Issue of Large Diameter Si Wafer Making

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Electronics grew up to the largest industry in the world supported by Si wafer. In near future, the Si wafer may use 300mm in diameter for economic requirement. This size wafer may use to produce large logic chip, 256Mbit DRAM or 1Gbit DRAM, and other large complex and high density chip. Then, the quality including flatness and crystal characters may be required very high performance. And, their price should be reasonable and high quantity may be required. These requirements should be solve lot of hard problems of crystal growth, wafering mechanical processing and their cost problems. In this presentation, I may discuss following items.

1) Introduction

1.1: History of Wafer Diameter Increasing
1.2: Si Wafer Diameter and Device Chip Size

2) Issue of Large Diameter Si Wafer Making

2.1: Issue of Large Diameter Si Crystal Growth
2.2: Issue of Wafer Making

3) Issue of Large Diameter Si Crystals

3.1: Temperature Gradient, Thermal History and Pulling Speed
3.2: Mechanical Strength of Seed
3.3: Large Size Puller
3.4: Thermal Properties of Related Materials
3.5: Economy of Large Diameter Si Crystal Growth

4) Issue of Mechanical Processing

4.1: Cost of Mechanical Processing
4.2: Slicing
4.3: Lapping and Polishing

5) Coming Problems

The 3rd Korea-Japan Electronic Materials Growth Symposium and
9th Meeting of KACG Joint Meeting

Issue of Large Diameter Si Crystal Growth
Requirement and Keeping up with the Trend

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Shin'Ichiro Takasu

at Hotel Dogo, Korea, June 7th, 1996

AGENDA

1 : Introduction
2 : Logic of Wafer Diameter Increasing and its History
    2.1 Logic of Wafer Diameter Increasing
    2.2 History of Diameter Increasing
    2.3 History of Flatness
    2.4 Case Study
3 : Keeping up with the Trend of Large Diameter Si Wafer
    3.1 Flow Chart of Wafer Production
    3.2 Change of Pulling Instruments
    3.3 Prediction of Wafer Demand and Crystal Growth
    3.4 Issue of Large Diameter Crystal Growth
        a Common Problems of Large Diameter Crystal Growth
        b In Case of Extrapolation
        c In Case of Change
4 : Summary and Future Issue

1 : Introduction

Information Revolution	Internet, Net System
System Change	Distribution System
Communication Mode	Mobil Communication

Requirement for System

→High Grade and High Speed Connumication with Image Processing

→High Performance Personal Computer

Requirement for Devices

→Large, Comprex and Low power Chips are required.

CMOS is main Device Structure

High performance μ-processor	>300mm^2
Large & High Speed DRAM	>300mm^2 for 256Mbit
Digital Signal Processor	High Performances & High Speed

Requirement for Wafer

→Large Diameter Si (Epi-) Wafer

Wafer Diameter	"/mm	2"/50	3"/75	100	125	150	200	(250)	300	(350)	(400)
Generation Change Area Ratio					1→	1.440		*1 →*	*1.440*		
				1→	1.563		*1 →*	*1.563*			
			1→	1.778		1→	1.778				
						1→			4.000		
		1→	2.250	1→		2.250	1→		2.250		
							1 →			*3.063*	
							1 →				*4.000*
Thickness	t("/mm)	0.011"	0.015"	0.625	0.625	0.625	0.725	0.750	0.775	0.800	0.825
Thickness/Diameter		*0.0055*	*0.0050*	*0.0063*	*0.0050*	*0.0042*	*0.0036*	*0.0030*	*0.0026*	*0.0023*	*0.0021*
	t(mm)			0.525		0.675					
				0.0053		*0.0045*					
Change of Diffusion Furnace		Auto sorter Furnace Horiz.→Vertical → Balanced Support Casing → Ramp up and Down Soft Landing Canti-lever One Wafer → Plate Cluster Tool → Strecher Mini Environment →									
Theory and Simulation		**Hu** Exp. Simulation → Computer Simulation **(IBM)** (Comp. Simulation)									
Slip Observation Methods		Etching Obs. Lang Topography IR photoelasticity		→ →	→ →	→ →	→ →		→ →		

2 : Logic of Wafer Diameter Increasing and its History

2.1 Logic of Wafer Diameter Increasing

100 Chips Rule

100 Chips Rule and Wafer Dia Change

Generation	0	1	2	3	4	5	
Wafer Dia D1	***>100chips***	***>100chips***	<100chips				6Years
Wafer Dia D2	>100chips	>100chips	***>100chips***	<100chips			3Years
Wafer Dia D3	>100chips	>100chips	***>100chips***	***>100chips***	<100chips		6Years
Wafer Dia D4	>100chips	>100chips	>100chips	>100chips	***>100chips***	***>100chips***	6Years

Wafer Diameter Change and Factory Generation

		Factory1	Factory2	Factory3	Factory4
Case 1	Wafer Dia D1→D2→D3→D4	6Years→	3Years→	3Years→	6Years
	Device Generation	0, 1	2	3	4, 5
Case 2	Wafer Dia D1→D3→D4	6Years→	6Years→	6Years	
	Device Generation	0, 1	2, 3	4, 5	

1 Device Generation Life : 3years, 1 factory Life : ~6Year

2 : Logic of Wafer Diameter Increasing and its History

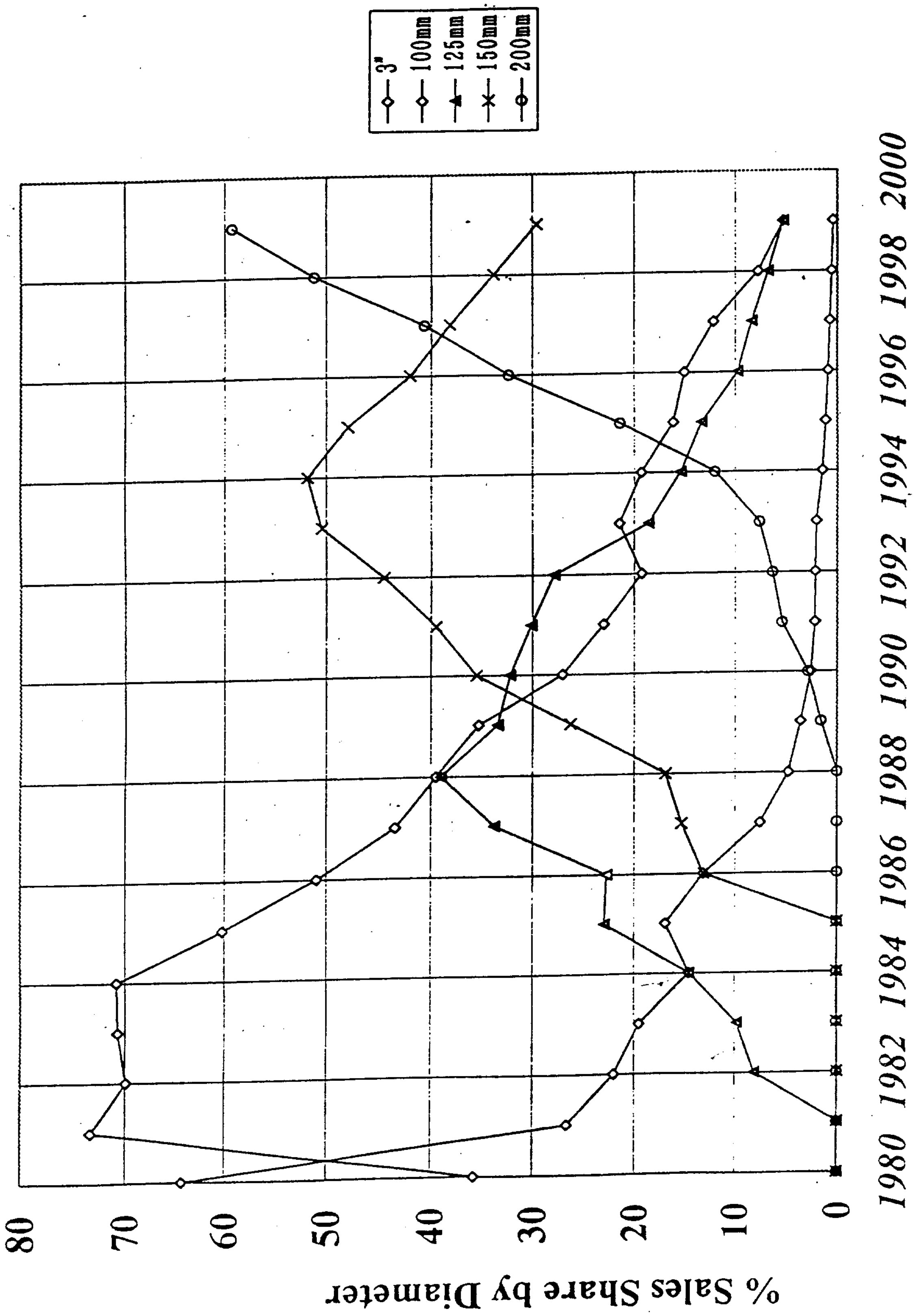
2.2 History of Diameter Increasing

The year of mass production starting for target largest wafer diameter is assumed the year that is over 10% in area rate to total shipping wafer area.

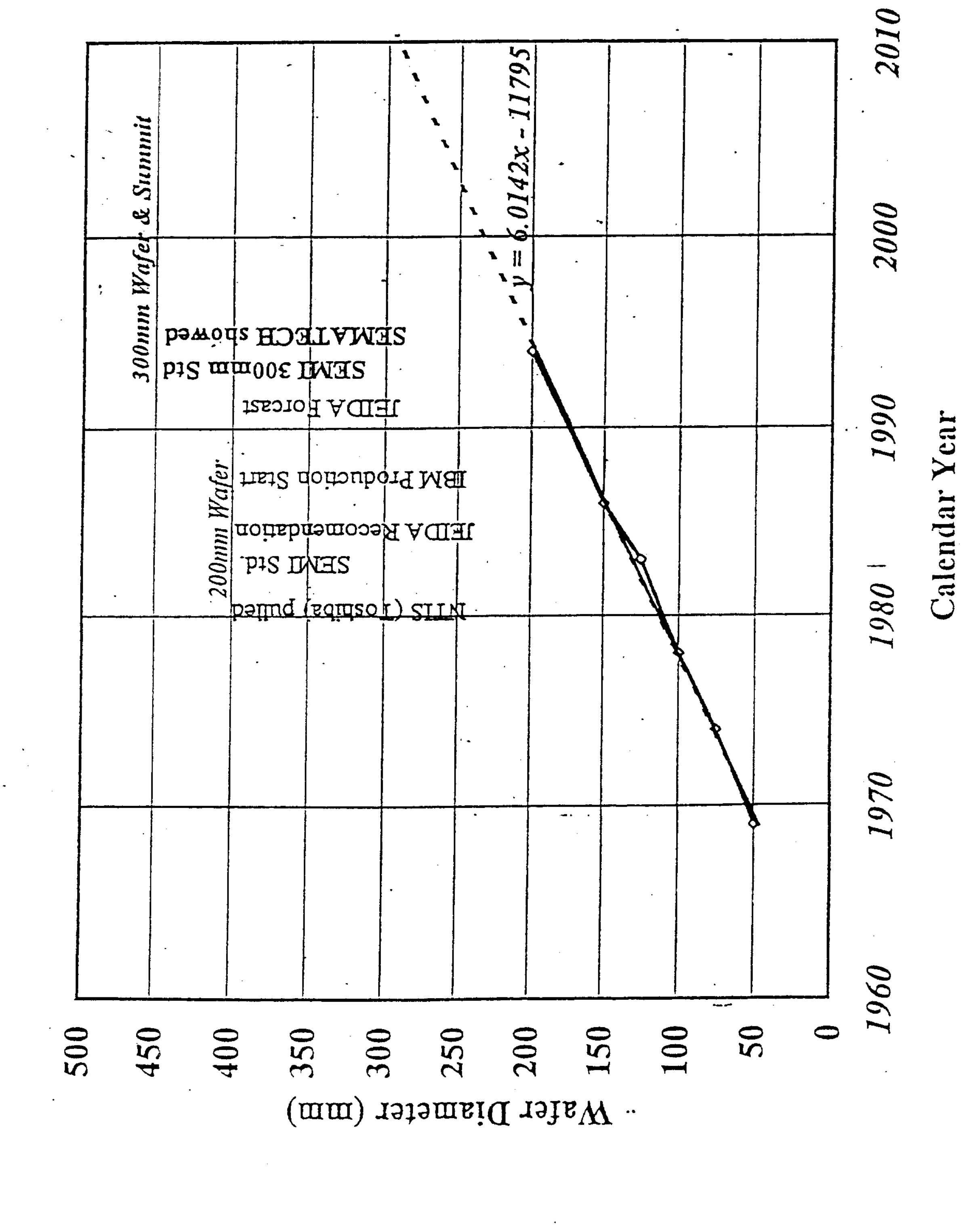
Wafer Diameter Increasing Rate = 6.01mm/year
～1inch/3year

Si Wafer Diameter in SEMI Standard

Diameter	2”		3”		100		125		150		200		300		(400)	in mm unit
Dia. Diff.		-25		-25		25		25		50		100		100		in mm unit
Time Diff.		3		3		3		3		6		12		12		in year unit
											↓		↓		↓	
Massproduction start											**1995**		***2007?***		*2019?*	



3"
100mm
125mm
150mm
200mm
% Sales Share by Diameter
0
10
20
30
40
50
60
70
80
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000


Wafer Diameter (mm)
0
50
100
150
200
250
300
350
400
450
500
Calendar Year
1960
1970
1980
1990
2000
2010
y = 6.0142x - 11795
NTIS (Toshiba) pulled
SEMI Std.
JEIDA Recomendation
IBM Production Start
200mm Wafer
JEIDA Forcast
SEMI 300mm Std
SEMATECH showed
300mm Wafer & Summit

2 : Logic of Wafer Diameter Increasing and its History

2.3 History of Flatness

Exposure Technique Changed

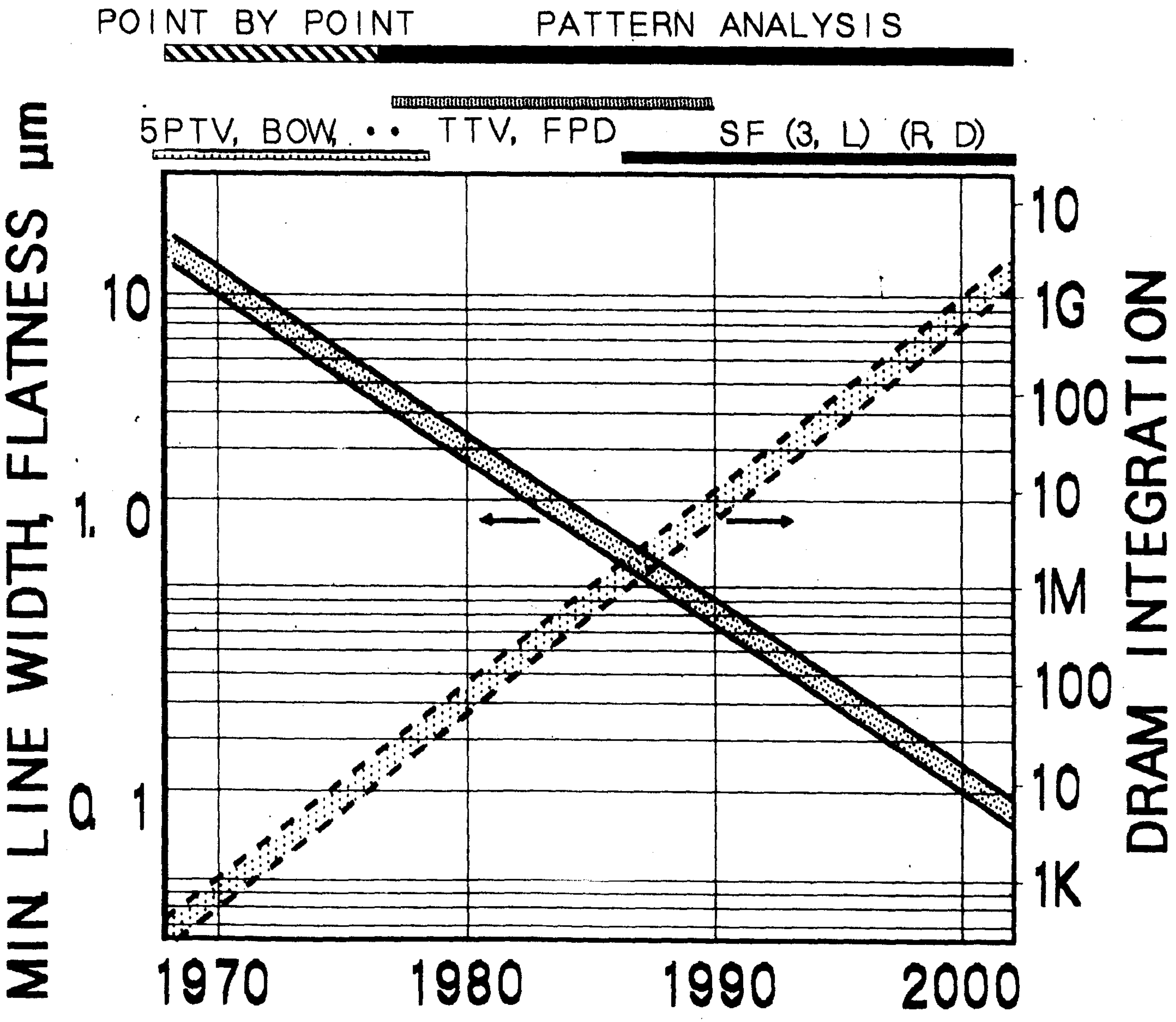
Contact Printing	1:1	Global Flatness	$\geqq 10\mu m$
Proximity Printing	1:1	Global Flatness	$\leqq 10\mu m$
Scanning Printing	1:1	Global Flatness	$\geqq \sim 2\mu m$
Stepping Projection	n:1	Site Flatness	$\leqq \sim 2\mu m$
Scanning Stepper	n:1	*Scanning Site Flatness*	$\leqq \sim 0.25\mu m$

