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MCZ: STRIATIONS IN CZ SILICON CRYSTALS GROWN UNDER VARIOUS AXIAL MAGNETIC FIELD STRENGTHS

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Suppression of fluid flow instabilities in the melt by the axial magnetic field in Czochralski silicon crystal growth (AMCZ) is investigated precisely by a high-sensitivity striation etching in conjunction with temperature measurements. The magnetic strength (B) was varied up to 4.0 kG, incremented in 0.5 kG/5 cm crystal length. The convection flow was substantially suppressed at $B \geq 1.0$ kG. A low oxygen level of 2-3 ppma and a high resistivity of 400 ohm-cm is achieved in the AMCZ silicon crystals at $B \geq 1.0$ kG. Details of the striation formation as a function of B will be presented. Computer simulation of the magneto-hydrodynamics of the AMCZ silicon crystal growth will be discussed briefly with regard to the solute, especially oxygen segregation at B=0, 1.0, and 2.0 kG, which has been published recently.[1]

Earlier studies in the inverted Bridgman growth of InSb[2] and Ge[3] are reviewed, which have established the cause and effect relationship between the convection in the melt and the striation formation as well as the suppression of the convections in the melt by transverse magnetic field.[4]

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(1) Lee, K.J., Langlois, W.E. and Kim, K.M., J. Physico-Chem. Hydrodynam., 5, 135 (1984)

(2) Kim, K.M., Witt, A.F., and Gatos, H.C., J. Electrochem. Soc., 119, 1218 (1972)

(3) Kim, K.M., Witt, A.F., and Gatos, H.C., J. Electrochem. Soc., 125, 475 (1978)

(4) Kim, K.M., J. Electrochem. Soc., 129, 427 (1982)

OVERVIEW

1. EARLIER STUDIES IN INVERTED BRIDGMAN GROWTH OF InSb AND Ge:

   - CONVECTION IN THE MELT AND STRIATION FORMATION
   - SUPPRESSION OF CONVECTIONS BY TRANSVERSE MAGNETIC FIELD

2. MCZ: SUPPRESSION OF CONVECTION IN CZ SILICON BY AXIAL MAGNETIC FIELD

   - AXIAL MCZ (AMCZ) APPARATUS
   - MAGNETIC FIELD UNIFORMITY
   - CONVECTION AND SUPPRESSION IN AMCZ SILICON CRYSTAL GROWTH:
     (A) TEMPERATURE MEASUREMENT
     (B) STRIATION FORMATION

3. COMPUTER SIMULATION AND MODELING OF AMCZ SILICON CRYSTAL GROWTH

4. SUMMARY

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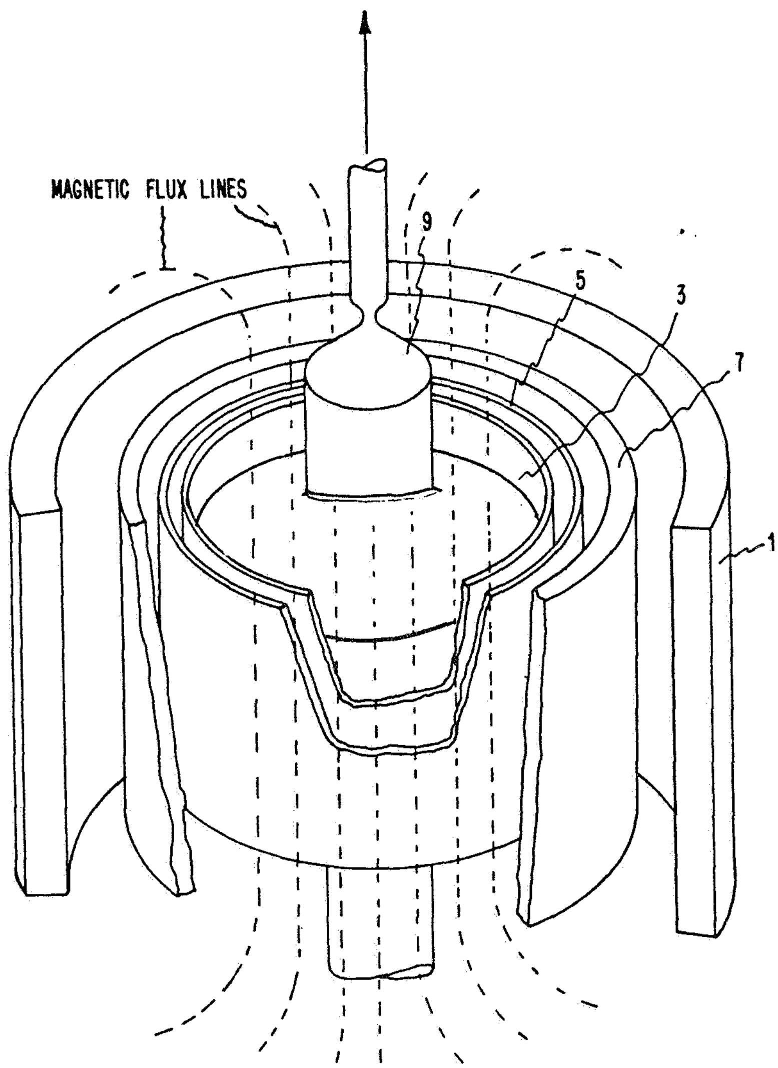
APPARATUS FOR CZOCHRALSKI SILICON CRYSTAL GROWTH THROUGH AXIAL MAGNETIC FIELD FLUID FLOW DAMPING

