N86-19726

FUTURE APPLICATION OF CZOCHRALSKI CRYSTAL PULLING FOR SILICON

J.H. Matlock

S.E.H. America
Vancouver, WA 98662

Czochralski (Cz) crystal pulling has been the predominant method used for preparing for silicon single crystal for the past twenty years. The fundamental technology used has changed little for 25 to 30 years. However, great strides have been made in learning how to make the crystals bigger and of better quality at ever increasing productivity rates. The question that exists today is whether this technology has reached a mature stage. Are limits in crystal size and productivity being reached? The answers at this point are not clear yet.

Currently charge sized of 50Kg of polycrystal silicon are being used for production and crystals up to ten inches in diameter have been grown without major difficulty. The largest material actually being processed in silicon wafer form is 150mm (6 inches) in diameter.

Recent efforts in Cz silicon development have concentrated on continuing the increase in wafer size and in higher productivity for lower costs. Also much effort has been extended in regard to the macroscopic and microscopic control of impurities in Cz crystals. Oxygen content is a special challenge for control as one must balance the dissolution rate of the quartz crucible, the free and forced convection in the silicon melt and the rate of surface evaporation. Much has been done here by programming changes in the crystal growth parameters throughout the process.

For control of dopant incorporation one must look for ways to balance natural segregation effects. The use of programmed reduced pressure (for a volatile element), the double crucible method and recharging have aided in this regard. Growing of crystals in a magnetic field has proved to be particularly useful for microscopic impurity control. Major developments in past years on equipment for Cz crystal pulling have included the automatic growth control of the diameter as well as the starting core of the crystal, the use of magnetic fields around the crystal puller to supress convection, various recharging schemes for dopant control and the use of continuous liquid feed in the crystal puller.

Continuous liquid feed, while far from being a reliable production process, is ideal in concept for major improvement in Cz crystal pulling. It combines a high theoretical productivity with the dopant leveling characteristics of the double crucible method. The buildup of unwanted impurities is much slower than for the use of recharging. It would seem that enough future promise exists for this method that further development is definitely warranted.

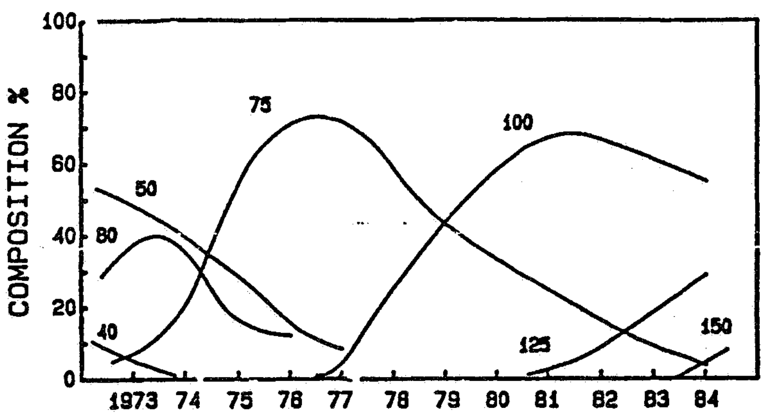
What other major breakthroughs exist for Cz crystal pulling are not certain, but what is clear is that this process will maintain its dominance of silicon crystal production for a number of years.

Cz Process

- LITTLE CHANGE IN FUNDAMENTAL TECHNOLOGY FOR 25 TO 30 YEARS
  - JUST
    MORE
    BIGGER
    BETTER
- ARE REASONABLE LIMITS BEING REACHED?

  IS PROCESS REACHING MATURITY?
  - NOT CLEAR YET

Silicon Wafer Diameter Trend (Area Gain)

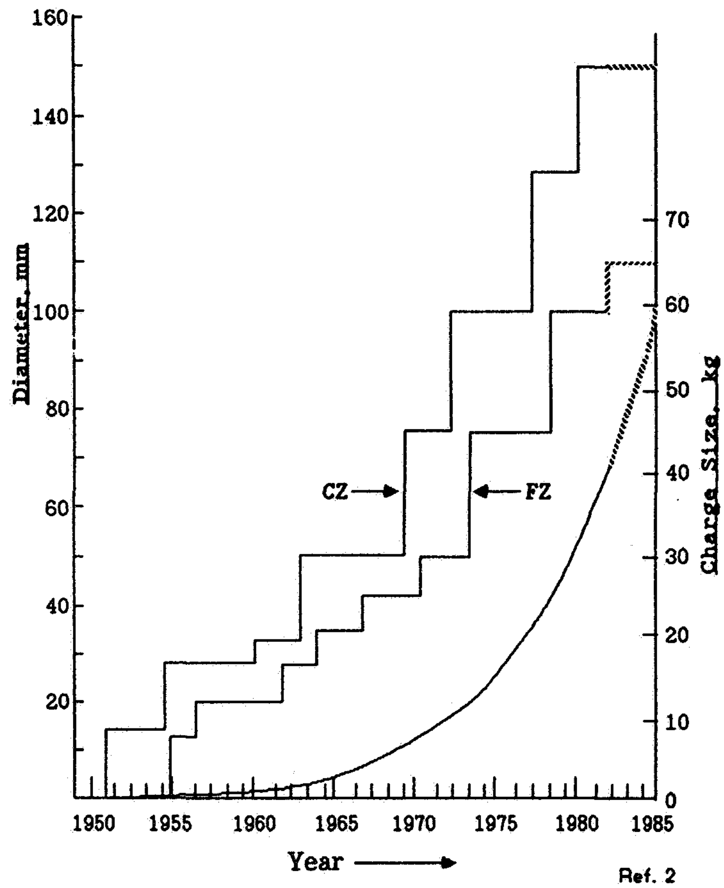


Silicon wafer diameter trend (area gain). 200mm diameter wafers are expected as next generation IC devices.