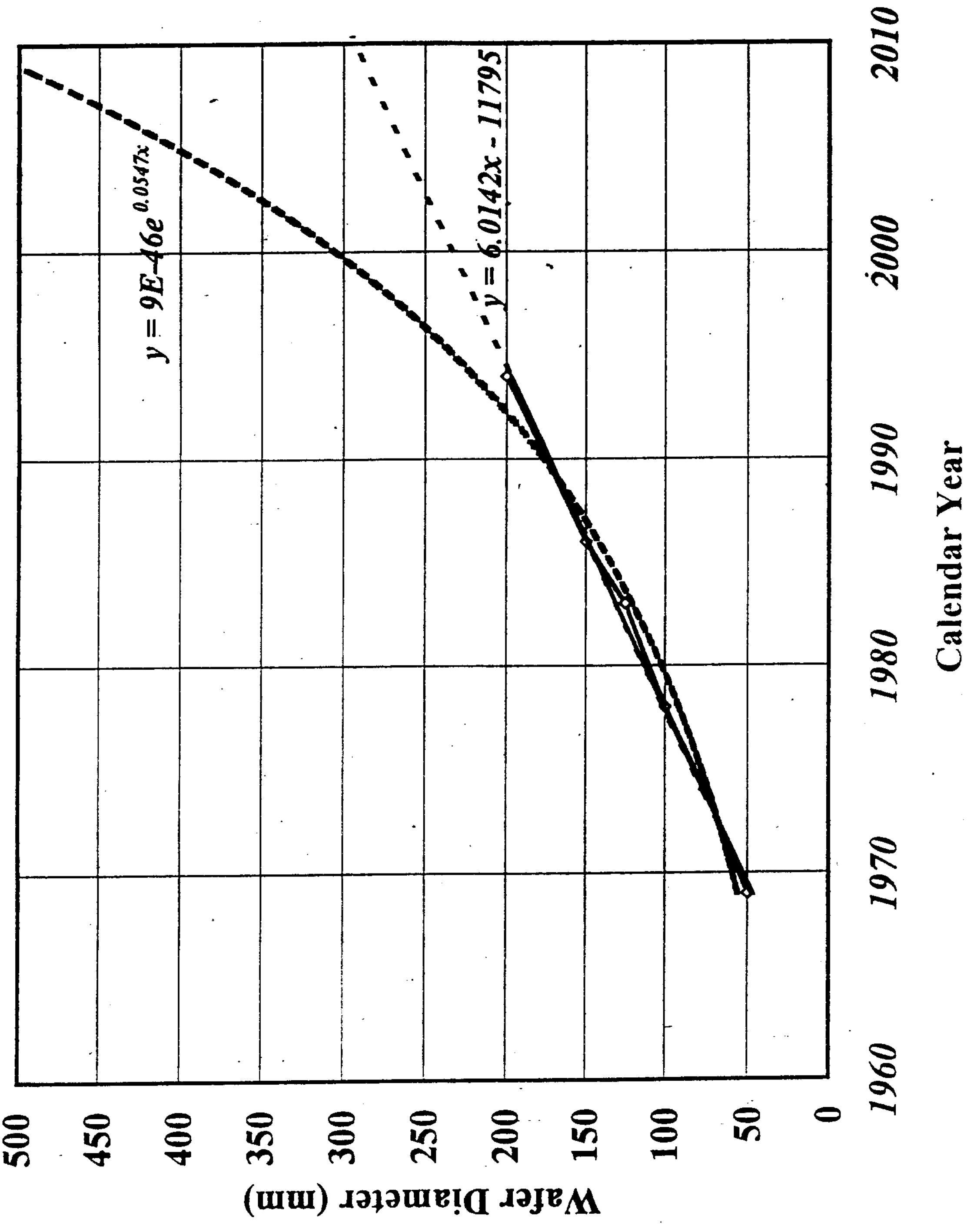
Flatness definitions changed.

Simple Thickness Variation
Global Flatness, Variation (Indicator Reading) and Deviation
Focal Plane Deviation
Site Flatness
Scanning Site Flatness

Measurement instruments changed.

Mechanical	hand, semi-automatic, automatic
Optical	hand, semi-automatic, automatic
Electronic	hand, semi-automatic, automatic


POINT BY POINT
PATTERN ANALYSIS
5PTV, BOW, • •
TTV, FPD
SF (3, L) (R, D)
MIN LINE WIDTH, FLATNESS µm
10
1. 0
0. 1
DRAM INTEGRATION
10
1G
100
10
1M
100
10
1K
1970
1980
1990
2000


Wafer Diameter (mm)
0
50
100
150
200
250
300
350
400
450
500
Calendar Year
1960
1970
1980
1990
2000
2010
$y = 9E\text{-}46e^{0.0547x}$
$y = 6.0142x - 11795$

2 : Logic of Wafer Diameter Increasing and its History

2.4 Case Study

Pentium μ-processer Version change
Wafer diameter and design rule were changed at each Version change.
The sales prices were reduced.

Pentium Ver. and Chips per Wafer

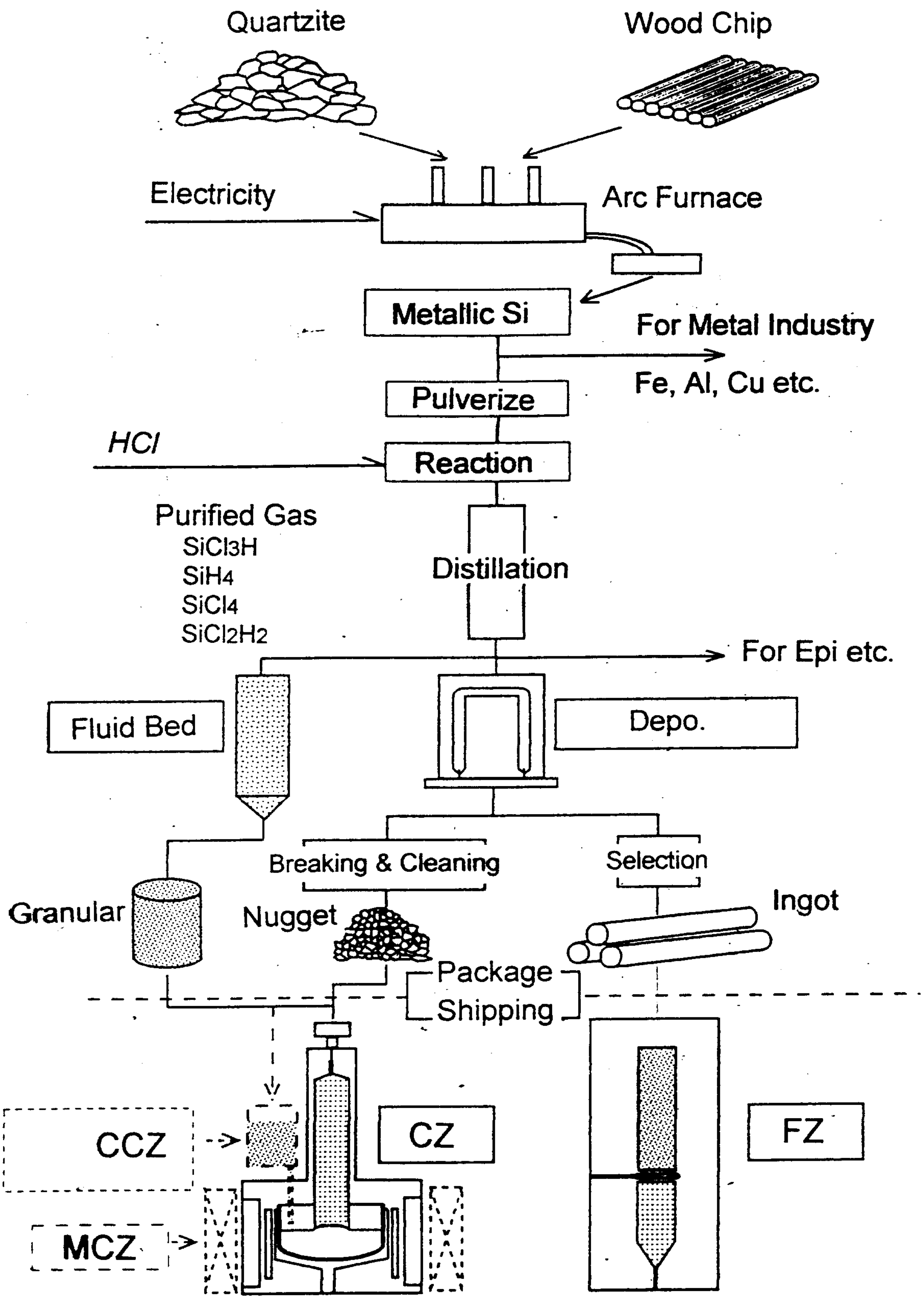
Ver. of Pentium	Unit	Ver.1	Ver.2	Ver.3
Chip Area*	sq. inch	0.416	0.235	0.115
Chip Area	mm^2	268.3	151.6	74.2
Edge Length	mm	16.38	12.31	8.61
Wafer Diameter	mm	150	200	200
Theoretical Chips per Wafer		58	186	392
Assumed Yield*	%	50	45	40
Chips per Wafer		29	84	156
Ratio of Chips per Wafer		1.0	2.9	5.4

* : E.M.R.

3 : Keeping up with the Trend of Large Diameter Si Wafer

3.1 Flow Chart of Wafer Production

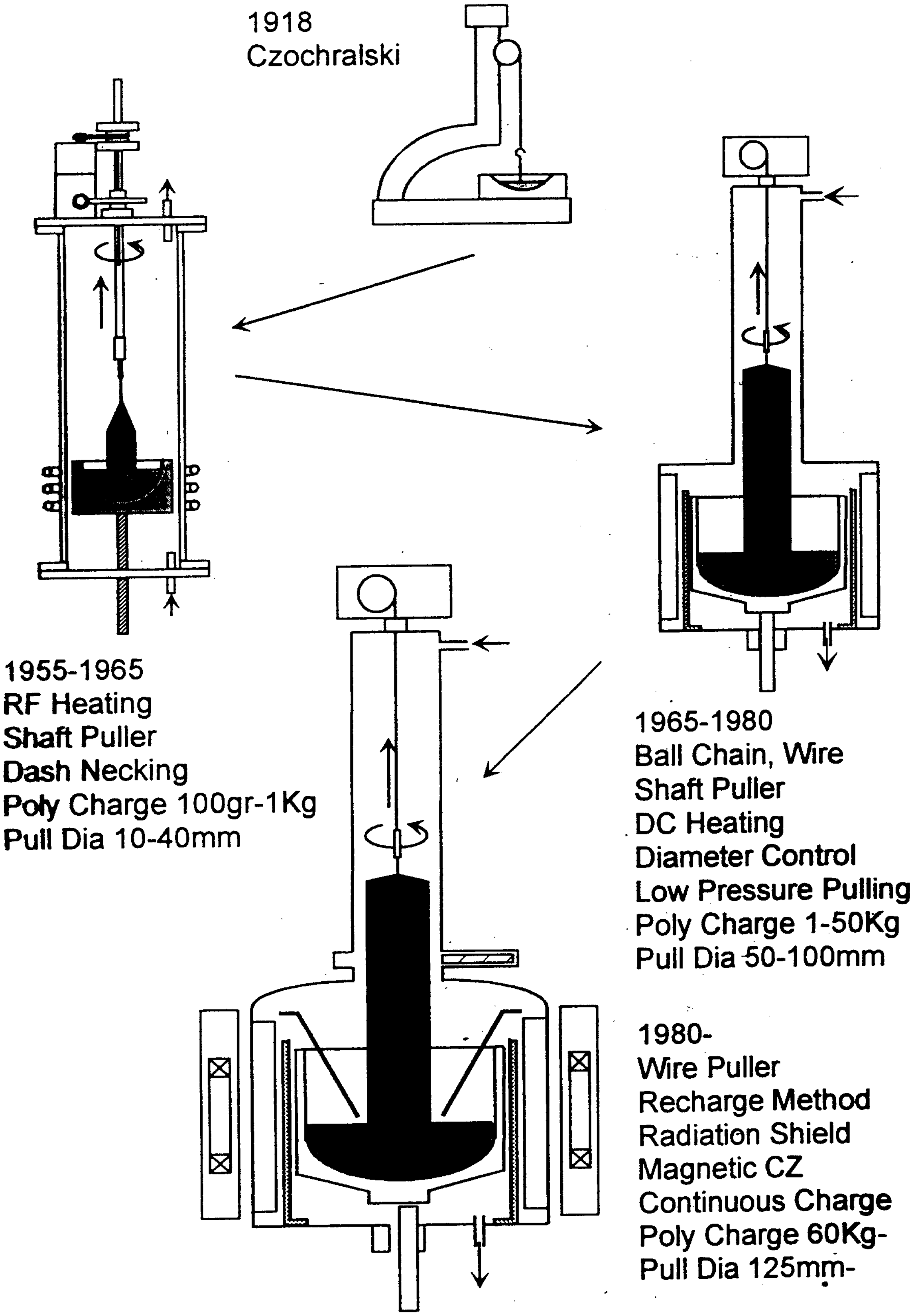
a) Flow chart from quartzite to Si crystal
b) Si crystal growth flow
c) Flow chart of mechanical wafer processing


Quartzite
Wood Chip
Electricity
Arc Furnace
Metallic Si
For Metal Industry
Fe, Al, Cu etc.
Pulverize
HCl
Reaction
Purified Gas
SiCl3H
SiH4
SiCl4
SiCl2H2
Distillation
For Epi etc.
Fluid Bed
Depo.
Breaking & Cleaning
Selection
Granular
Nugget
Ingot
Package
Shipping
CCZ
CZ
MCZ
FZ

3 : Keeping up with the Trend of Large Diameter Si Wafer

3.2. Change of Pulling Instruments

Foundamental concept was developed by Czochralski in 1918.
For application to Si crystal growth, many improvement was added.
The requirements were economic, and the solutions were based on foundamental aspects.

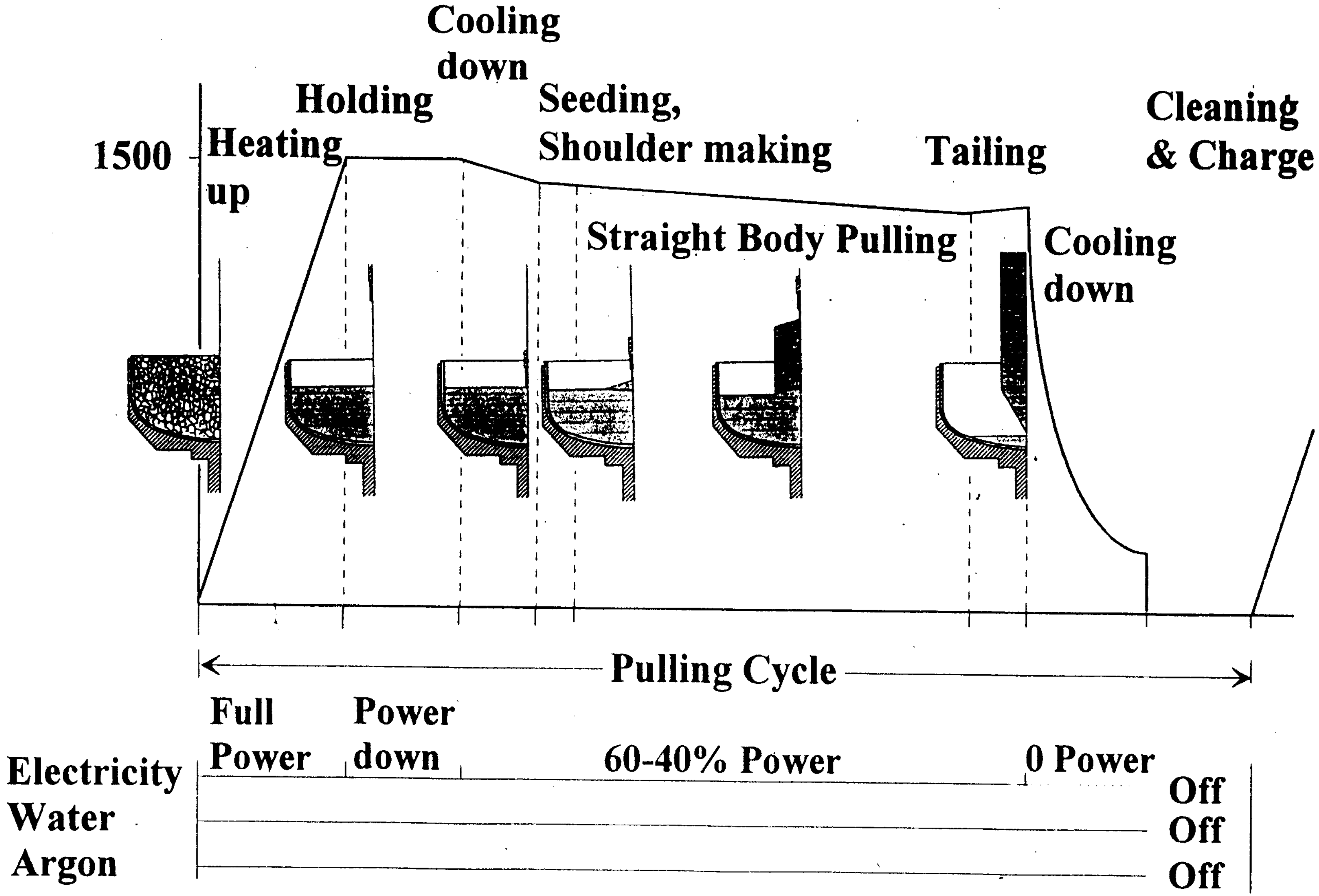


1918
Czochralski

1955-1965
RF Heating
Shaft Puller
Dash Necking
Poly Charge 100gr-1Kg
Pull Dia 10-40mm

