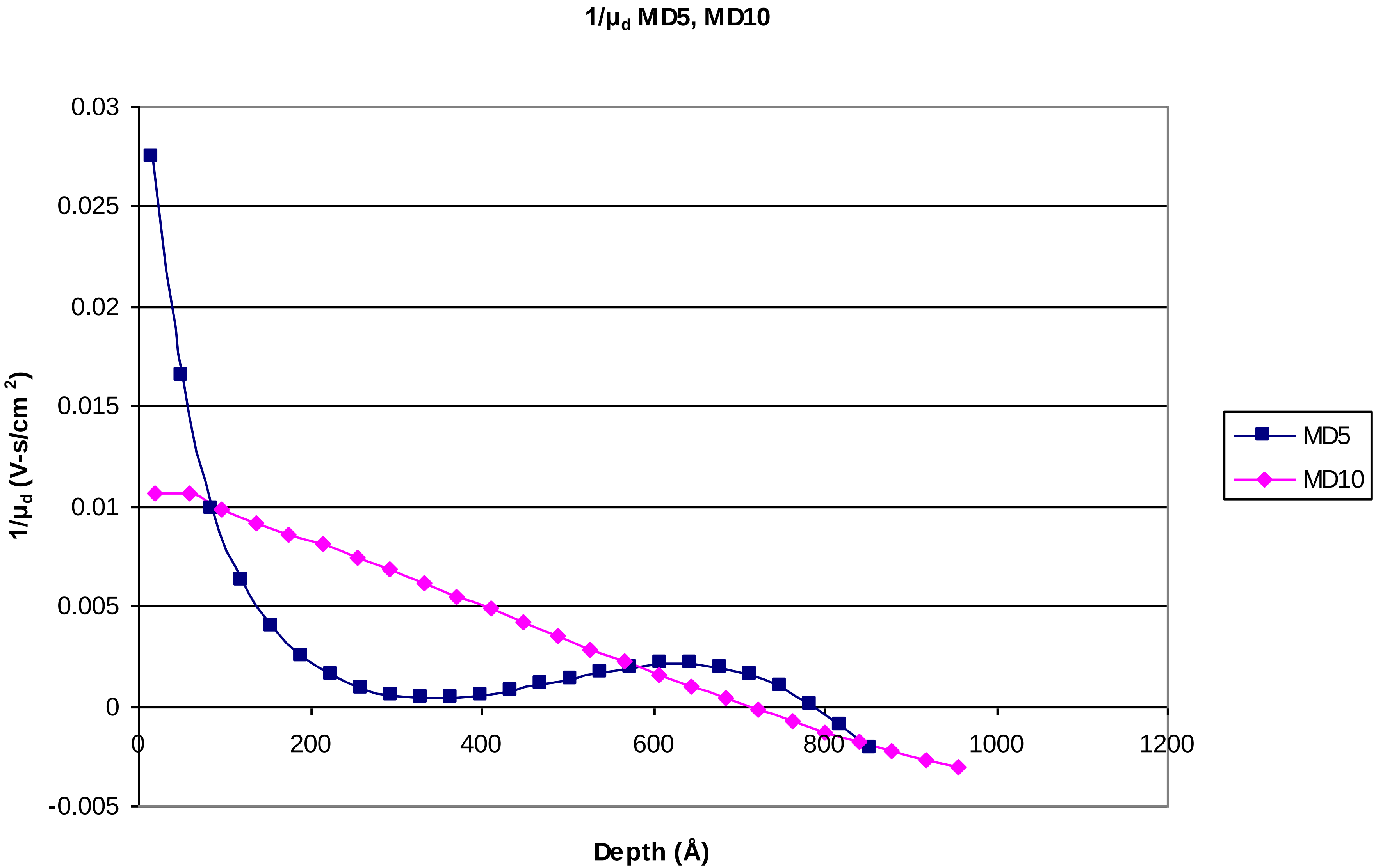

1/μd MD2,MD7
1/μd (V-s/cm2)
0.25
0.2
0.15
0.1
0.05
0
-0.05
0
100
200
300
400
500
600
700
Depth (Å)
MD2
MD7



1/μd MD3,MD8
0.02
0.015
0.01
0.005
0
-0.005
1/μd (V-s/cm 2)
0
100
200
300
400
500
600
700
800
Depth (Å)
MD3
MD8



1/μd MD4,MD9
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
1/μd (V-s/cm 2)
0
200
400
600
800
1000
1200
Depth (Å)
MD4
MD9



1/μd MD5, MD10
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
0
200
400
600
800
1000
1200
1/μd (V-s/cm 2)
Depth (Å)
MD5
MD10

Measurement Capabilities

- Accurate Carrier Concentrations up to the Surface
- Total Activated Dose
- Accurate Drift Mobilities
- Location and Magnitude of Scattering Defects
- Magnitude of Strain Enhanced Mobility
- Polysilicon Grain Size

Measurable Structures

- p+n , n+p USJ’s
- Doped Polysilicon Films
- Processed SOI
- Strain Enhanced Mobility Layers

Contributions of CAOT

- 1. CAOT can be completely automated, allowing for push-button operation.
- 2. Time for a complete evaluation was greatly decreased, from hours to minutes.
- 3. Precision was increased, permitting atomic layer resolution, especially useful for surface evaluation.
- 4. Drift mobility profiles are obtainable.
- 5. Active dopant profiles can be obtained rather than the total dopant distribution obtained with SIMS.
- 6. Permits the evaluation of the magnitude and location of carrier de-activation and scattering defects

Conclusions

- The CAOT applied to DHE permits us to accurately evaluate ultra shallow junctions making it possible to also evaluate the higher carrier concentrations above 1E20 cm^{-3}.
- The distribution of the defect contribution to the mobility can be determined
- Comparison of the carrier concentration distribution below 1E20 cm^{-3} with the A.S.T.M. algorithm permits us to evaluate the accuracy of our measurements.
- For doped polysilicon films, it is possible to determine the carrier concentration distribution as well as the mobility scattering component distribution due to grain boundaries.
- The DHE data permits us to comparatively evaluate different doping and thermal annealing techniques.
- Potential to study strain enhanced mobility.