PRECEDING PAGE BLANK NOT FILMED

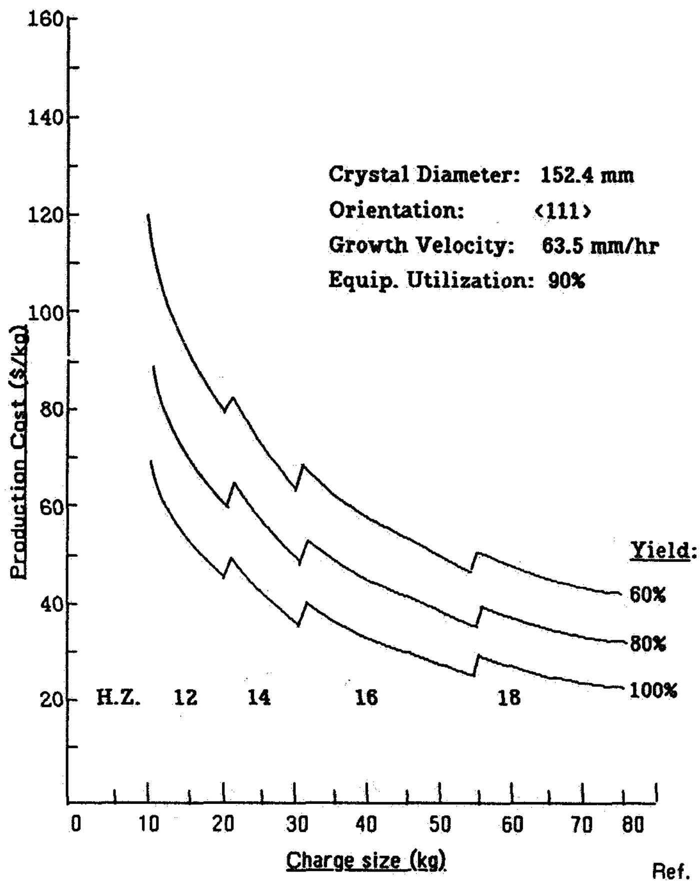
REF (1)

Cz/FZ Crystal Diameters and Cz Charge Sizes



Ref. 2

Crystal Production Costs Dependent on Charge Size and Yield



Ref. 2

Goals of Silicon Cz Development

- LOWER COST / HIGHER PRODUCTIVITY
- LARGER WAFER SIZE
- IMPURITY CONTROL
    - DOPANTS
    - OXYGEN
    - OTHERS
- DEFECT CONTROL

Reduce Cost, Increase Productivity

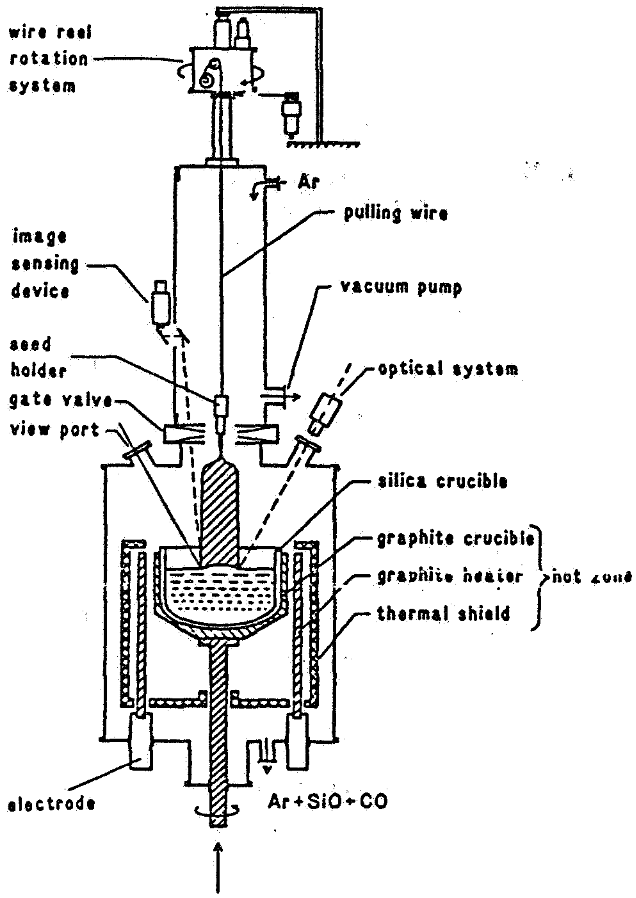
- INCREASE YIELD
- INCREASE PULL SPEED
- INCREASE CHARGE/BATCH SIZE
- DECREASE SUPPLY COST / UNIT

Current Production Process

- 30 - 50 KG CHARGE
- 150MM DIAMETER CRYSTAL
- 12 - 16 INCH HOT ZONE

DEVELOPMENT PROCESS

- UP TO 100KG
- UP TO 250+ MM DIAMETER
- 16 - 18 INCH HOT ZONE



Schematic drqwing of a Czochralski pulling equipment with heating, automatic optical and image sensing diameter controls, a valve between furnace and front opening chamber and wire reeling system.

REF (1)

Impurity Control

- OXYGEN - MAJOR IMPURITY
  - CONTINUOUS ADDITION FROM CRUCIBLE DISSOLUTION
  - SEGREGATION COEFF $\approx$ 1.0

    MUST CONSIDER:

    DISSOLUTION RATE

    FREE CONVECTION

    FORCED CONVECTION

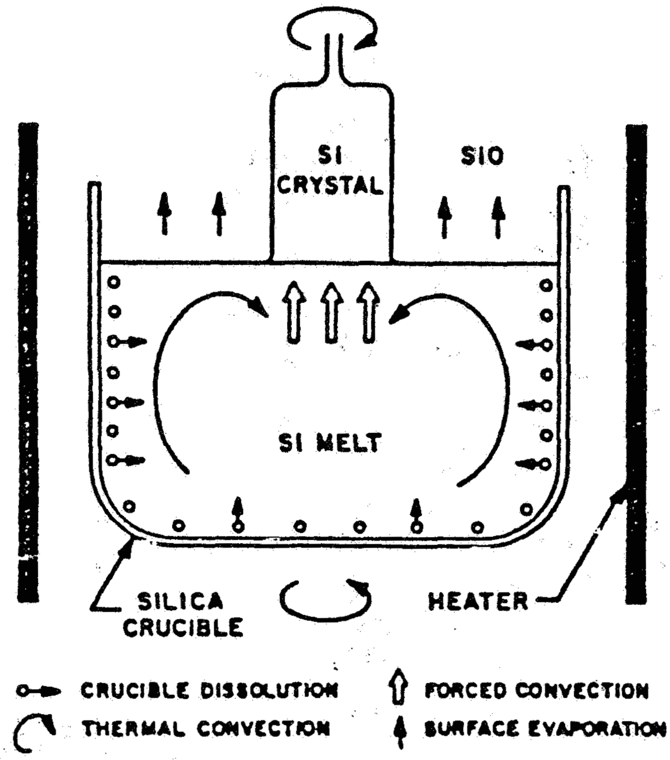
    SURFACE EVAPORATION
- DOPANTS

  MUST COMBAT SEGREGATION EFFECTS

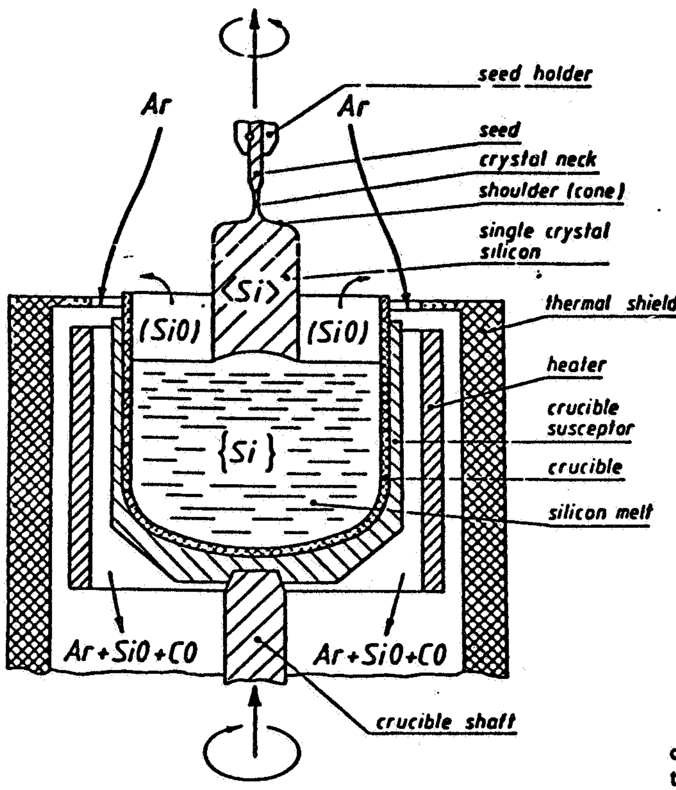
  AND KEEP AT DESIRED LEVEL
- OTHER IMPURITIES (INCL. C)

  MUST COMBAT SEGREGATION EFFECTS

  AND KEEP AS LOW AS POSSIBLE

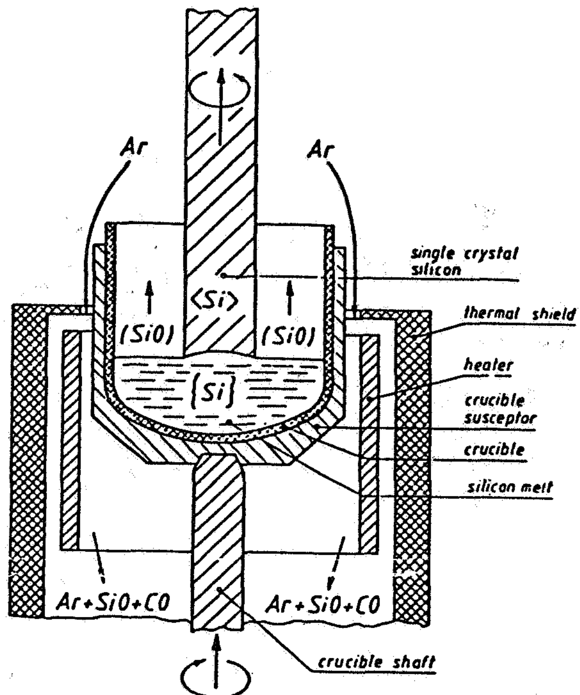


Schematic of a CZ growth system showing relationship between oxygen controlling functions.

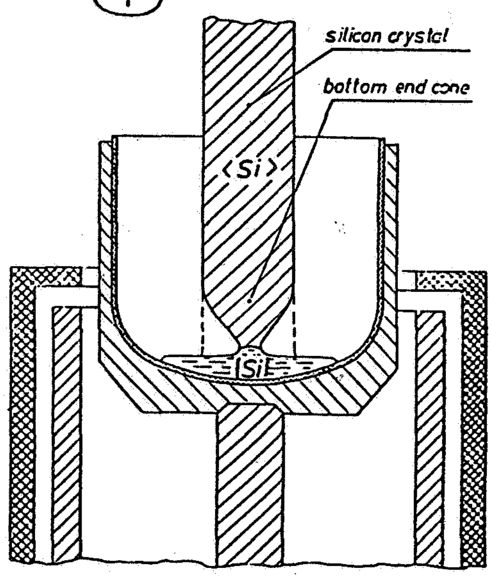


Czochralski single crystal pulling; initial stage of the process

REF (4)