1965-1980
Ball Chain, Wire
Shaft Puller
DC Heating
Diameter Control
Low Pressure Pulling
Poly Charge 1-50Kg
Pull Dia 50-100mm

1980-
Wire Puller
Recharge Method
Radiation Shield
Magnetic CZ
Continuous Charge
Poly Charge 60Kg-
Pull Dia 125mm-

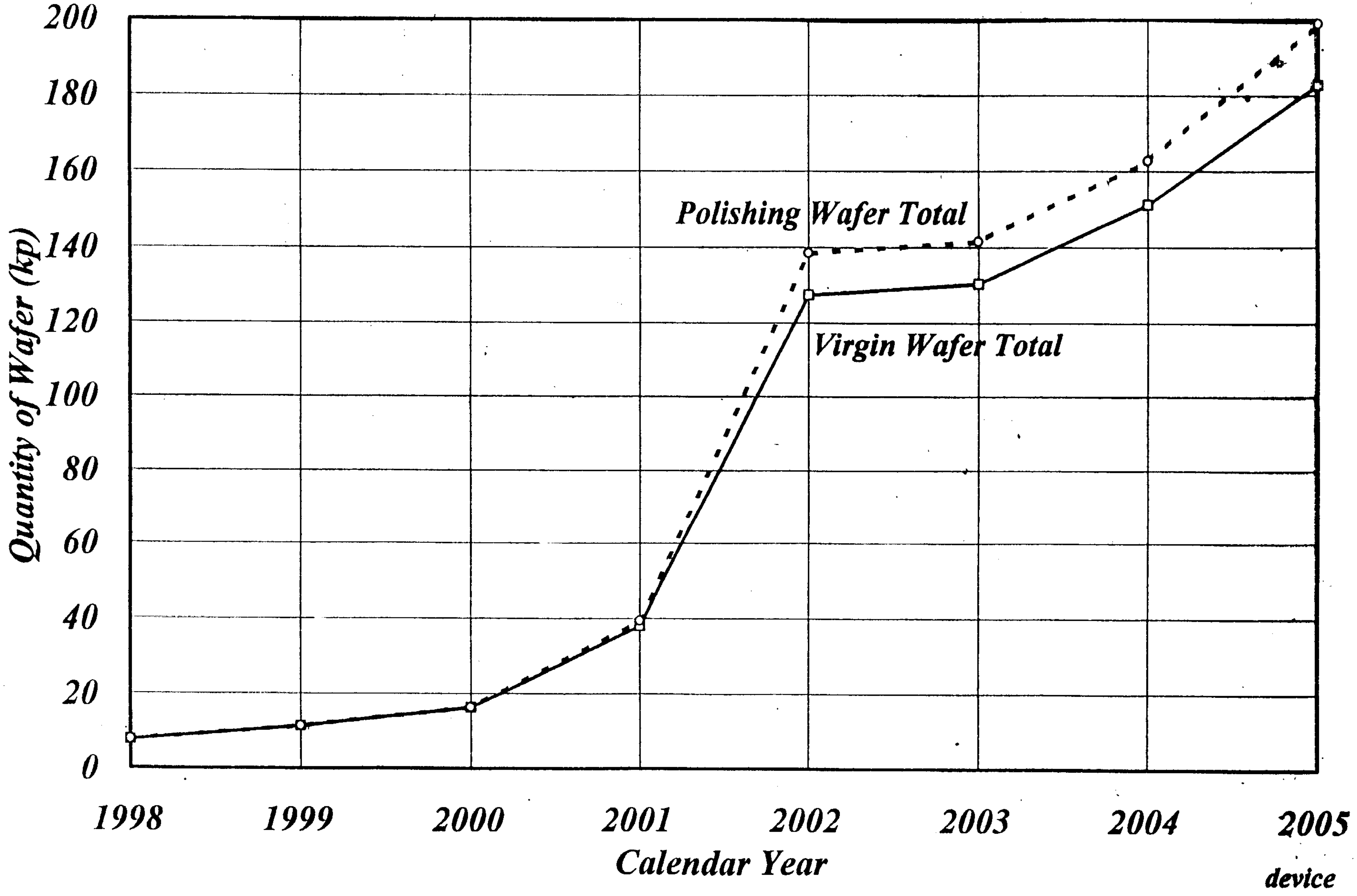

Cooling
down
Holding
Seeding,
Shoulder making
Tailing
Cleaning
& Charge
1500
Heating
up
Straight Body Pulling
Cooling
down
Pulling Cycle
Full
Power
Power
down
60-40% Power
0 Power
Electricity
Water
Argon
Off
Off
Off

3 : Keeping up with the Trend of Large Diameter Si Wafer

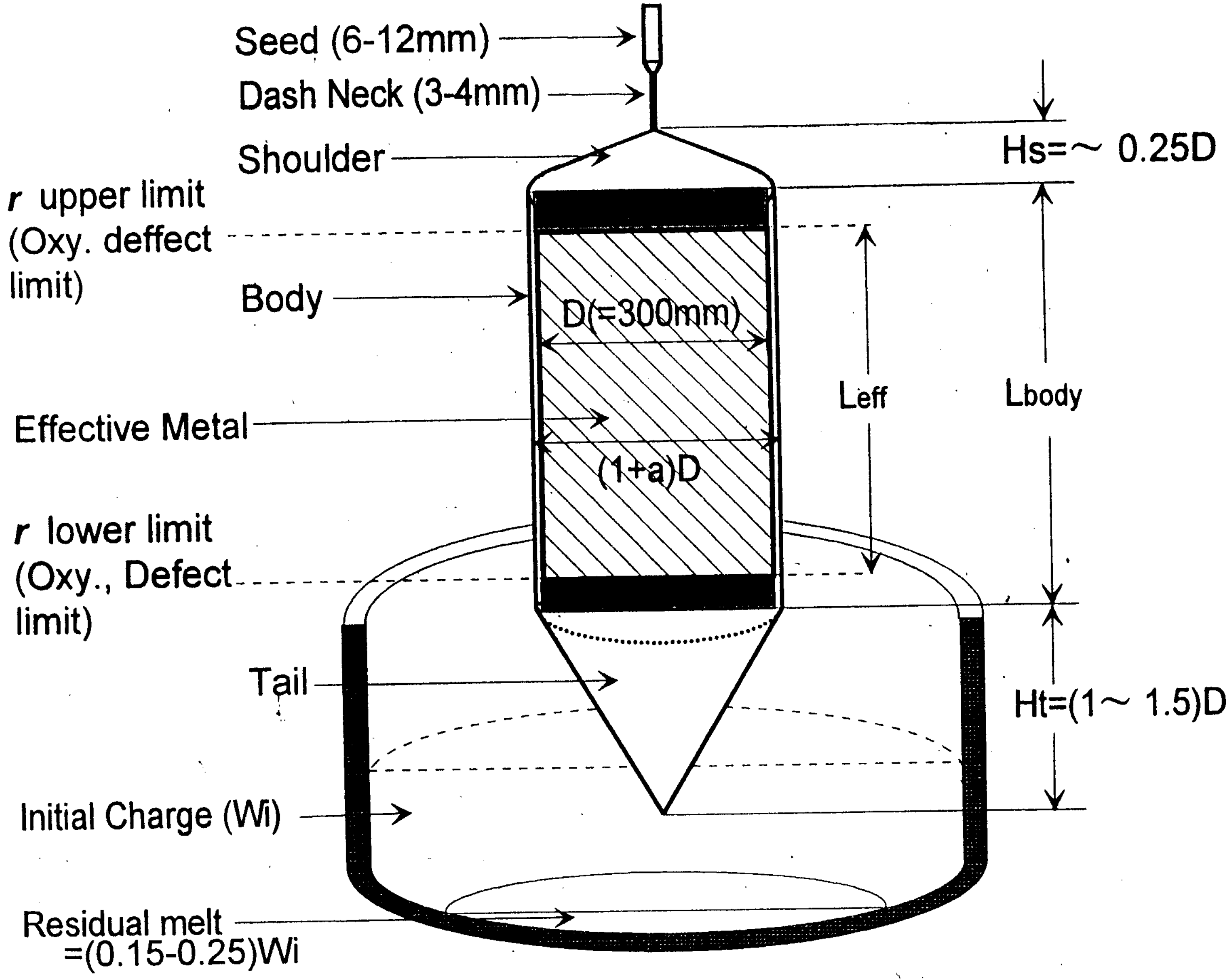
3.3 Prediction of Wafer Demand and Crystal Growth

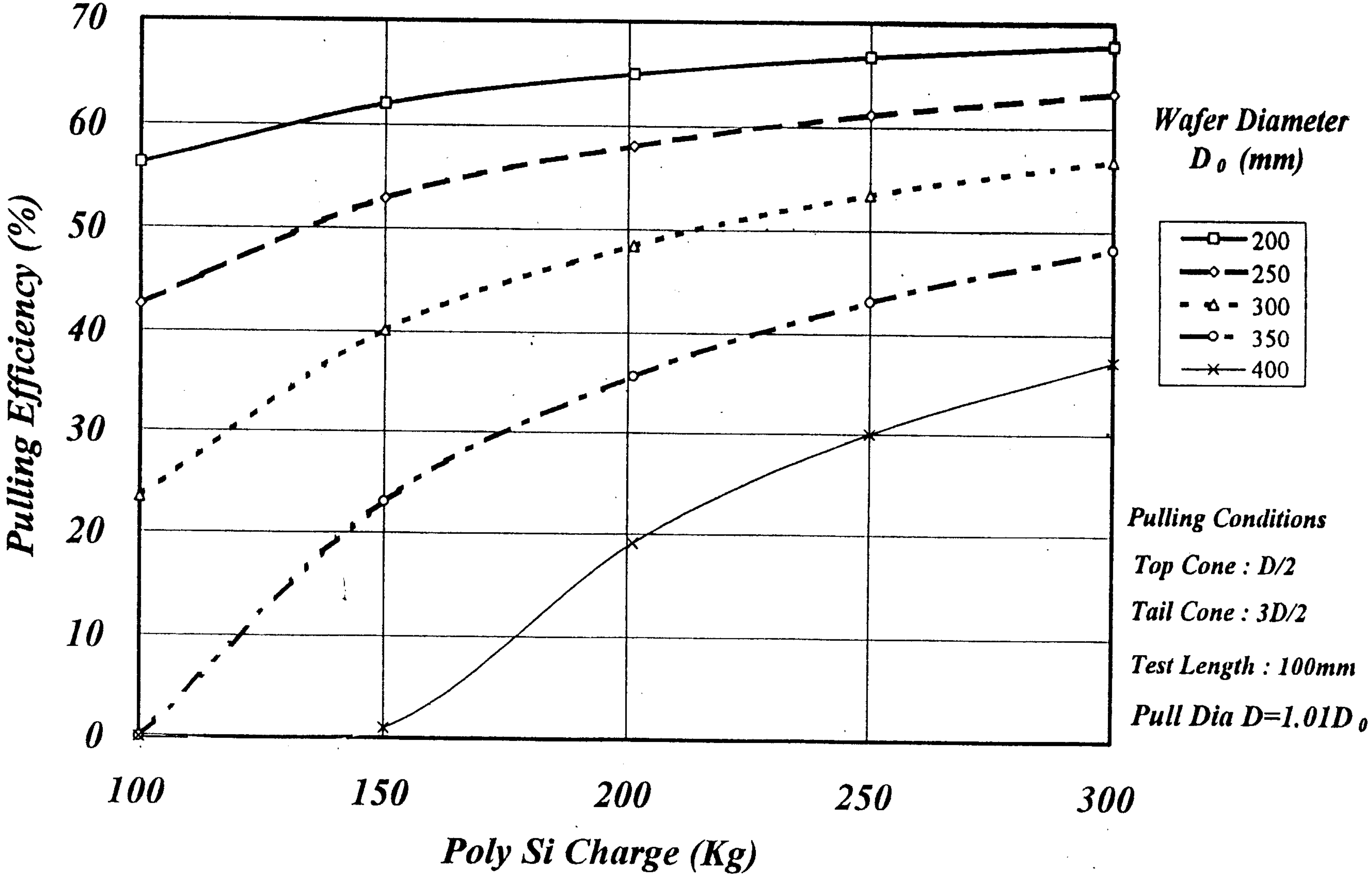
In 1995, Silicon Manufacturer Group of SEMI had a questionnaire type survey on 300mm Si wafer and its relating technology.
The survey results revealed big issue on economic large diameter Si crystal growth.

SEMI : Semiconductor Equipment and Materials International



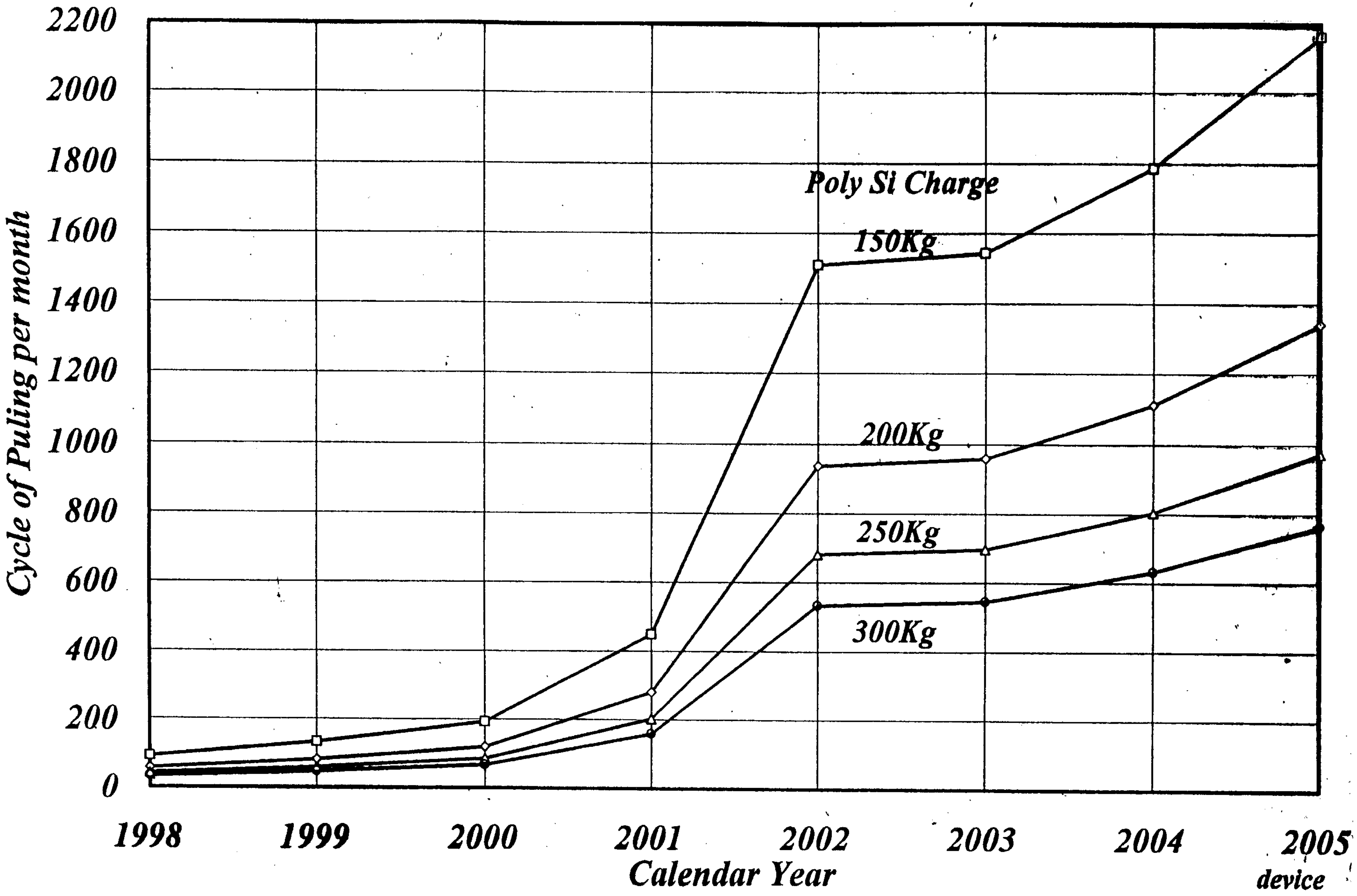
A,G,H,L,M,N,O,P) Demand Total


Seed (6-12mm)
Dash Neck (3-4mm)
Shoulder
r upper limit (Oxy. deffect limit)
Body
Effective Metal
r lower limit (Oxy., Defect limit)
Tail
Initial Charge (Wi)
Residual melt =(0.15-0.25)Wi
D(=300mm)
(1+a)D
Leff
Lbody
Hs=~ 0.25D
Ht=(1~ 1.5)D