K. M. Kim, G. H. Schwuttke and P. Smetana



An arrangement is provided for utilizing axial magnetic fields to suppress the fluid flow in the melt of Czochralski-type silicon crystal growth systems.

FIGURE CAPTIONS

Fig. 1. (a) - Schematic illustration of an AMCZ silicon crystal growth arrangement. (b) magnetic field distribution inside the crystal growth chamber. Note that the field uniformity is within $\pm$ 3% in the silicon melt.

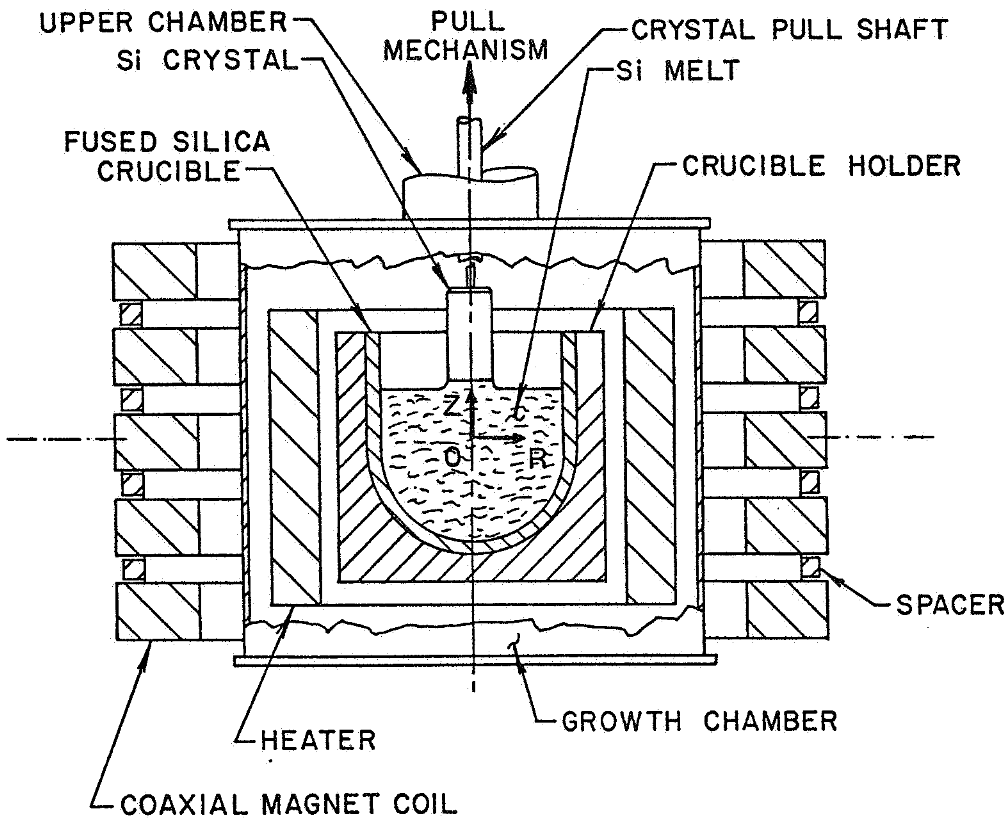
Fig. 2. Measured temperature change and the amplitude of the temperature fluctuations vs. the axial magnetic field strength at a fixed position in the melt at half the crucible radius, 5mm below the melt surface.