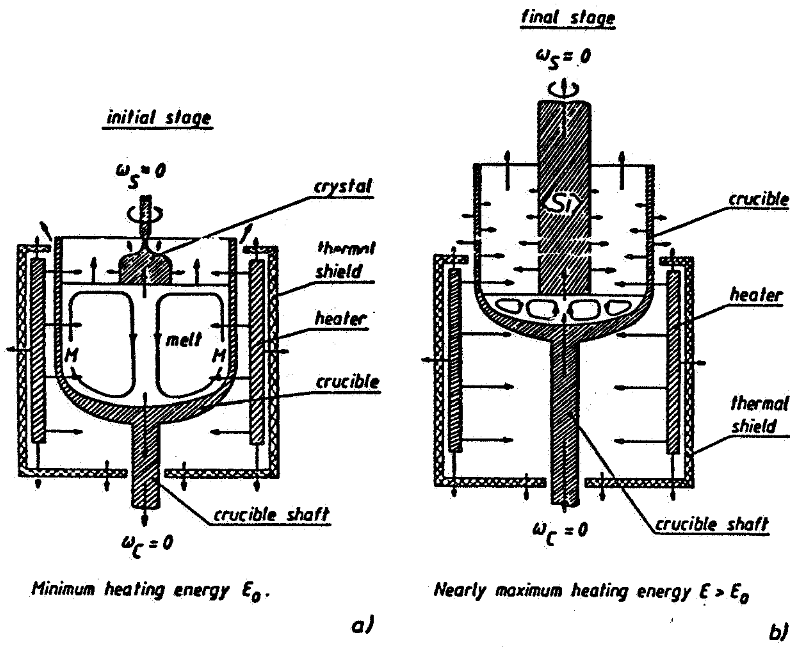


Czochralski single crystal pulling; advanced stage of the process



REF (4)

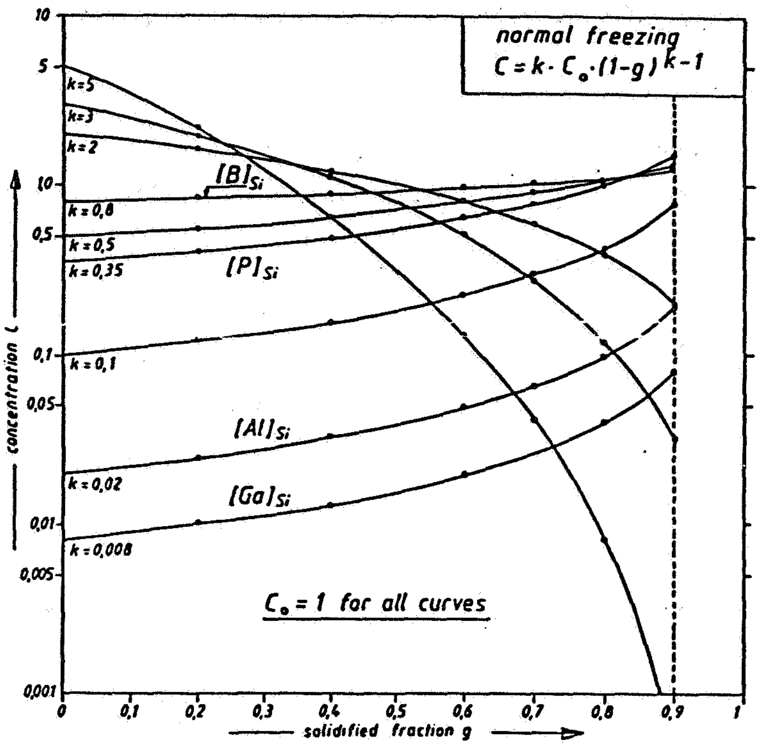
Czochralski single crystal pulling; final stage of the process. If the crystal would have the shape of the dashed lines, it could not be finished dislocation-free



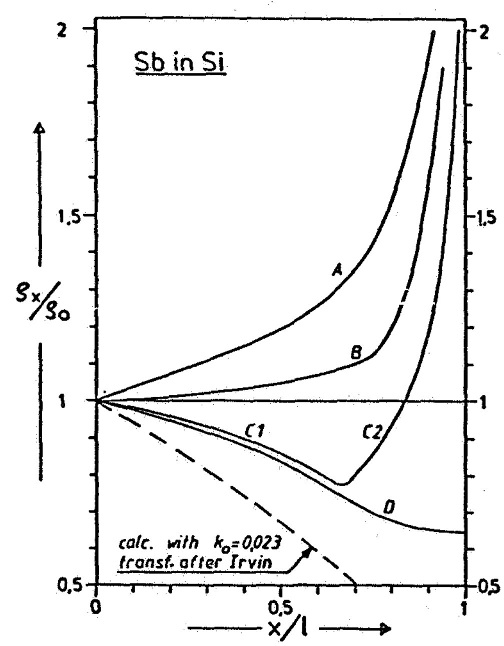
Heat flow conditions during CZ crystal growth. The *arrows* indicate the approximate direction of the heat flow. a shows the initial stage (= short crystal) and b the final stage (= end of cylindrical crystal) of the growth

Dopant Control

- PRESSURE CONTROL
  (FOR VOLATILE ELEMENT)
- DOUBLE CRUCIBLE
- RECHARGE
- MAGNETIC FIELD
  - MICROSCOPIC CONTROL

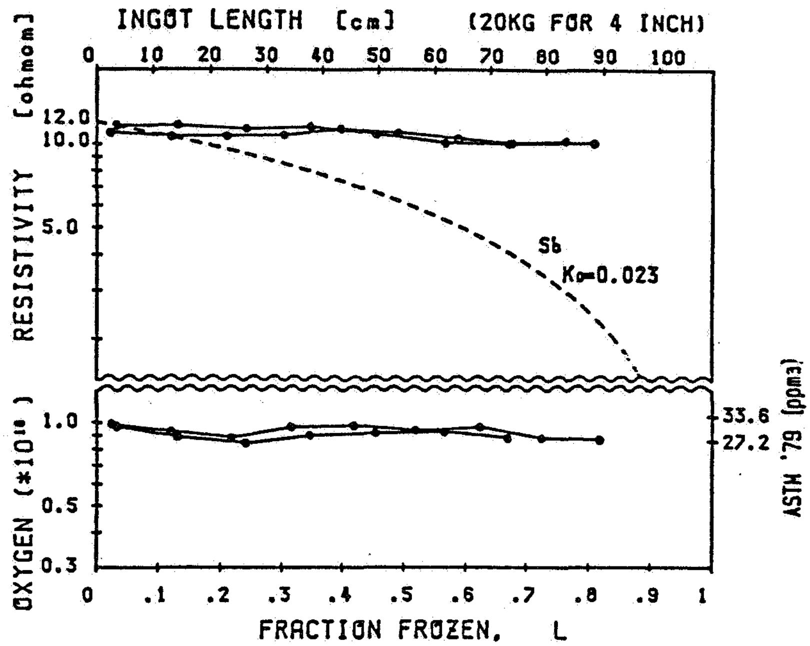


Axial impurity distributions for normal freezing and different k values according to Pfann[33,34]