Ideal Pulling Efficiency for Poly Si Charge

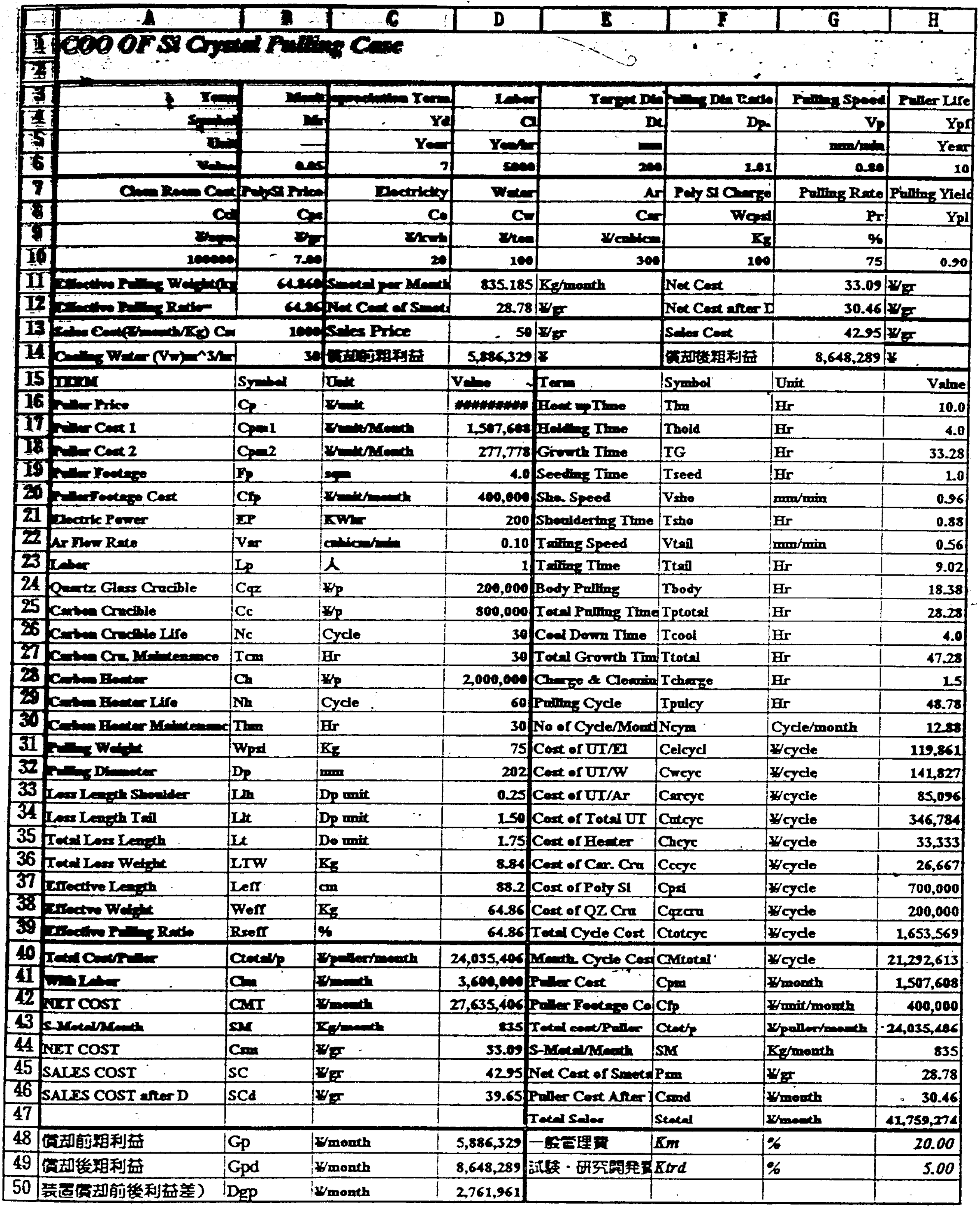
A,G,H,L,M,N,O,P) Required Pulling Cycle



3 : Keeping up with the Trend of Large Diameter Si Wafer

3.4 Issue of Large Diameter Crystal Growth

- a Common Problems of Large Diameter Crystal Growth
  - 1 Necking
  - 2 Pulling speed limit
  - 3 Oxygen concentration and thermal history
  - 4 Safety
  - 5 Melt surface stability
  - 6 Increasing effective crystal
- b In Case of Extrapolation
  - 1 Holding of large volume melt
- c In Case of Change
  - 1 Simple double crucible
  - 2 Re-crystal growth in double crucible method
  - 3 Measures of long crystal growth time
  - 4 Are there another economic large diameter Si crystal growth method?



	A	B	C	D	E	F	G	H
1	***COO OF Si Crystal Pulling Case***							
2								
3	**Term**	**Maint**	**epreciation Term**	**Labor**	**Target Dia**	**ulling Dia Ratio**	**Pulling Speed**	**Puller Life**
4	**Symbol**	**Mr**	**Yd**	**Cl**	**Dt**	**Dp**	**Vp**	**Ypf**
5	**Unit**	**—**	**Year**	**Yen/hr**	**mm**		**mm/min**	**Year**
6	**Value**	**0.05**	**7**	**5000**	**200**	**1.01**	**0.80**	**10**
7	**Clean Room Cost**	**PolySi Price**	**Electricity**	**Water**	**Ar**	**Poly Si Charge**	**Pulling Rate**	**Pulling Yield**
8	**Ccl**	**Cps**	**Ce**	**Cw**	**Car**	**Wcpsi**	**Pr**	**Ypl**
9	**¥/sqm**	**¥/gr**	**¥/kwh**	**¥/ton**	**¥/cubicm**	**Kg**	**%**	
10	**100000**	**7.00**	**20**	**100**	**300**	**100**	**75**	**0.90**
11	**Effective Pulling Weight(kg**	**64.860**	**Smetal per Month**	835.185	**Kg/month**	**Net Cost**	33.09	**¥/gr**
12	**Effective Pulling Ratio=**	**64.86**	**Net Cost of Smet**	28.78	**¥/gr**	**Net Cost after D**	30.46	**¥/gr**
13	**Sales Cost(¥/month/Kg) Cs**	**1000**	**Sales Price**	**50**	**¥/gr**	**Sales Cost**	42.95	**¥/gr**
14	**Cooling Water (Vw)m^3/hr**	**30**	**償却前粗利益**	5,886,329	**¥**	**償却後粗利益**	8,648,289	**¥**
15	**ITEM**	**Symbol**	**Unit**	**Value**	**Term**	**Symbol**	**Unit**	**Value**
16	**Puller Price**	Cp	**¥/unit**	#########	**Heat up Time**	Thu	Hr	10.0
17	**Puller Cost 1**	Cpm1	**¥/unit/Month**	1,507,608	**Holding Time**	Thold	Hr	4.0
18	**Puller Cost 2**	Cpm2	**¥/unit/Month**	277,778	**Growth Time**	TG	Hr	33.28
19	**Puller Footage**	Fp	**sqm**	4.0	**Seeding Time**	Tseed	Hr	1.0
20	**PullerFootage Cost**	Cfp	**¥/unit/month**	400,000	**Sho. Speed**	Vsho	mm/min	0.96
21	**Electric Power**	EP	**KWhr**	200	**Shouldering Time**	Tsho	Hr	0.88
22	**Ar Flow Rate**	Var	**cubicm/min**	0.10	**Tailing Speed**	Vtail	mm/min	0.56
23	**Labor**	Lp	人	1	**Tailing Time**	Ttail	Hr	9.02
24	**Quartz Glass Crucible**	Cqz	¥/p	200,000	**Body Pulling**	Tbody	Hr	18.38
25	**Carbon Crucible**	Cc	¥/p	800,000	**Total Pulling Time**	Tptotal	Hr	28.28
26	**Carbon Crucible Life**	Nc	Cycle	30	**Cool Down Time**	Tcool	Hr	4.0
27	**Carbon Cru. Maintenance**	Tcm	Hr	30	**Total Growth Tim**	Ttotal	Hr	47.28
28	**Carbon Heater**	Ch	¥/p	2,000,000	**Charge & Cleanin**	Tcharge	Hr	1.5
29	**Carbon Heater Life**	Nh	Cycle	60	**Pulling Cycle**	Tpulcy	Hr	48.78
30	**Carbon Heater Maintenanc**	Thm	Hr	30	**No of Cycle/Mont**	Ncym	Cycle/month	12.88
31	**Pulling Weight**	Wpsi	Kg	75	**Cost of UT/El**	Celcycl	¥/cycle	119,861
32	**Pulling Diameter**	Dp	mm	202	**Cost of UT/W**	Cwcyc	¥/cycle	141,827
33	**Loss Length Shoulder**	Llh	Dp unit	0.25	**Cost of UT/Ar**	Carcyc	¥/cycle	85,096
34	**Loss Length Tail**	Llt	Dp unit	1.50	**Cost of Total UT**	Cutcyc	¥/cycle	346,784
35	**Total Loss Length**	Lt	Do unit	1.75	**Cost of Heater**	Chcyc	¥/cycle	33,333
36	**Total Loss Weight**	LTW	Kg	8.84	**Cost of Car. Cru**	Cccyc	¥/cycle	26,667
37	**Effective Length**	Leff	cm	88.2	**Cost of Poly Si**	Cpsi	¥/cycle	700,000
38	**Effective Weight**	Weff	Kg	64.86	**Cost of QZ Cru**	Cqzcru	¥/cycle	200,000
39	**Effective Pulling Ratio**	Rseff	%	64.86	**Total Cycle Cost**	Ctotcyc	¥/cycle	1,653,569
40	**Total Cost/Puller**	Ctotal/p	**¥/puller/month**	24,035,406	**Month. Cycle Cost**	CMtotal	¥/cycle	21,292,613
41	**With Labor**	Clm	**¥/month**	3,600,000	**Puller Cost**	Cpm	¥/month	1,507,608
42	NET COST	CMT	**¥/month**	27,635,406	**Puller Footage Co**	Cfp	¥/unit/month	400,000
43	**S-Metal/Month**	**SM**	**Kg/month**	835	**Total cost/Puller**	Ctot/p	**¥/puller/month**	24,035,486
44	NET COST	Csm	¥/gr	33.09	**S-Metal/Month**	SM	Kg/month	835
45	SALES COST	SC	¥/gr	42.95	**Net Cost of Smets**	Psm	¥/gr	28.78
46	SALES COST after D	SCd	¥/gr	39.65	**Puller Cost After**	Csmd	¥/month	30.46
47					**Total Sales**	**Stotal**	**¥/month**	41,759,274
48	償却前粗利益	Gp	¥/month	5,886,329	一般管理費	*Km*	%	*20.00*
49	償却後粗利益	Gpd	¥/month	8,648,289	試験・研究開発費	*Ktrd*	%	*5.00*
50	装置償却前後利益差）	Dgp	¥/month	2,761,961				

Relation between Pulling Speed and Thermal Gradient

$$\underset{\substack{\downarrow \\ G_S}}{\frac{dT_S}{dZ}} K_S = \underset{\substack{\downarrow \\ G_L}}{\frac{dT_L}{dZ}} K_L + \rho \Delta L V$$

$$V = \frac{G_S K_S - G_L K_L}{\rho \Delta L} = C\,(G_S K_S - G_L K_L)$$

$$C = 1/(\rho \Delta L)$$

if $V_A = V_B$ $\quad G_{SA}K_{SA} - G_{LA}K_{LA} = G_{SB}K_{SB} - G_{LB}K_{LB} = \rho \Delta L V$

$K_{SA} = K_{SB}, \; K_{LA} = K_{LB}$

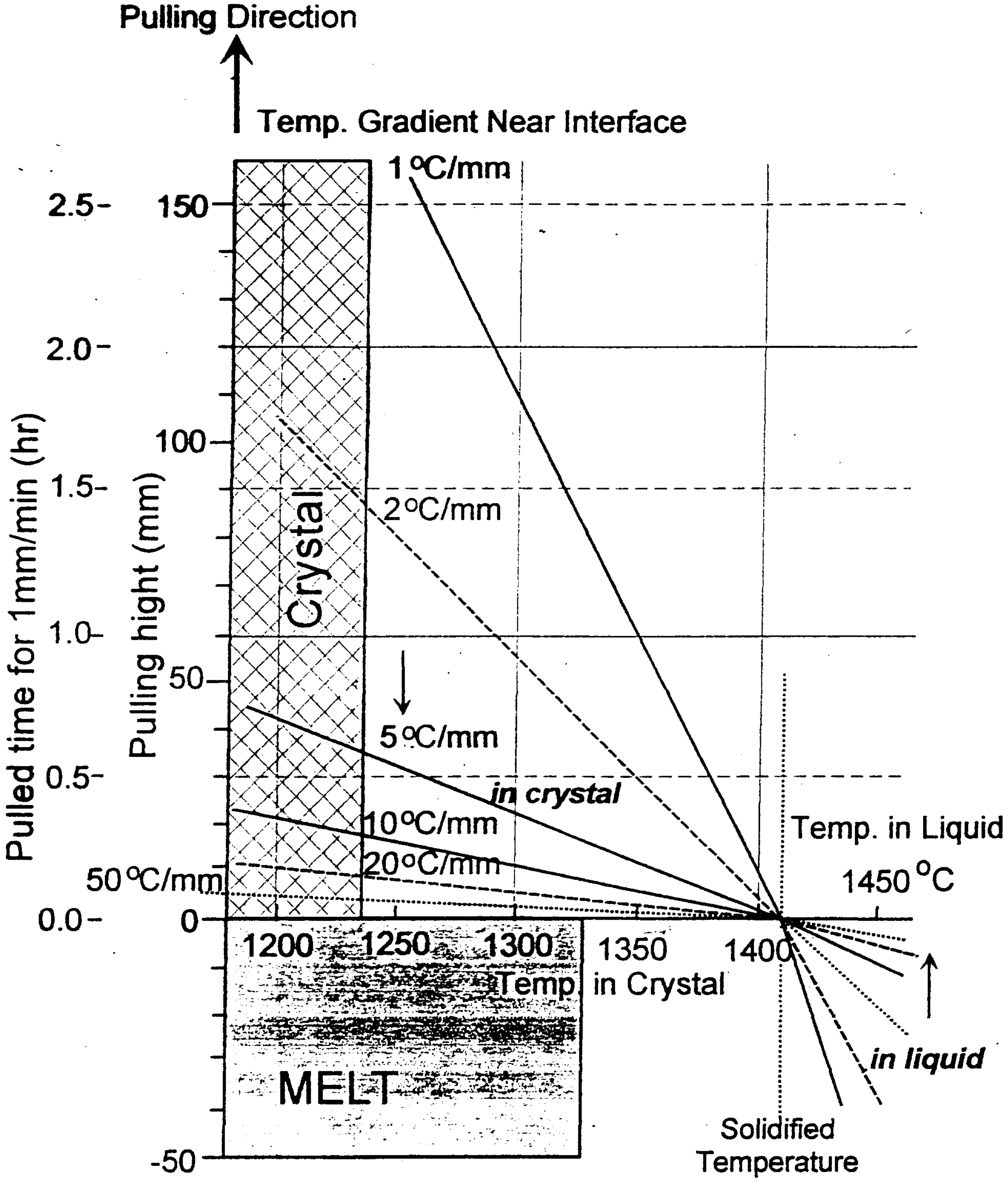
$$K = K_{SA}/K_{LA} = K_{SB}/K_{LB} = 27.3/56 = 0.4875 = \frac{(G_{LA} - G_{LB})}{(G_{SA} - G_{SB})}$$

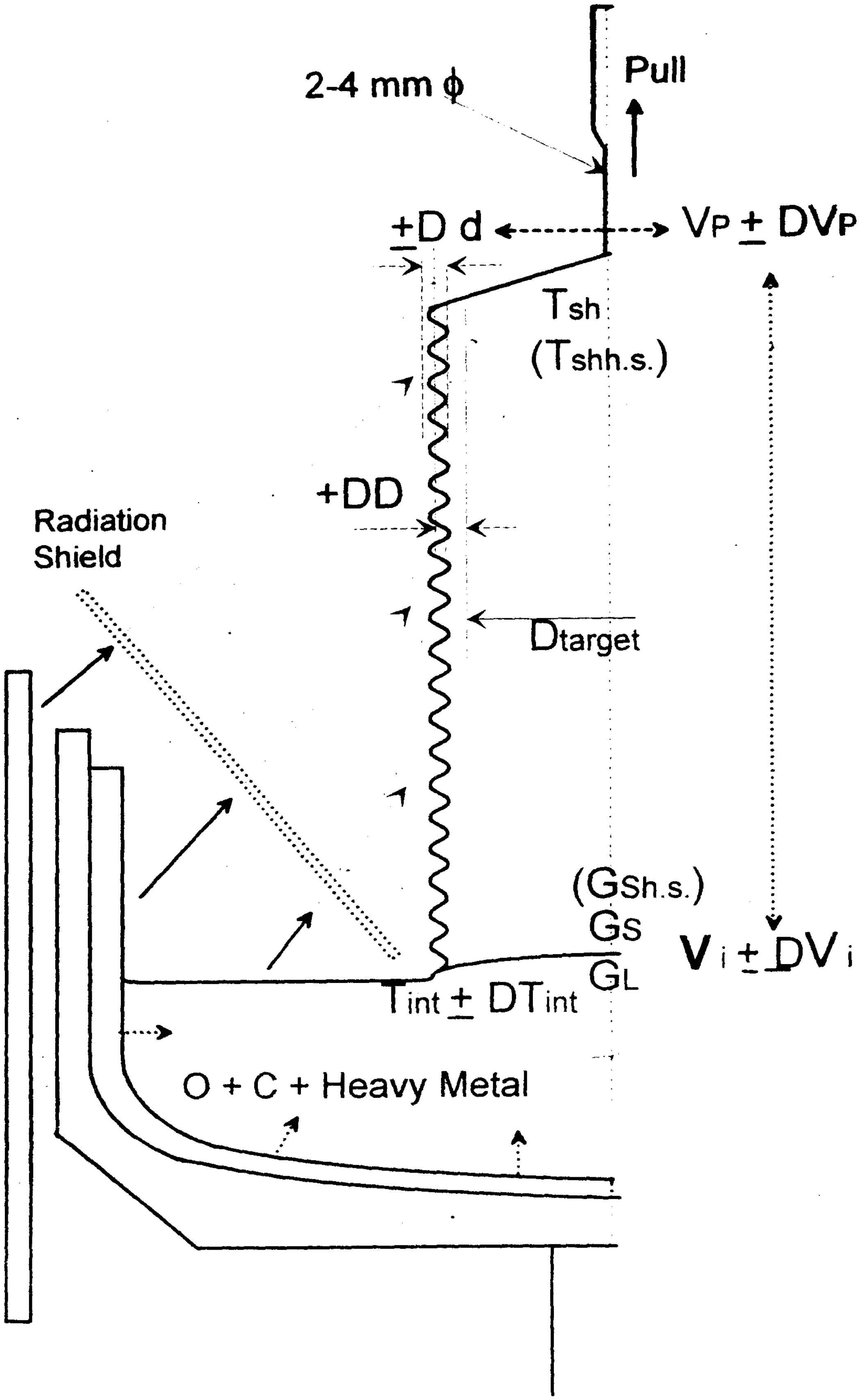
$G_{LA} = 10$ *C/cm*, $\quad G_{LB} = 2$ *C/cm*