Fig. 3. Sketch of the striation pattern of an etched longitudinal crystal section. Random striations at B=0 assumed progressively a periodic pattern at $0.35 < B \lesssim 4.0$ kG. Note that the periodic striations have a non-uniform contrast, and some weak localized striations persist near the crystal periphery.

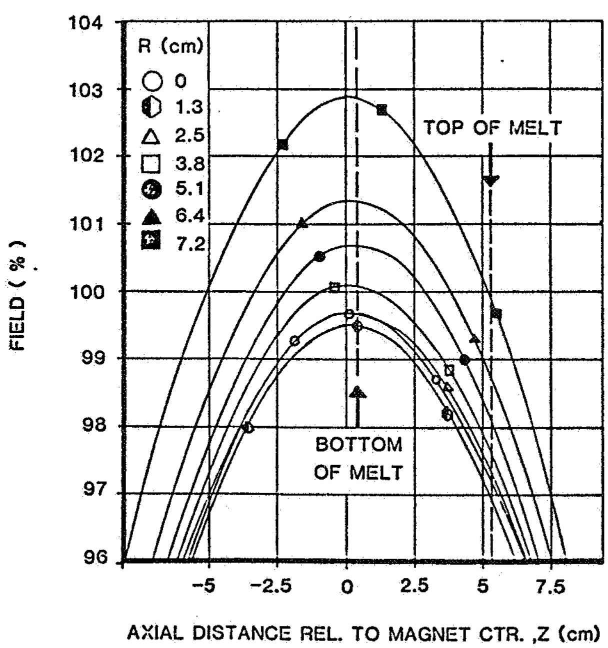
Fig. 4. Photomicrographs of some representative AMCZ crystal sections shown in Fig. 3. (a) B=0, (b) 0.35, (c) and (d) 1.0, (e) and (f) 4.0 kG. Note that the central region of the crystal grown at 4 kG is free of striations. Some dislocation etch pits are present in (f).

Fig. 5. Spreading resistance profile (a)-(f), parallel to the growth axis in typical crystal sections as seen in Fig. 4 (a)-(f), respectively.

Figure 1


UPPER CHAMBER
PULL MECHANISM
CRYSTAL PULL SHAFT
Si CRYSTAL
Si MELT
FUSED SILICA CRUCIBLE
CRUCIBLE HOLDER
Z
O
R
SPACER
HEATER
GROWTH CHAMBER
COAXIAL MAGNET COIL

(a)


R (cm)
0
1.3
2.5
3.8
5.1
6.4
7.2
TOP OF MELT
BOTTOM OF MELT
FIELD (%)
104
103
102
101
100
99
98
97
96
-5
-2.5
0
2.5
5
7.5
AXIAL DISTANCE REL. TO MAGNET CTR. ,Z (cm)

(b)