Axial resistivity variations in antimony-doped CZ Si single-crystals. The initial doping concentration (= 0.018 Ωcm), melt volume and crystal diameter were the same for all curves. Due to the high vapour pressure of Sb, a great variety of axial resistivity profiles can be realized by applying different pressure and gas flow conditions. *Curves A* and *B:* Same pressure of 11 mbar but different gas flow characteristics. *Curve C:* 67 mbar in region C1, 11 mbar in region C2. *Curve D:* 75 mbar

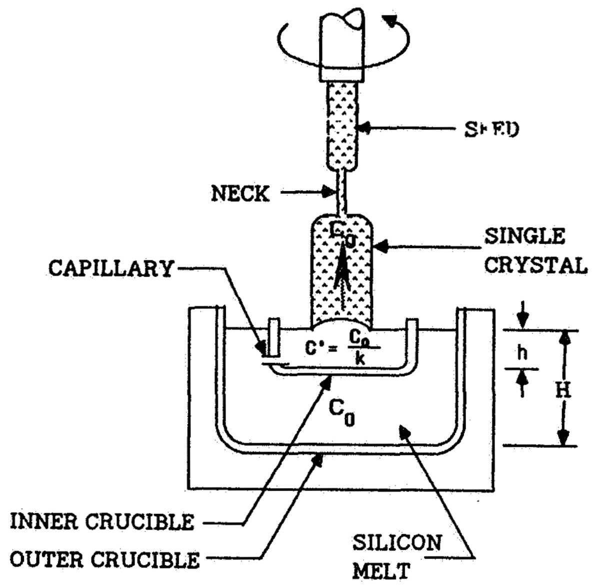
Improved Sb Concentration Distribution by Pressure Control



Constant resistivity distributions along the growth direction. The resistivity and oxygen distributions of lightly Sb-doped CZ crystals were grown by the controls of furnace pressure and crucible rotation rate for Sb an oxygen, respectively.

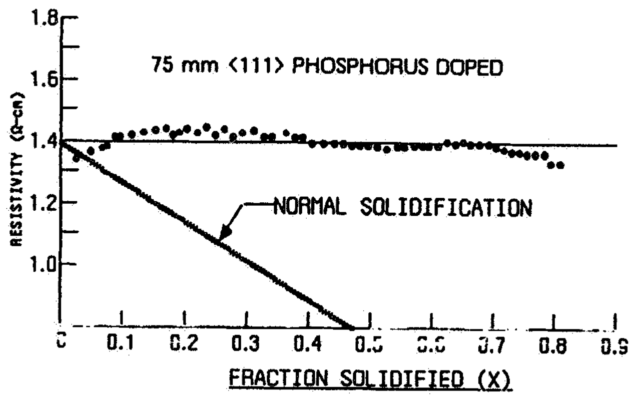
REF (1)

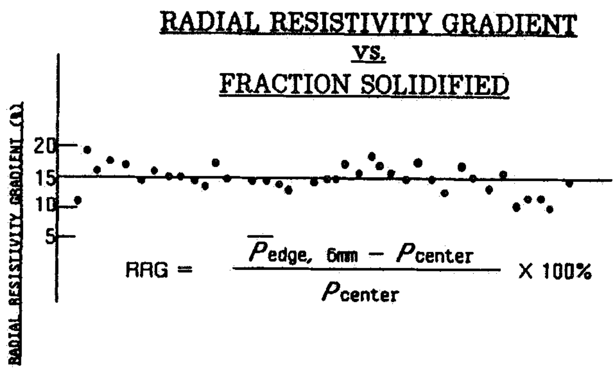
Schematic Representation of a Double-Crucible Growth Arrangement



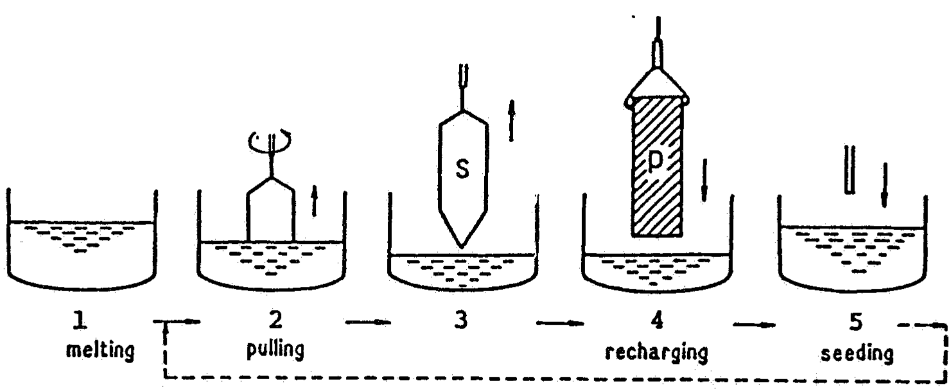
REF (3)