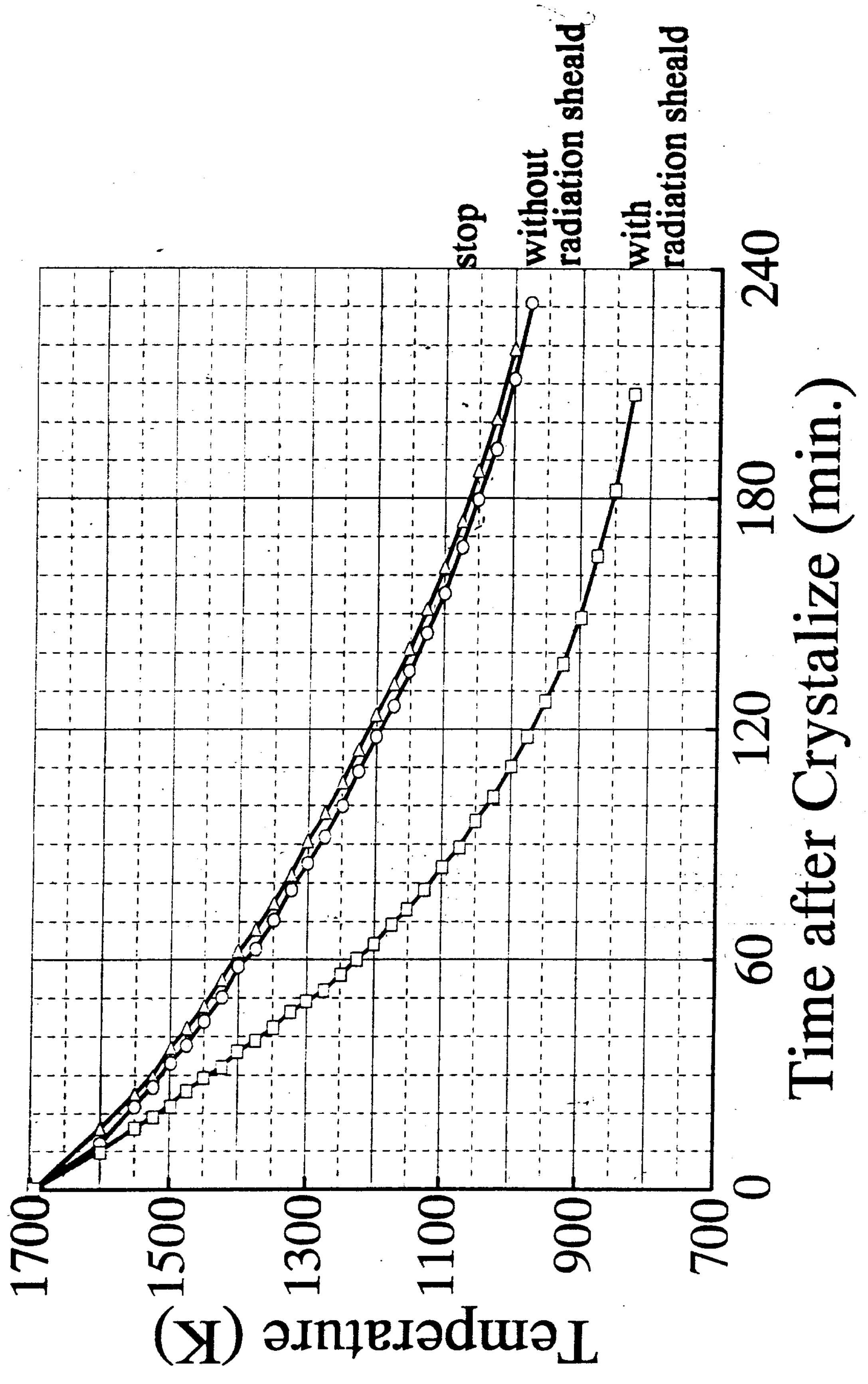
$$G_{SA} = G_{SB} + \frac{(G_{LA} - G_{LB})}{K} = G_{SB} + 2.05\,(G_{LA} - G_{LB})$$

$$= G_{SB} + 16.4 \; (C/cm)$$

Thermal Condition of Si Crystal Pulling




Pull
2-4 mm ϕ
±D d
VP ± DVP
Tsh
(Tshh.s.)
+DD
Radiation Shield
Dtarget
(GSh.s.)
GS
GL
Vi ± DVi
Tint ± DTint
O + C + Heavy Metal


Temperature (K)
1700
1500
1300
1100
900
700
Time after Crystalize (min.)
0
60
120
180
240
stop
without radiation sheald
with radiation sheald

1 Mdyne/cm^{-2} = 1.01972 Kg/cm^{-2}

2.00E+09 dyne/cm^{-2} = 2.04E+03 Kg/cm^{-2} = 20.4 Kg/mm^{-2}

W.D.Sylwestrowicz, Phyl. Mag. 7 (1962) 1825

K.M.Kim & P.Smetana, J. Cry. Growth 100 (1990) 527

Seed Dia	20.4 Kg/mm^{-2}
2.00 mm	64.09 Kg
2.50 mm	100.14
3.00 mm	144.20
3.50 mm	196.27
4.00 mm	256.35
4.50 mm	324.45
5.00 mm	400.55

L=8.76*(D/d)*10^5 After Kim

Seed Dia (mm)	Strength (Kg)	Wafer Diameter (mm)								
		100	150	200	250	300	350	400	450	500
2.0	64.1	350.4	155.7	87.6	56.1	38.9	28.6	21.9	17.3	14.0
2.5	100.1	547.5	243.3	136.9	87.6	60.8	44.7	34.2	27.0	21.9
3.0	144.2	788.4	350.4	197.1	126.1	87.6	64.4	49.3	38.9	31.5
3.5	196.3	1073.1	476.9	268.3	171.7	119.2	87.6	67.1	53.0	42.9
4.0	256.4	1401.6	622.9	350.4	224.3	155.7	114.4	87.6	69.2	56.1
4.5	324.4	1773.9	788.4	443.5	283.8	197.1	144.8	110.9	87.6	71.0
5.0	400.6	2190.0	973.3	547.5	350.4	243.3	178.8	136.9	108.1	87.6

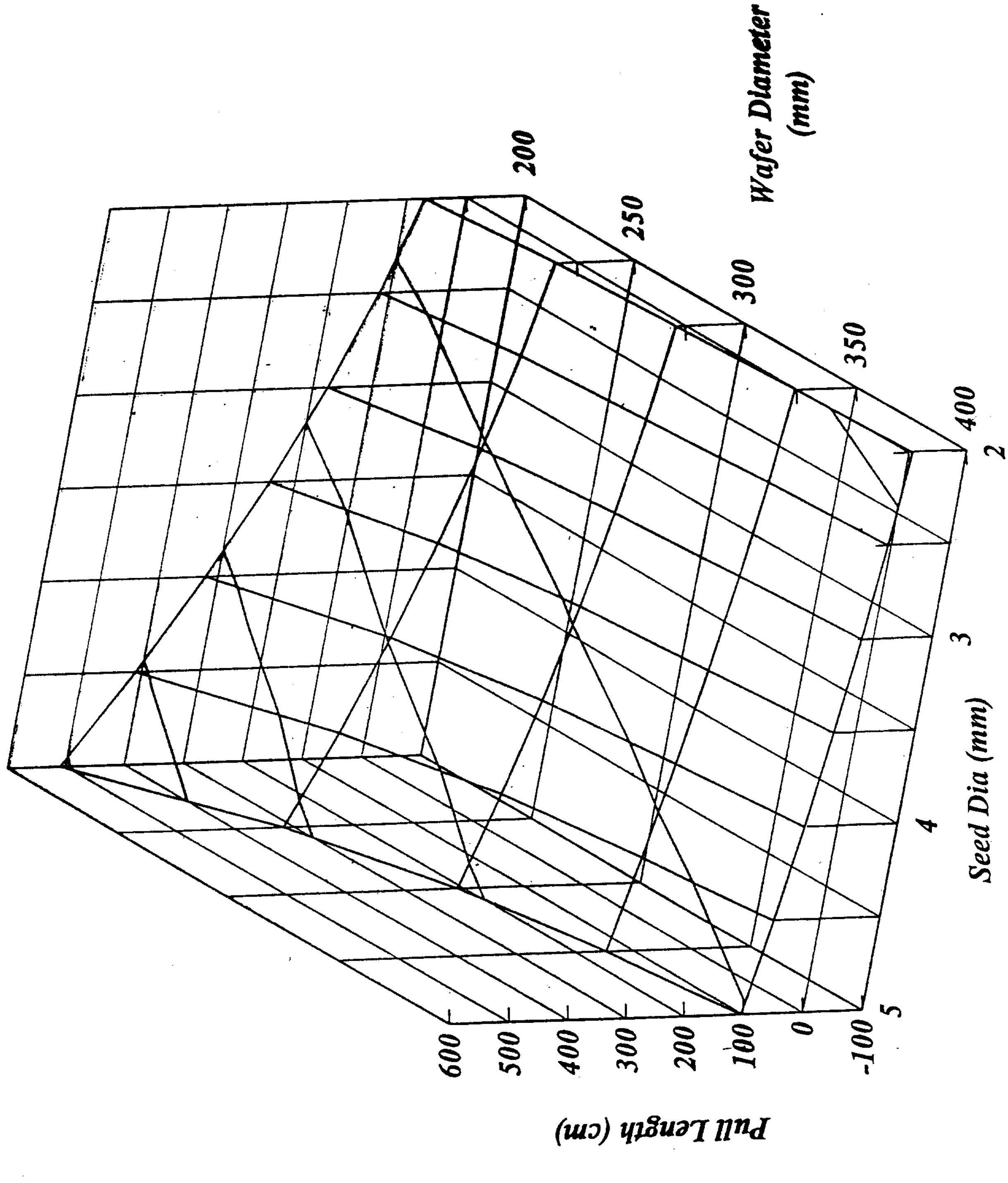
L=8.718*(10`5)*(d/D)^2-(Ldeff+1.75/3)*D

=8.718*(10^5)*(d/(1.02*D))^2-(Ldeff+0.583)*D*1.02

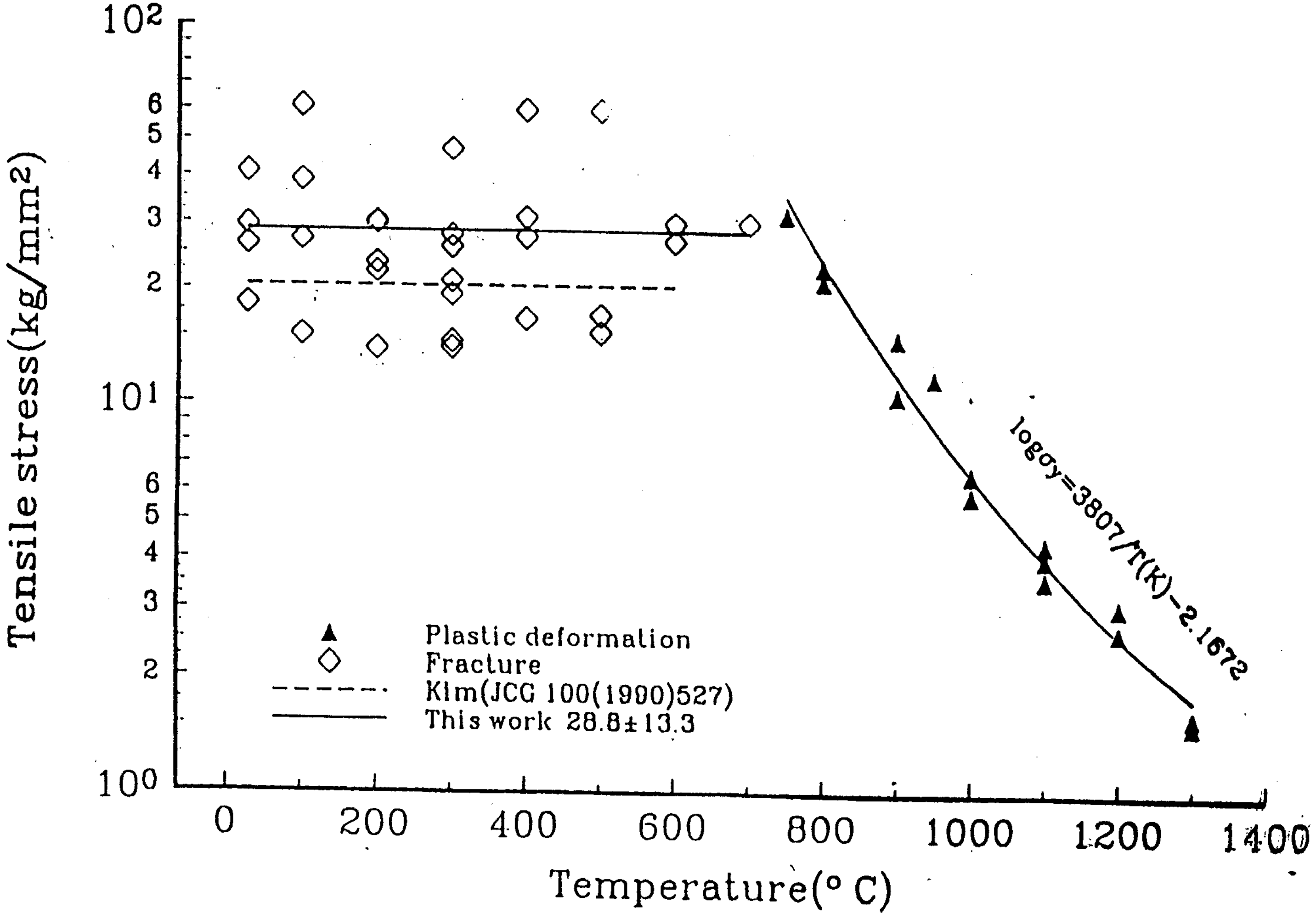
kD= 1.02 *D

Ldeff= 0.2 *D

	100	150	200	250	300	350	400	450	500
2.0	327.2	137.0	67.8	33.7	13.3	-0.6	-11.0	-19.4	-26.1
2.5	515.7	220.8	115.0	63.8	34.2	14.8	0.8	-10.1	-19.0
3.0	746.2	323.2	172.6	100.7	59.8	33.6	15.2	1.3	-9.8
3.5	1018.5	444.2	240.6	144.3	90.1	55.8	32.2	14.8	1.1
4.0	1332.7	583.9	319.2	194.5	125.0	81.5	51.8	30.3	13.7
4.5	1688.9	742.2	408.2	251.5	164.6	110.6	74.1	47.9	27.9
5.0	2086.9	919.1	507.7	315.2	208.8	143.1	99.0	67.5	43.9

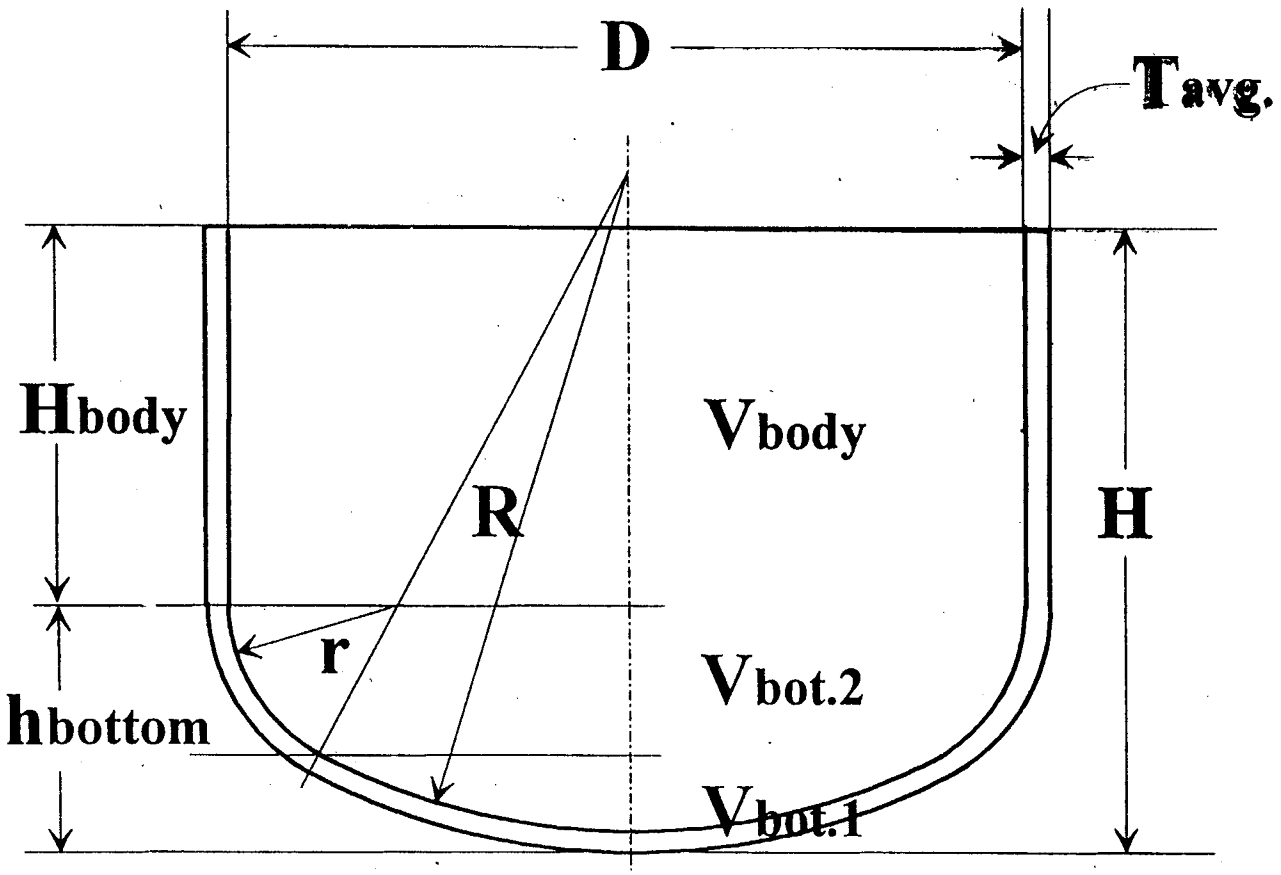

Wafer Diameter (mm)
200
250
300
350
400
Seed Dia (mm)
2
3
4
5
Pull Length (cm)
600
500
400
300
200
100
0
-100