Axial Resistivity Profile of Double-Crucible-Grown Crystal



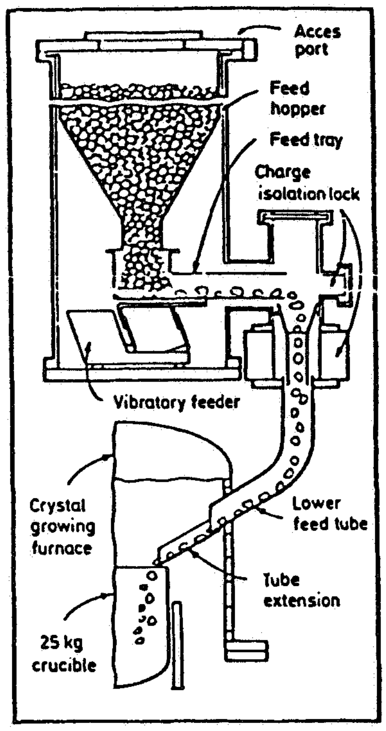


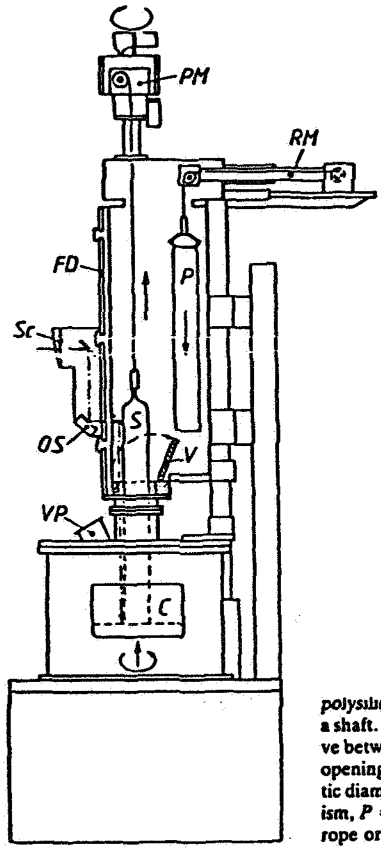
REF (3)



Recharging method. The tight resistivity ranged crystal is pulled with leaving Si melt in a crucible and then feed material together with dopant impurity are melted to grow the second crystal.

Recharging the Hot Crucible With Polysilicon Chips





CZ crystal puller with recharging equipment for a polysilicon rod and crystal pulling by rope or chain instead of a shaft. *S* = single crystal, *C* = crucible, *V* = separating valve between furnace and front opening chamber, *FD* = front opening door, *Sc* = screen, *OS* = optical system for automatic diameter control, *VP* = view port, *PM* = pulling mechanism, *P* = poly-silicon rod, *RM* = recharging mechanism with rope or chain. According to Lane and Kachare[237]

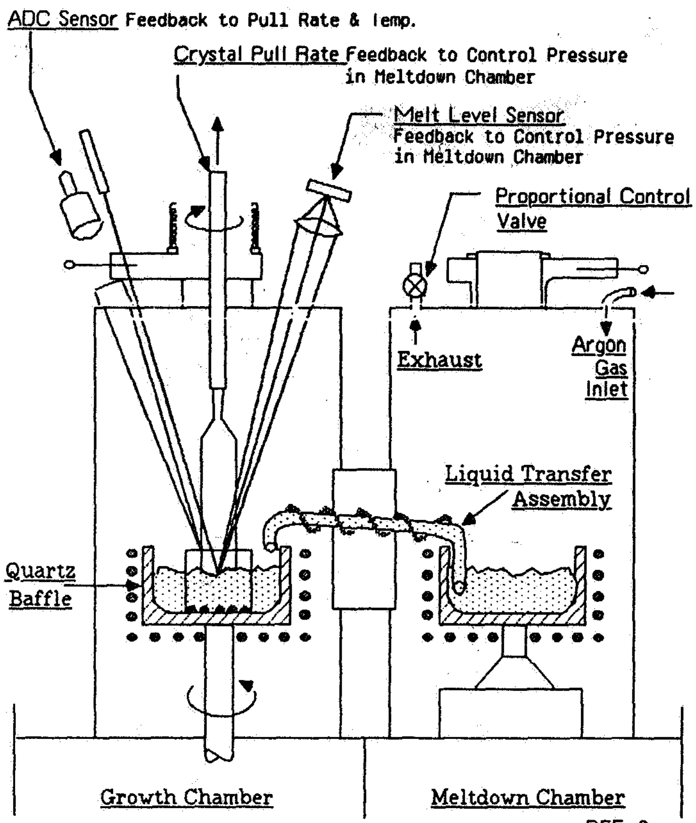
Defect Control

CONSISTENT
THERMAL ENVIRONMENT
NEEDED THROUGHOUT
CRYSTAL GROWTH CYCLE.

Major Equipment Developments

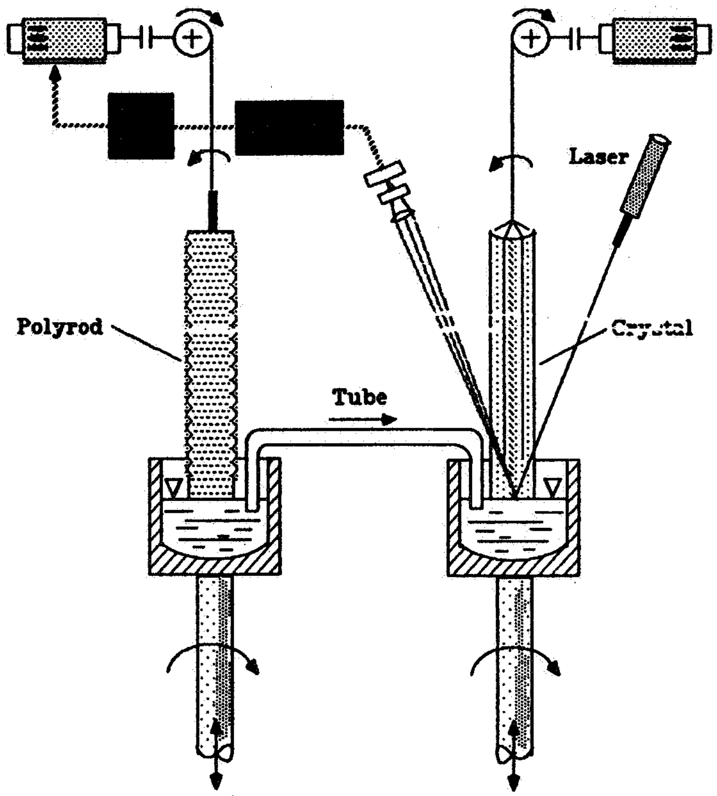
- AUTOMATIC GROWTH CONTROL
  - DIAMETER
  - CONE
- MAGNETIC CZ
- RECHARGING
- CONTINUOUS LIQUID FEED
  - IDEAL IN CONCEPT