Mechanical strength of Dash neck

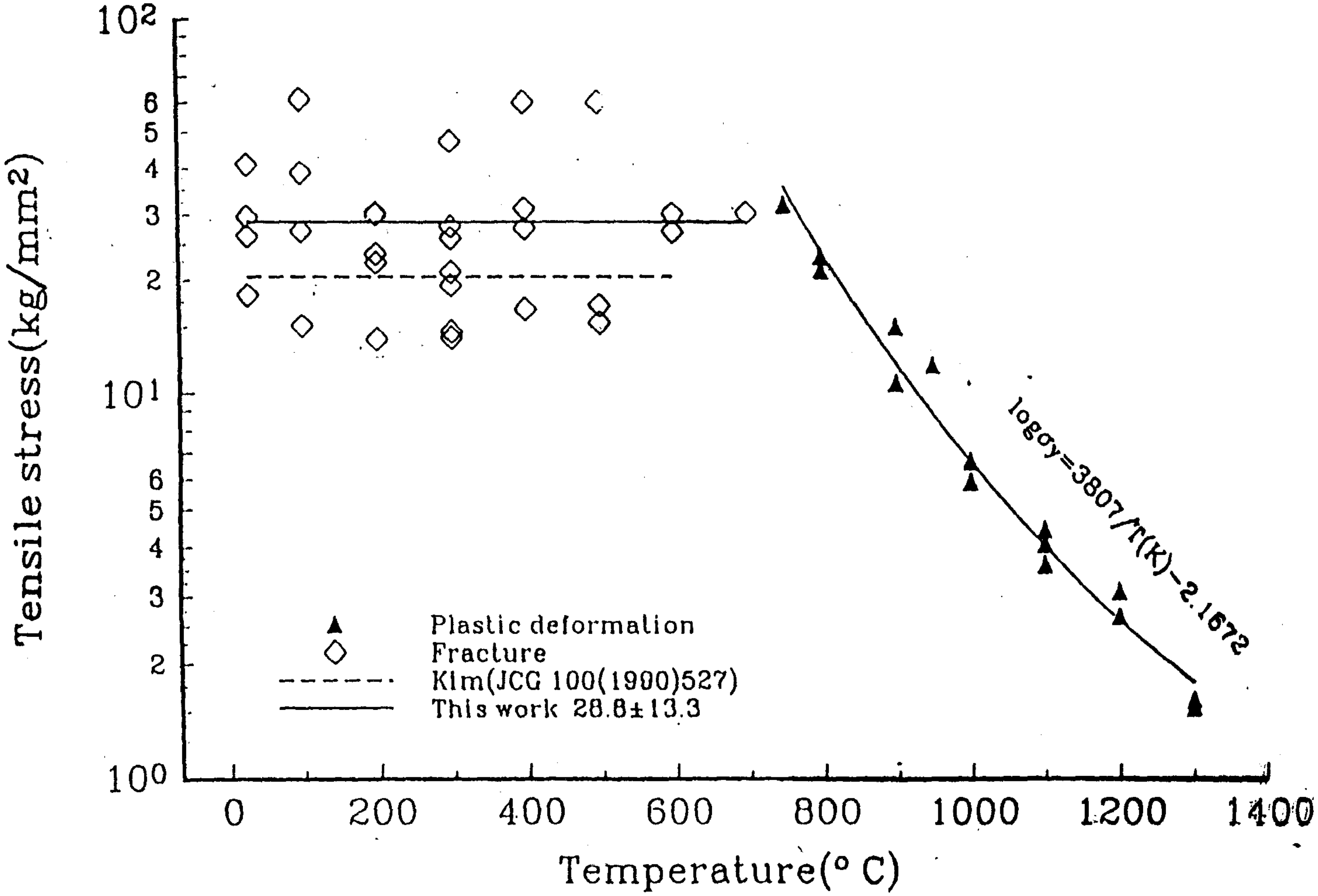


SEMICON Forum 94.7.18

Qz. Glass Crucible Dimension

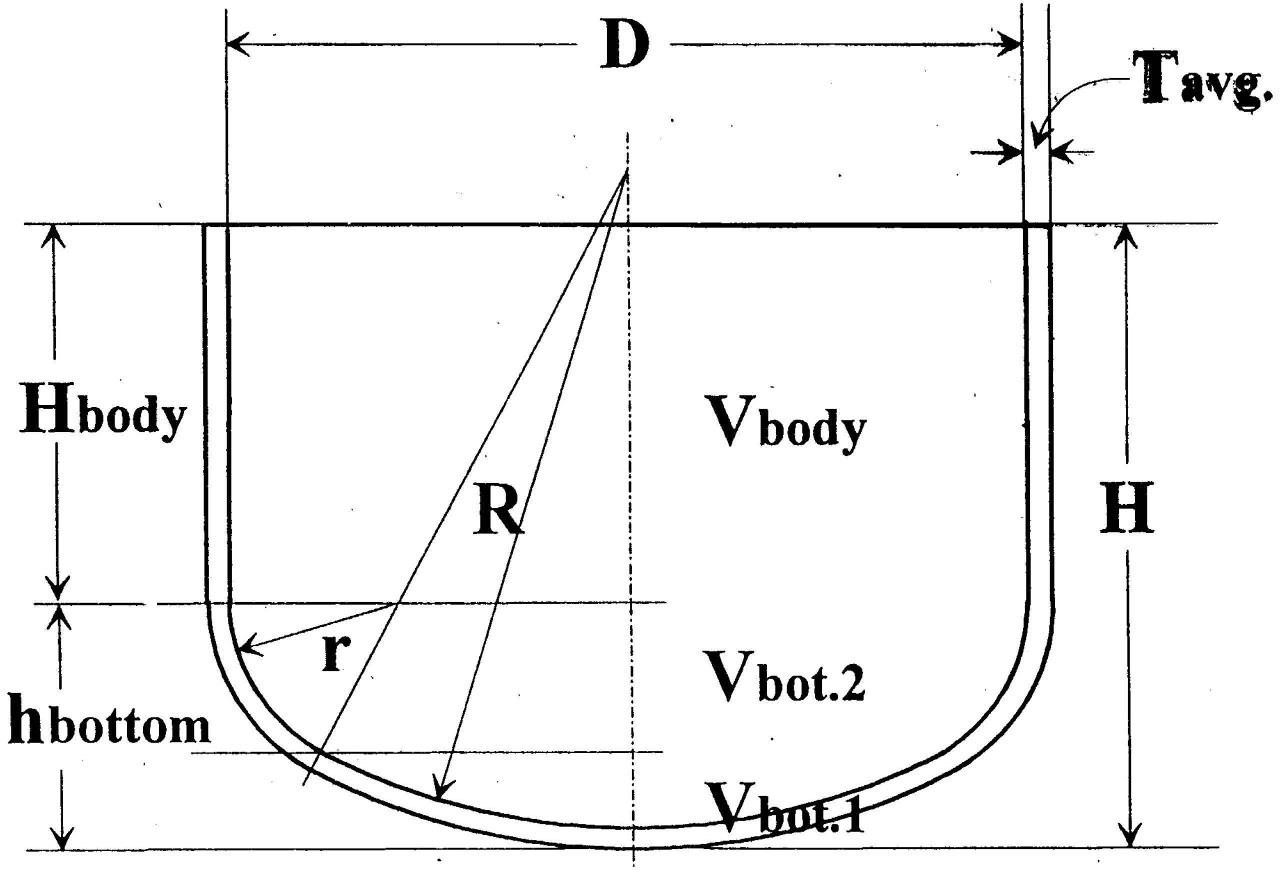


Mechanical strength of Dash neck



SEMICON Forum 94.7.18

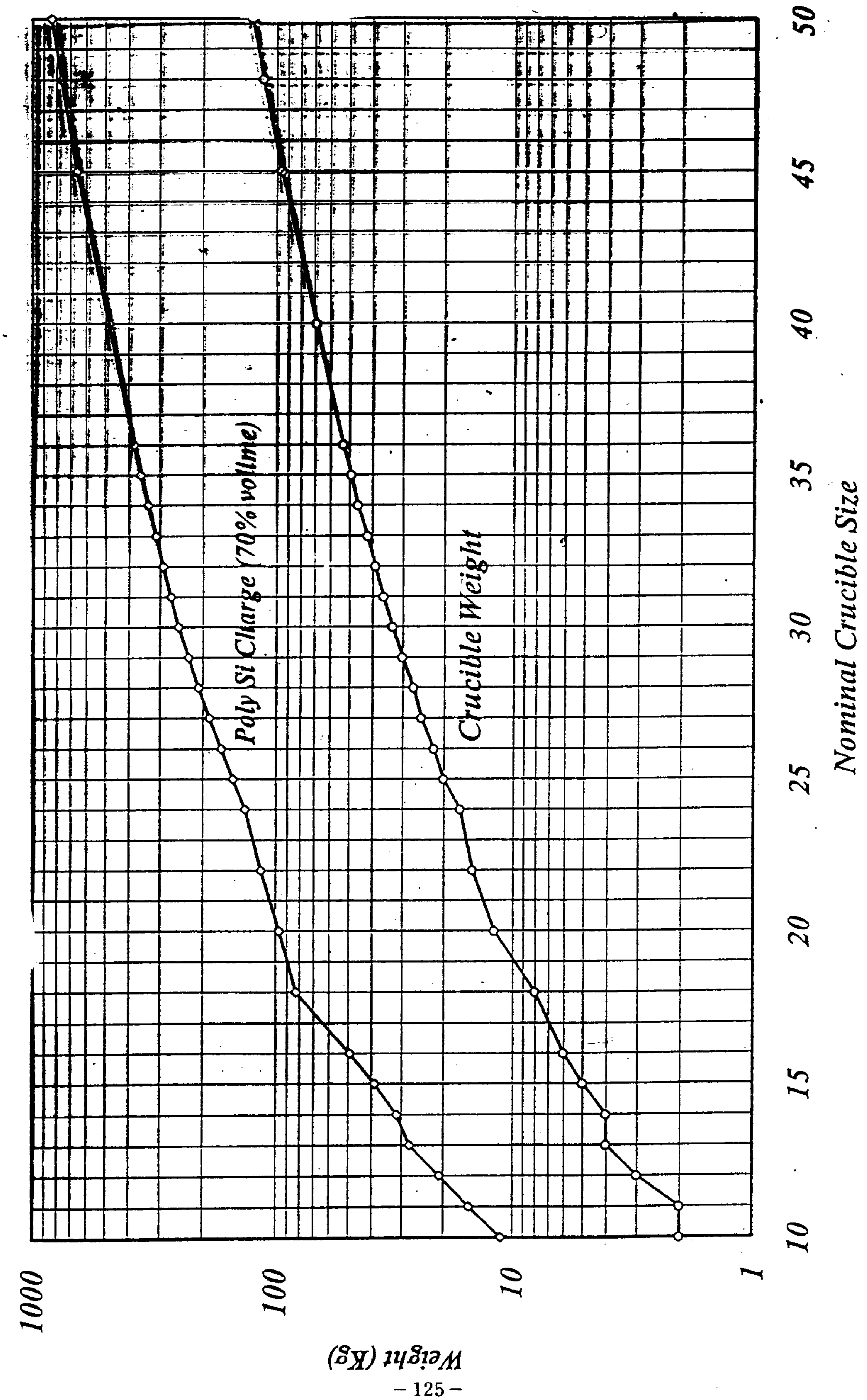
Qz. Glass Crucible Dimension

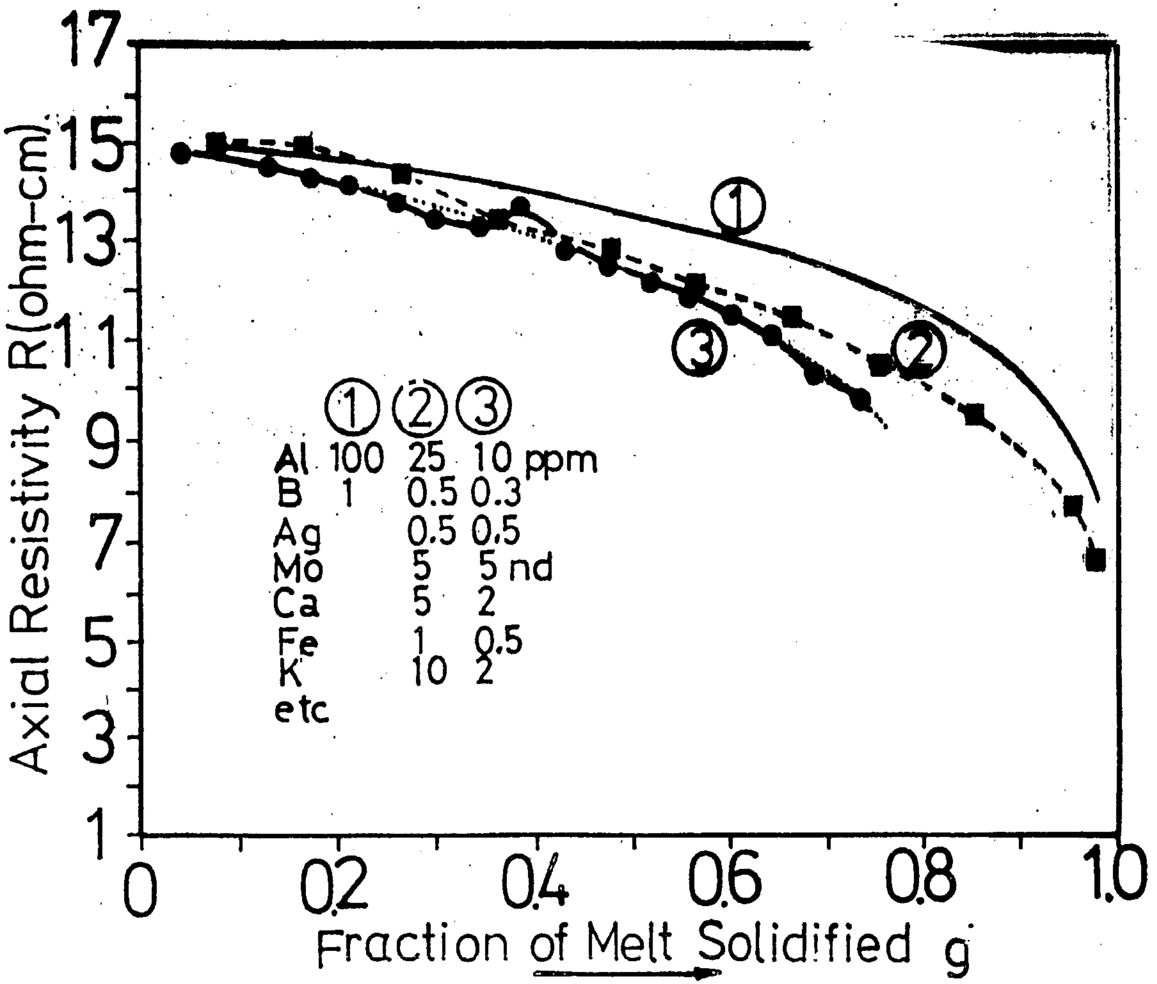


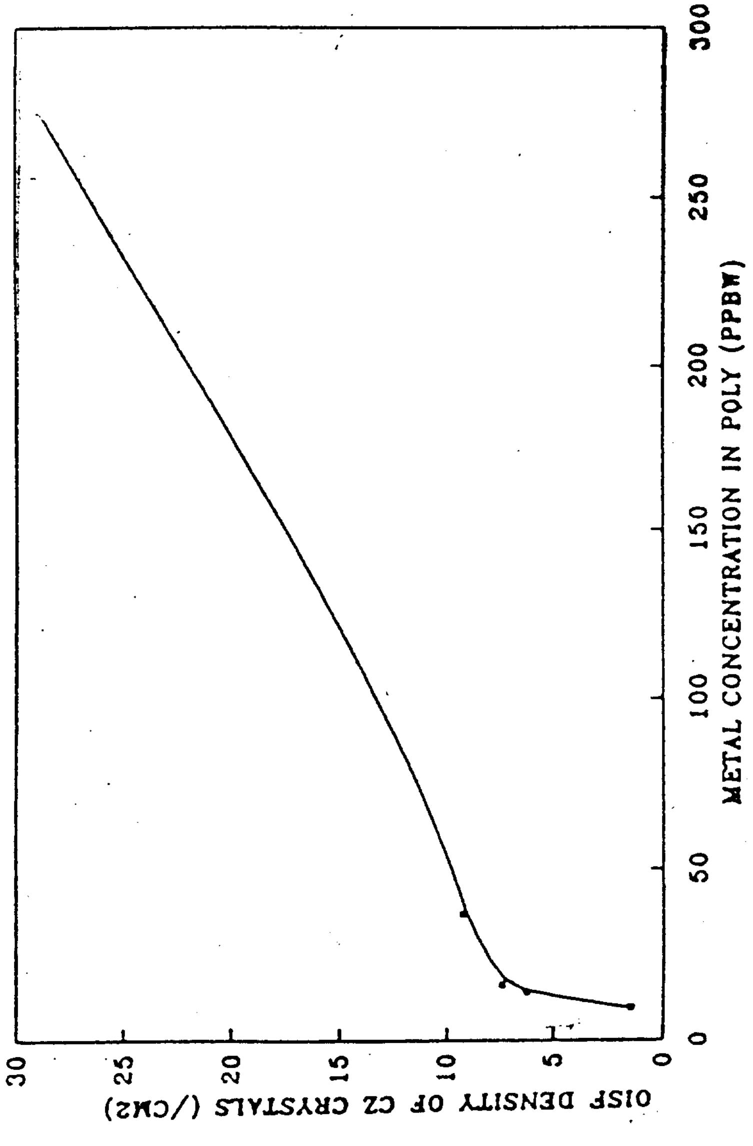
Fused Quartz Crucible Dia vs Crystal Dia