Concept of CLF Furnace



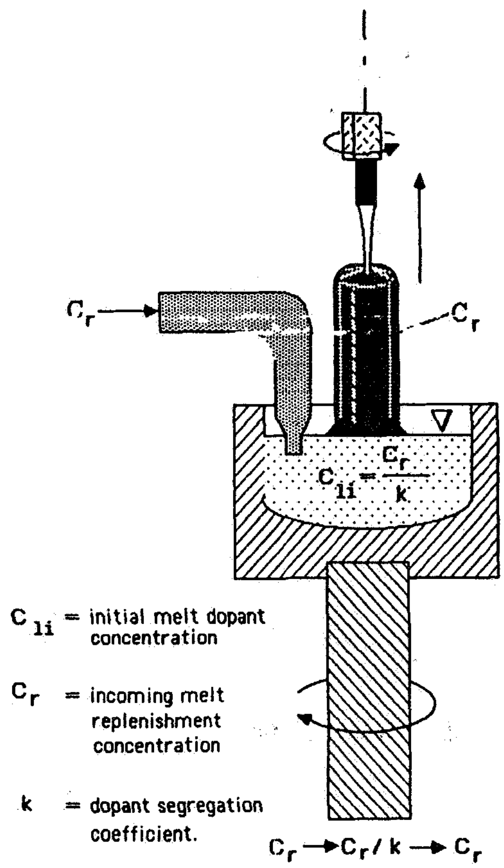
REF. 2

Arrangement for Continuous Melting and Solidification



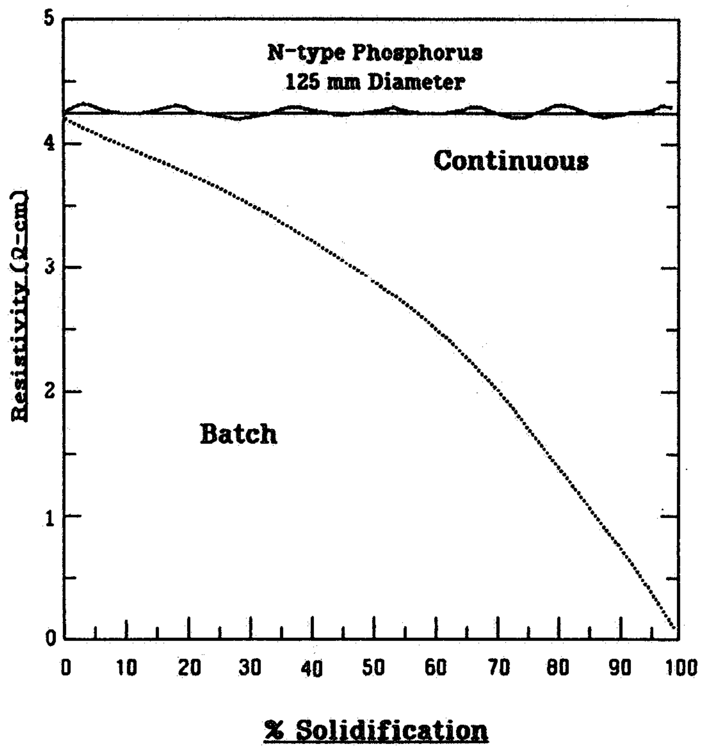
Ref. 2

Doping Concentration Relationship, CLF Furnace



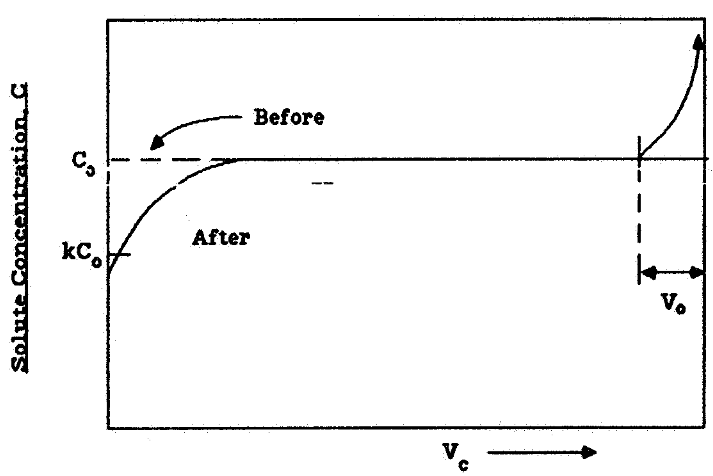
Ref. 2

Axial Resistivity Profile, CLF Furnace



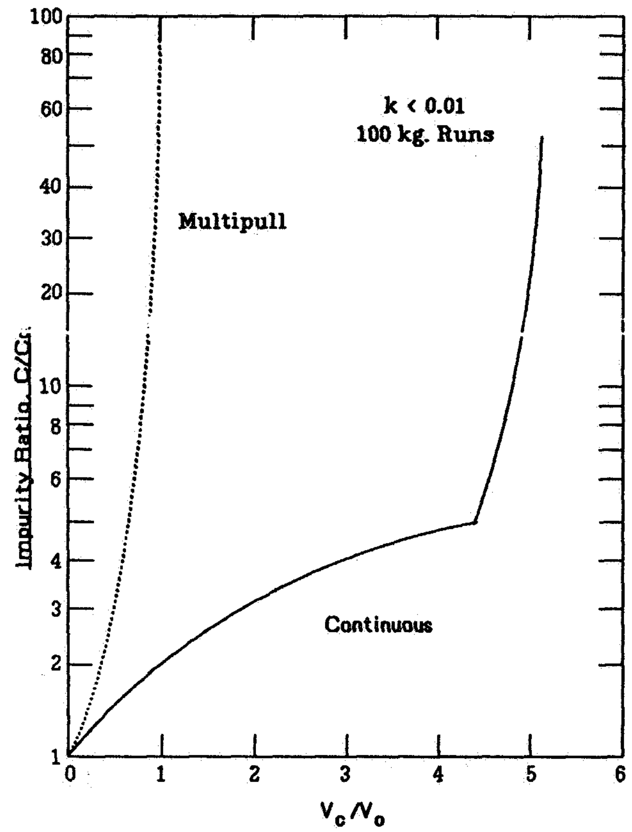
Ref. 2

Solute Concentration Buildup, CLF Furnace



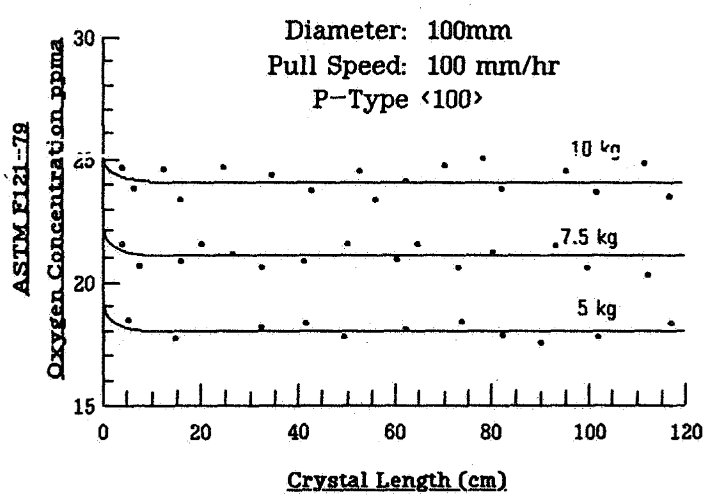
Ref. 2

Impurity Buildup, Continuous vs Batch

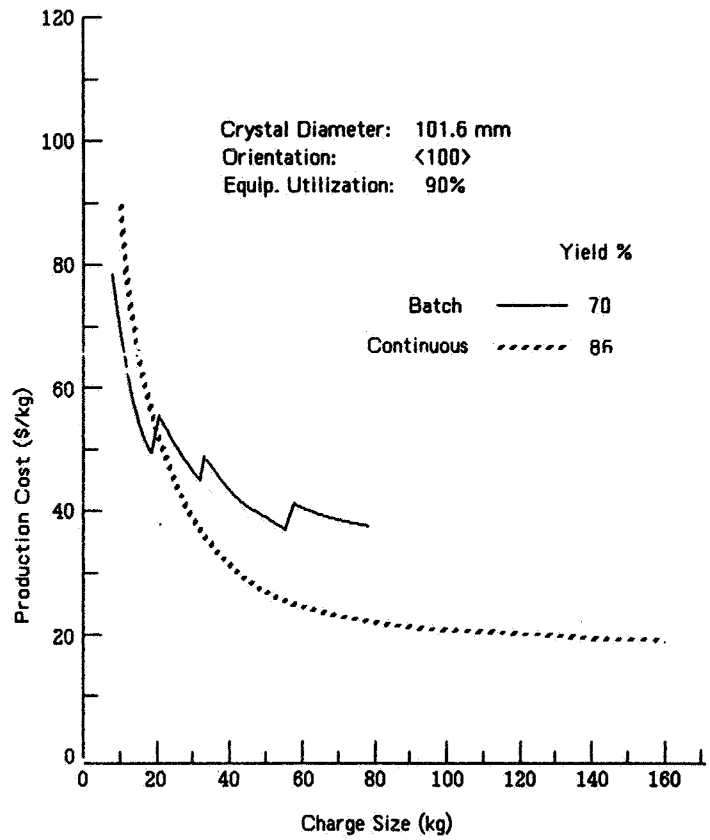


Ref. 2

Oxygen Distribution in Crystal, CLF Furnace



Crystal Production Costs, Batch vs Continuous



Ref. 2

What is the Future of the Cz Process?

- MAIN EFFORTS NOW
  STILL

  MORE
  BIGGER
  BETTER

  OF SAME PRODUCT
  AND PROCESS

- WHAT IS NEXT???

References

(1) T. Abe, to be published.

(2) G. Fiegl, Solid State Technology, August 1983, p.121.

(3) K. Benson, W. Lin, E. Martin, Semiconductor Silicon - 1981, ECS, 1981, p.33.

(4) W. Zulehner and D. Huber, Crystals - 8, 1982.

(5) W. Lin, D. Hill, Silicon Processing, ASTM STP 804, ASTM, 1983, p.24.

(6) A. Murgai, Silicon Processing, ASTM STP 804, ASTM, 1983 p.39.

(7) P. Burggraaf, Semiconductor International, October 1984, p.54.

DISCUSSION

LESK: Do you feel that 70% production yield is a good practical figure?

MATLOCK: On a standard Czochralski process, yes.

STORTI: What are the primary sources of the heavy-metal impurities?

MATLOCK: One of the sources is the polycrystal itself, particularly as it is enriched through the process. The reactors where the polycrystals are grown have a lot of silver in the environment, and nickel parts. The Czochralski chamber and the seed holder have metal parts where some evolution of that metallic impurity is bound to occur.

MORRISON: We are led to understand that a very open dialogue exists between producers and users in Japan and that part of the success of the industry in Japan is due to that open dialogue. Do you see any kind of a dialogue opening up in this country that is going to help the users and the producers reach some state of excellence and understanding?

MATLOCK: Yes, I certainly do, and I think that a number of companies have become very intimately involved in that kind of interactive dialogue to maximize material effects on device performance.