Nominal Crucible Diameter	100		125		150		200	
	Dia Ratio	Area Ratio	Dia Ratio	Area Ratio	Dia Ratio	Area Ratio	Dia Ratio	Area Ratio
12	2.000	8.000						
13	2.250	9.560						
14	2.500	11.250	1.800	6.840	1.330	4.400		
15	2.750	13.060	2.000	8.000	1.500	5.250		
16			2.200	9.240	1.670	5.890		
18					2.000	8.000	1.250	4.050
20							1.500	5.250
22							1.750	6.625
24							2.000	8.000

Area Ratio : $(\pi R^2-\pi r^2)/\pi r^2$


Poly Si Charge (70% volume)
Crucible Weight
Nominal Crucible Size
10
15
20
25
30
35
40
45
50
Weight (Kg)
1
10
100
1000


17
15
13
11
9
7
5
3
1
Axial Resistivity R(ohm-cm)
0
0.2
0.4
0.6
0.8
1.0
Fraction of Melt Solidified g
①
②
③
① ② ③
Al 100 25 10 ppm
B 1 0.5 0.3
Ag 0.5 0.5
Mo 5 5 nd
Ca 5 2
Fe 1 0.5
K 10 2
etc


OISF DENSITY OF CZ CRYSTALS (/CM2)
0
5
10
15
20
25
30
METAL CONCENTRATION IN POLY (PPBW)
0
50
100
150
200
250
300

Fused Quartz Crucible Purity

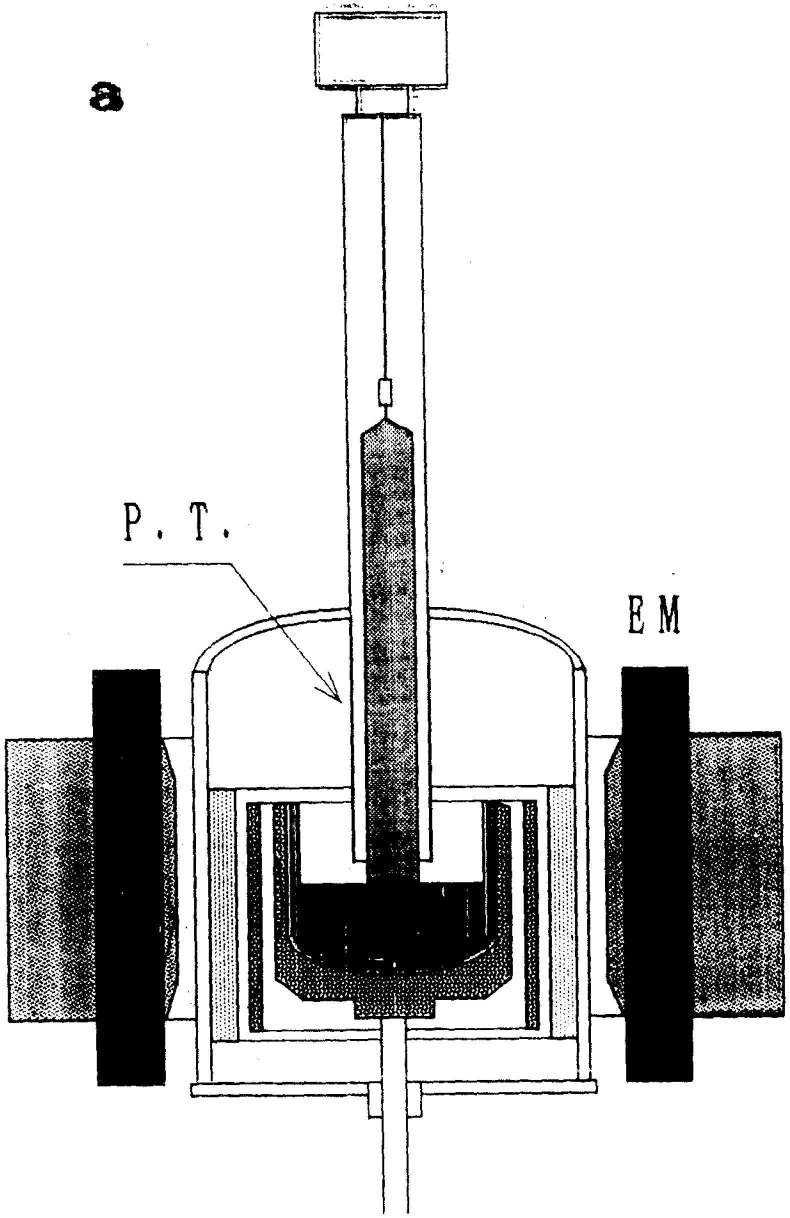
Atoms	Al	Fe	Na	K	Cu	B
High Purity	8	0.8	1	1	0.02	0.03
Ultra High Purity	7	0.5	0.05	0.05	0.01	0.03

(Unit : ppm)

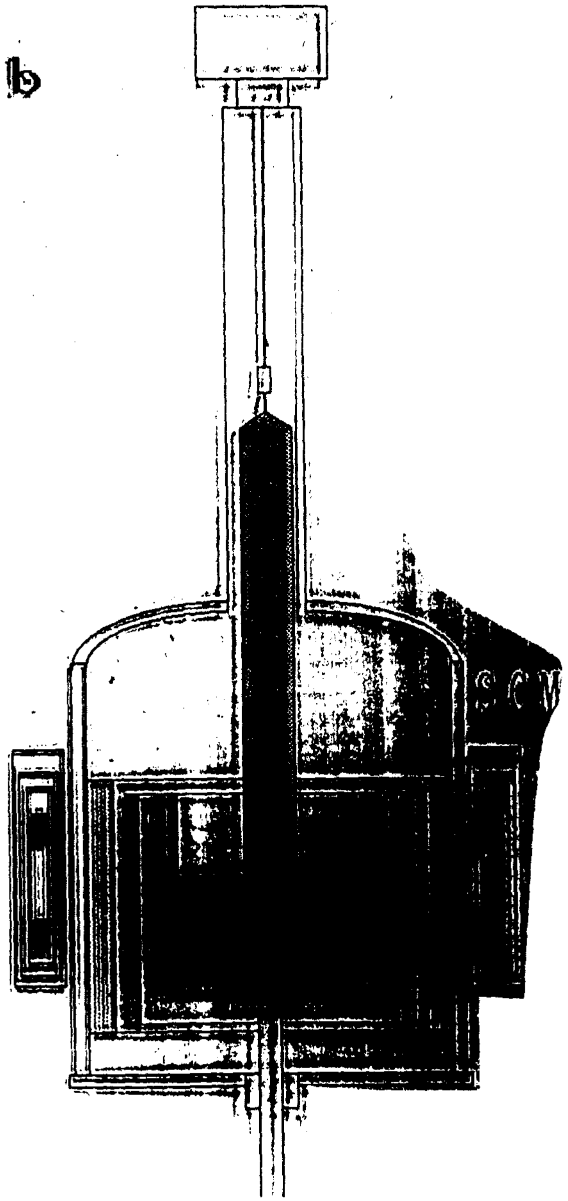
LARGE PULLER CHARACTERISTICS

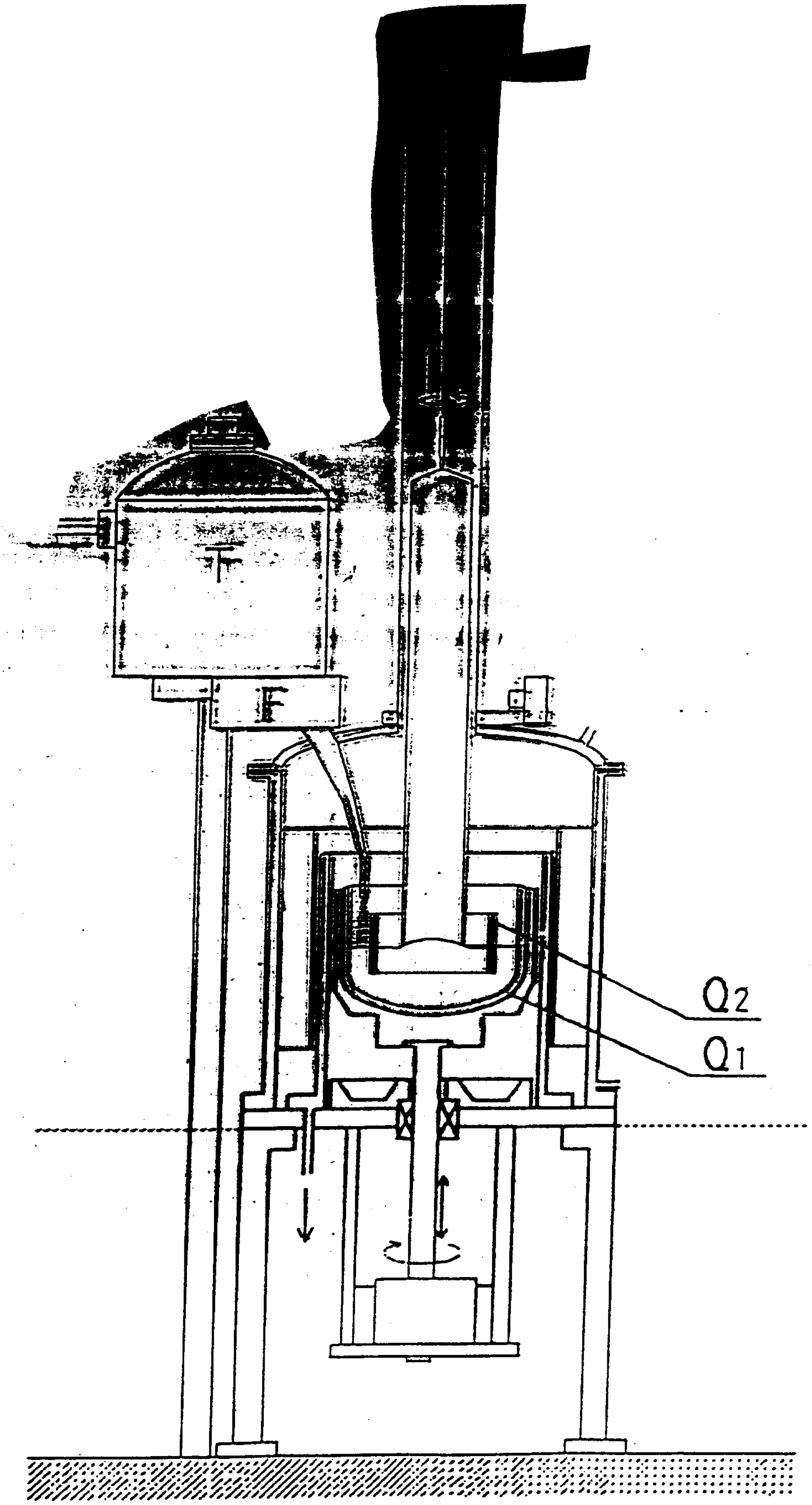
Item	Unit	200	250	300	350	400
Puller Cost	Yen	100000000	2.61E+02	3.25E+02	3.91E+02	4.59E+02
Puller Footage	mm^2	4	6	8	10	12
Heater Power	KWHr	200	327	488	685	919
Cooling Water	m^3	30	51	76	106	142
Ar Flow	m^3	0.1	0.16	0.23	0.31	0.40
Labour	man	1	1.5	1.5	2	2
QZ Gl. Cru. Price	Yen	350,000	611,425	964,487	1,417,957	1,979,899
C. Cru. Price	Yen	800,000	1,397,542	2,204,541	3,241,045	4,525,483
C. Cru. Life	Cycle	30	30	25	25	20
C. Cru. Exch.	Hr	30	36	42	48	48
C. Heater Price	Yen	2000000	3,125,000	4,500,000	6,125,000	8,000,000
C. Heater Life	Cycle	50	45	40	35	30
C. Heater Exch.	Hr	30	36	42	48	48
Heat Up Time	Hr	10	12	14	16	18
Holding Time	Hr	4	5.5	7.1	8.8	10.6
Cool Down Time	Hr	4	5.9	8.1	10.6	13.3

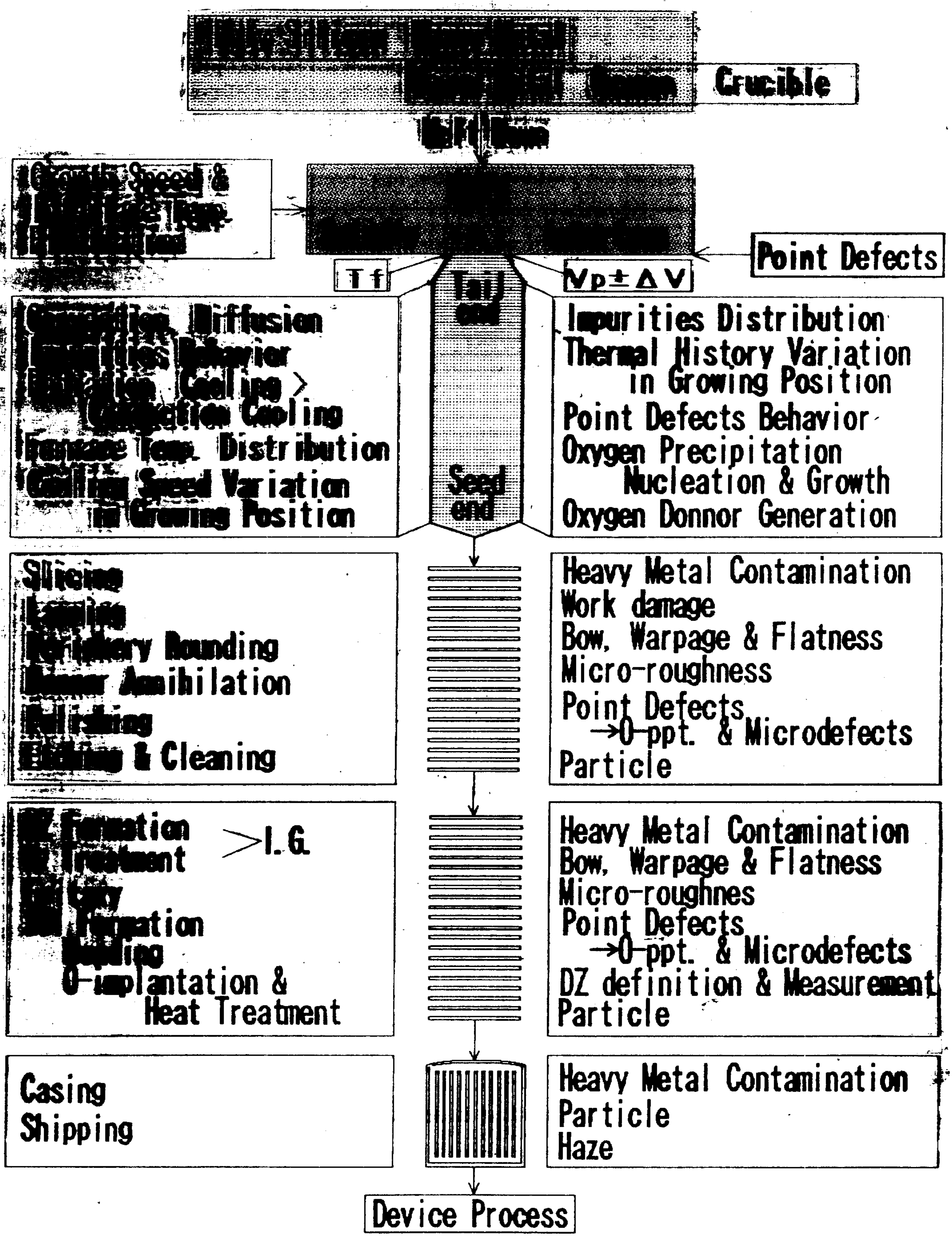
a



b




T
F
Q2
Q1

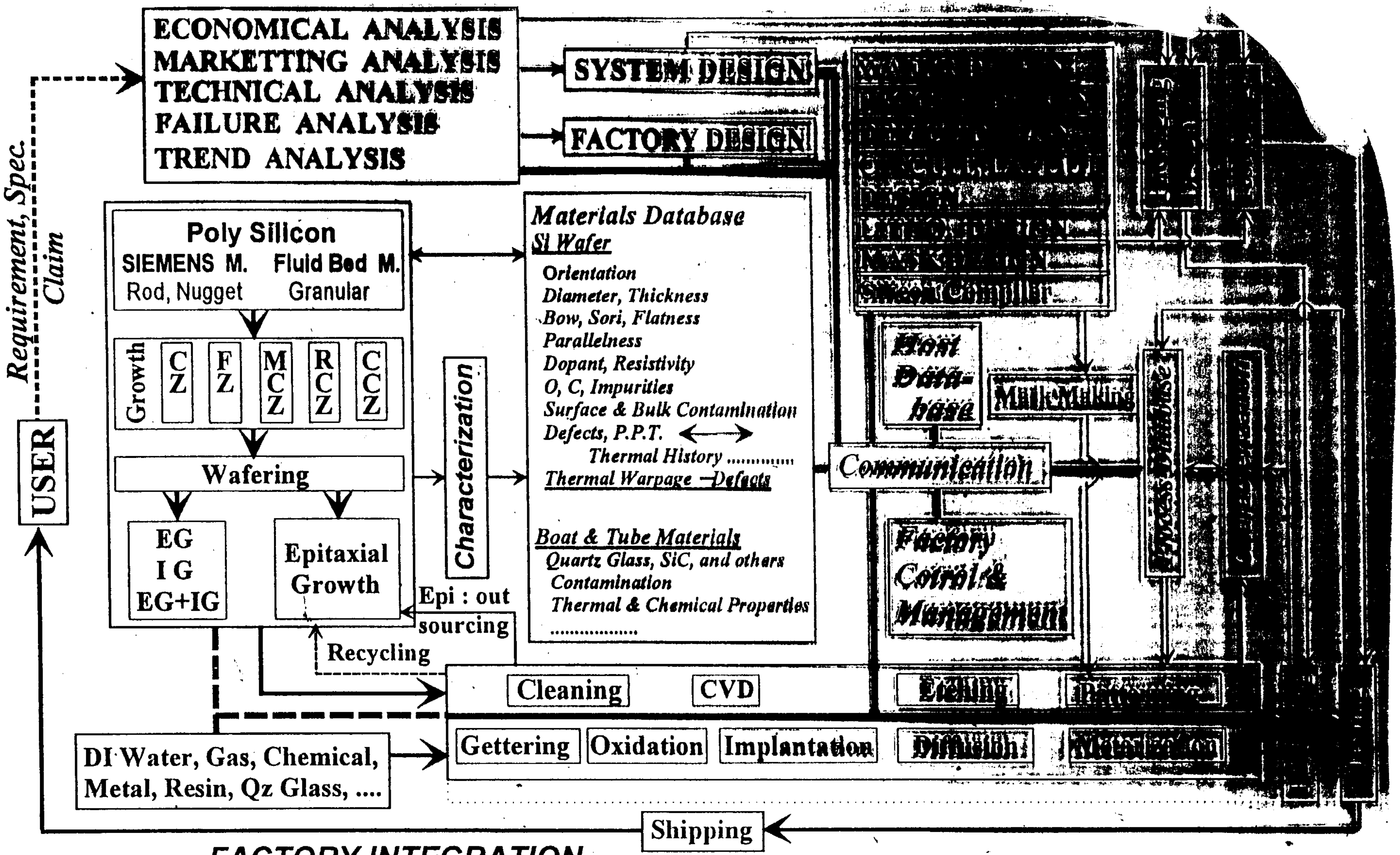

[illegible]
[illegible] Crucible
Melt Flow
Growth Speed &
Interface Temp.
Distribution
[illegible]
Point Defects
Tf
Vp±ΔV
Tail end
Seed end
Convection, Diffusion
Impurities Behavior
Radiation, Cooling >
Conduction Cooling
Furnace Temp. Distribution
Cooling Speed Variation
in Growing Position
Impurities Distribution
Thermal History Variation
in Growing Position
Point Defects Behavior
Oxygen Precipitation
Nucleation & Growth
Oxygen Donnor Generation
Slicing
Lapping
Periphery Rounding
Donnor Annihilation
Polishing
Etching & Cleaning
Heavy Metal Contamination
Work damage
Bow, Warpage & Flatness
Micro-roughness
Point Defects
→O-ppt. & Microdefects
Particle
DZ Formation
IG Treatment
>I.G.
Epi Grow
SOI Formation
Bonding
O-implantation &
Heat Treatment
Heavy Metal Contamination
Bow, Warpage & Flatness
Micro-roughnes
Point Defects
→O-ppt. & Microdefects
DZ definition & Measurement
Particle
Casing
Shipping
Heavy Metal Contamination
Particle
Haze
Device Process

4 : Summary and Future Issue

300 mm diameter Si Crystal growth is not difficult, but its economic mass productions for ULSI device production contain many difficult issues.
Economic large diameter Si crystal growth requires basic approach and widely fundamental data accumulation.
And, it may be need global cooperation.

Required Data

Constants	**at**	**for**	**by**	[illegible]	
Thermodynamic **parameter**					
Melt properties					
dρ/dt		melt		[illegible]	
Volume expansion					
Linear expansion **coefficient**					
Viscosity		melt		[illegible]	
Surface tension(μ)		temperatire gradient			
dμ/dt					
Yield strength	near melting point	Pure Si/Doped Si		[illegible]	
Young's Modulus					
Elastic Modulus	around melting point				
Stress distribution					
Conductivity					
Mobility					
Absorption coefficient of RF					
Latent heat					
Absolute temperature			contactless		
in situ observation					
Vacancy					
Point defects, Cv, Ci		thermal equilibrium			
Self interstitial					
Electronic state of defect					
O-defects					
O-precipitation potential					
Kinetics of SiO					
Configration of O in melt Si					
Rare earth solubility					
Volume contamination					
Surface contamination					

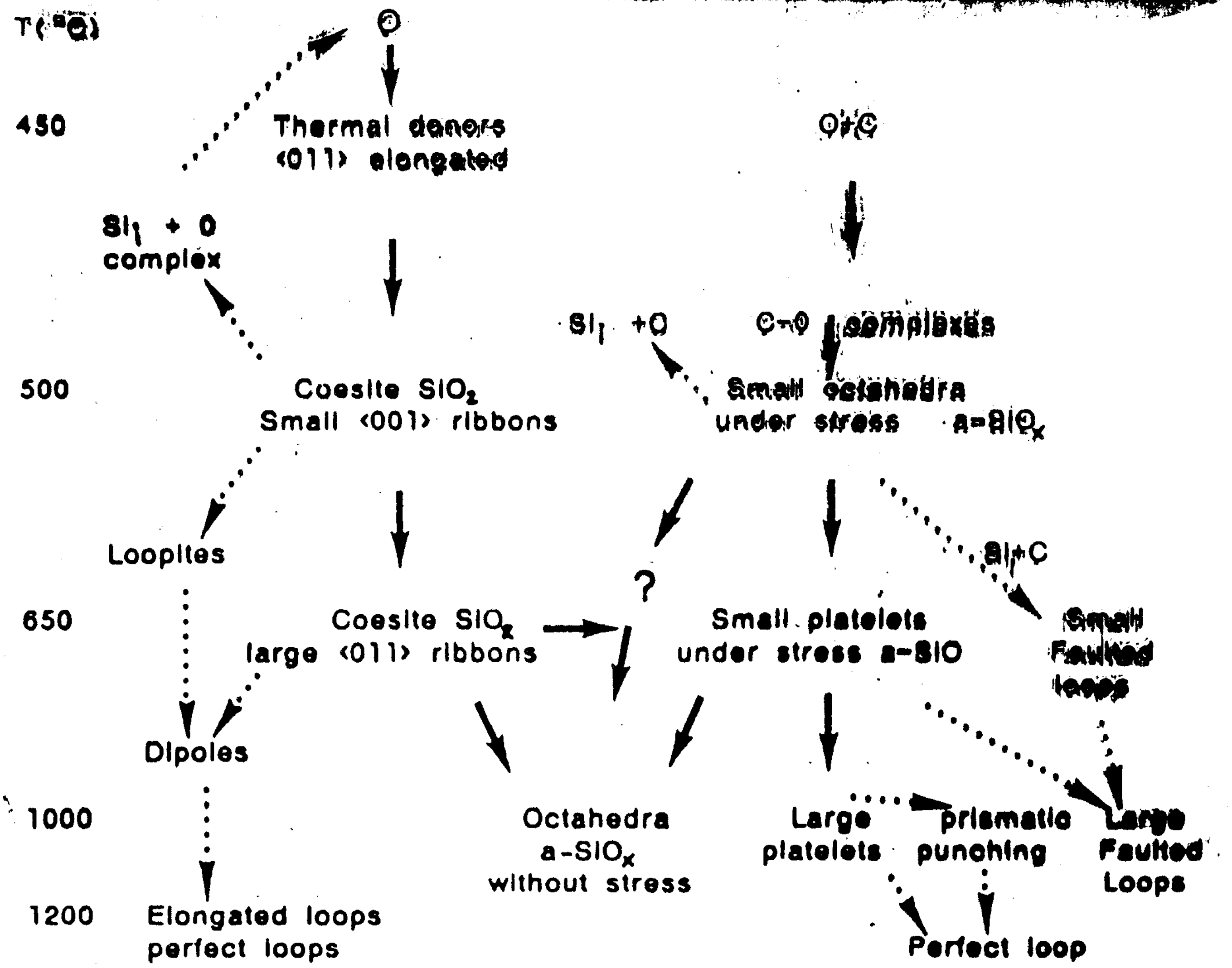


FACTORY INTEGRATION

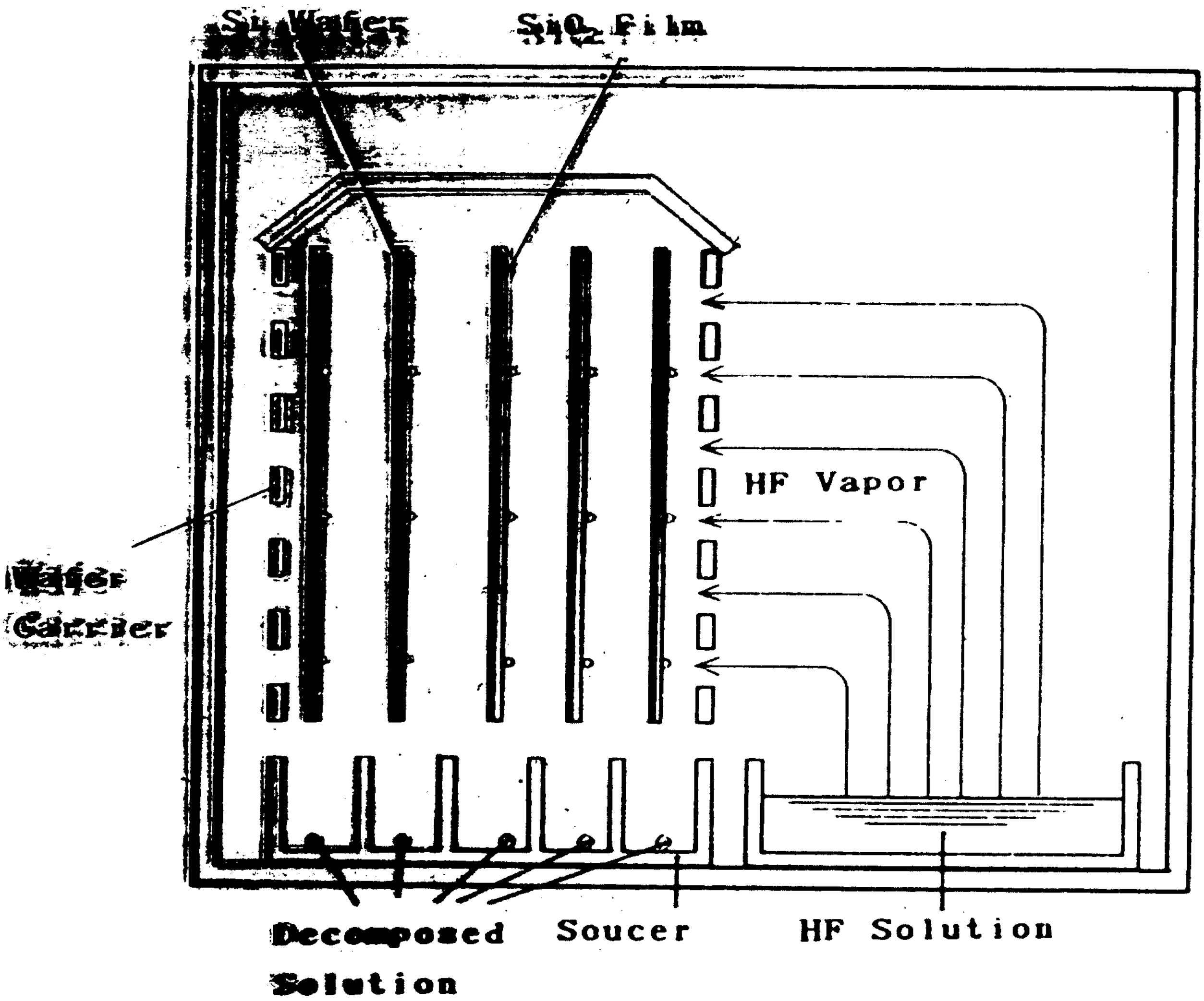
History of Large Diameter Si Wafer

1962		Si Strength W.D.Sylwestrowicz *Phil. Mag.* p1825
[illegible]		Crystal Growth and wafering of 200mm wafer, Results of VLSI Cooperative Association, (NTIS) 200mm Si Crystal Growth, T.Usami & Shin.Takasu, *Symposium on Semiconductors and Integrated Circuit* [illegible] p[illegible] (Toshiba)
[illegible]		200mm SEMI Standard
1985		200mm JEIDA Standard
1988	May	Processing and Characterization of 200mm Si Wafer, D.L.Golland *SEMICON/West STS*, p102 (MONSANTO) 200mm Wafer Introduction, G.E.Thyng, ibid. p153 (IBM)
	July	200mm Wafer Introduction, G.E.Thyng & G.G.Collins, *SEMICON/Kansai STS*, p272, (IBM)
1989	March	JEIDA *Report of Large Diameter Silicon Wafer Trends* I
	June	Technology Problems for Large Wafer Diameter in VLSI Manufacturing, M.Nakamura, *SEMICON/Osaka STS*, Large Diameter Wafer, p243 (Toshiba) **Advantage of 200mm Wafer Operation, Y.Nagano, ibid.** p257 (T.I. Japan) Productivity and Wafer size Rationale and Practice **A.C.Tobey, ibid. p271** Crystal growth, Wafering and Epitaxy of 200mm Si Crystals, **T.Abe, I.Matrock, ibid.** p297 (SEH)
1990	March	JEIDA *Report of Large Diameter Silicon Wafer Trends* II
	May	CZ Crystal Growth, W.Zulehner, *Semiconductor Silicon 1990*, p30 (Wacker) Thermal insulator near pulling crystal. Si Crystal Growth **under Magnetic Field, Shin.Takasu**, S.Takahashi, M.Ohwa, O.Suzuki, T.Higuchi, ibid. p45 (Toshiba Ceramics) **pointed out that large diameter** Si Crystal growth may require H-MCZ method and neck downed seed **form is important** Neck Strength at Large **Diameter Si CZ Pulling**, K.M.Kim & P.Smetana, *J.Cry.Growth* Vol.100, p527 (IBM)
1991	May	*SEMI/JEIDA Joint Technical Conference on Silicon Materials for Advanced IC Application* SEMICON/West At this **conference, JESSI showed** 300mm Si Wafers.
	Nov.	**Silicon Materials** for MEGA-IC Applications, H.R.Huff, Symposium on *"Advanced Science and Technology of Silicon Materials" As Industry-University Cooperative International Symposium, JSPS*, p140(SEMATECH) **Large Diameter** Si Wafer Mechanical Processing Shin.Takasu, H.Terauchi, T.Araki, ibid. p171, (Toshiba **Ceramics)** Silicon Wafer Properties for Future Applications, P.O.Hahn, ibid. (p180) Wacker
	Dec.	**The Next Wafer** Size Challenge-300mm, L.T.Gallinger & L.A.Kieny, *SEMICON/Japan STS*, (IBM) **Economy of 8" Wafer** line, S.Kaga, ibid. p167 (T.I. Japan)
1992	March	**JEIDA** *Report of Multi-Layer Silicon Wafers (MLSW)* II
	Apr.	**300mm SEMI Std.**
	Sept.	**Discussion of 300/**350/400mm SEMI Std.Wafer
	Nov.	**SIA-SEMATECH Si Future** Technology W.S.
1993	May	*4th International Symposium on ULSI Science and Technology, Electronic Materials Technologies for the 21st Century,* **at ECS Hawaii** Meeting, , *SIA Semiconductor Technology*, Workshop Working Group Reports.
	July	**SEMICON/West,** *"SEMI/JEIDA Joint Technical Symposium, What's Ahead for 200mm Wafers?* **200mm wafer is used to 2007,** D.Rose,p11 (Intel), **Needs** of International Cooperation, W.O'Mara p33
	Dec.	**SEMATECH showed the** results of W.S. on large diameter Si wafer at JEIDA/ASTM/SEMI Annual Meeting.
1994	March	**JEIDA** *Report of Multi-Layer Silicon Wafers (MLSW)* III (User's Specification Discussion)
	Apr./11	*International Consortium Summit Meeting* was held at SEMICON/EUROPA, Geneva.
	May	**SEMATECH** showed the possibility of 400mm Wafer at ECS *Si Symposium*.
	July/19	*"Forum On Silicon Wafer Diameter : Is there a change in the future?"* was held at SEMICON/West **In this forum,** M. Watanabe showed Si strength temperature dependency.
	July/21	***Si Wafer SUMMIT MEETING*** was Coordinated by SEMI. Resolutions 1 Organize US/Europe & Asia Task Force 2 Held meeting at 3 SEMICON and discuss the results of each Task Force. 3 Temporary target is 300mm.
1995		Many discussion on 300mm Si wafer Standard.
1996	Jan./Feb.	SEMI SMG 300mmWafer Questionnaire Survey.

Nucleation and growth paths for oxygen precipitation in silicon



Si$_I$ ⁝ = Easy pipe diffusion along coesite ~ 480°C
⁝ = Easy pipe diffusion along dislocation ~ 550-600°C
⁝ = Easy emission from a SiO$_x$ precipitate ~ 700-750°C


Si Wafer
SiO2 Film
HF Vapor
Wafer Carrier
Decomposed Solution
Soucer
HF Solution