Figure 2

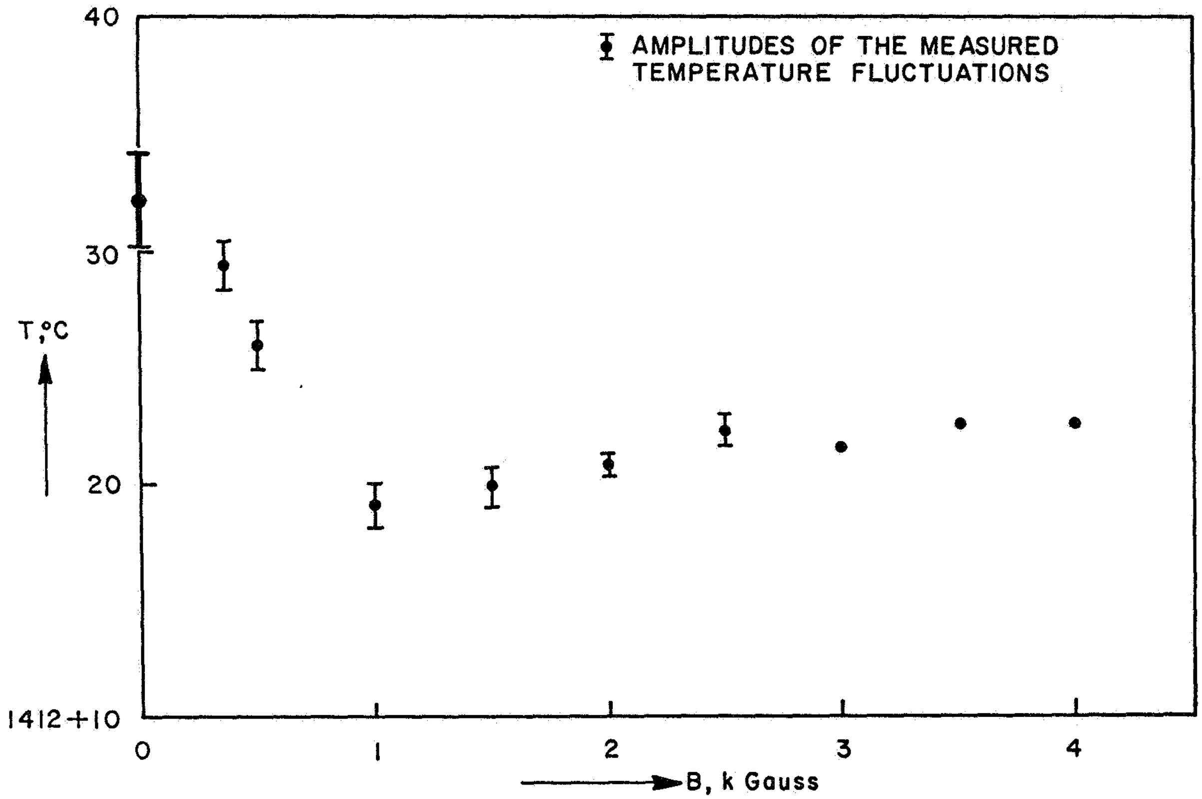


Figure 3

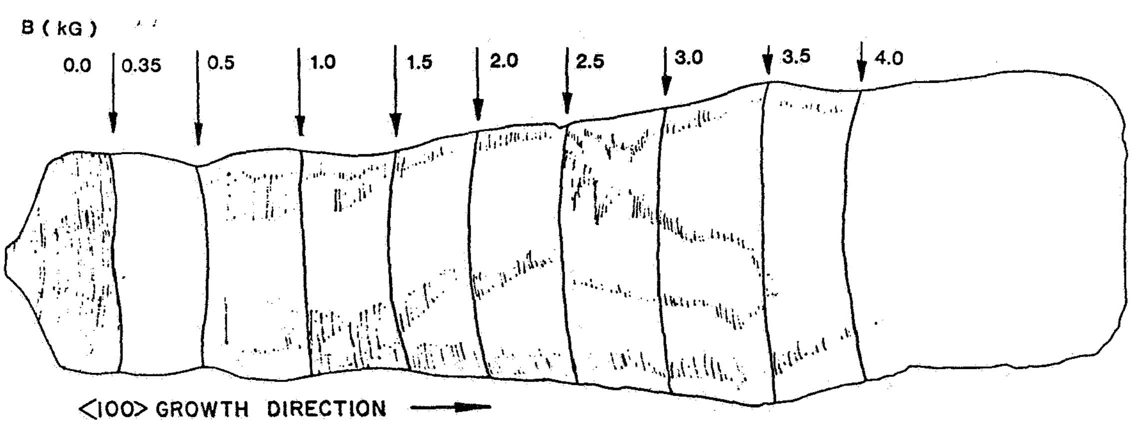


Figure 4

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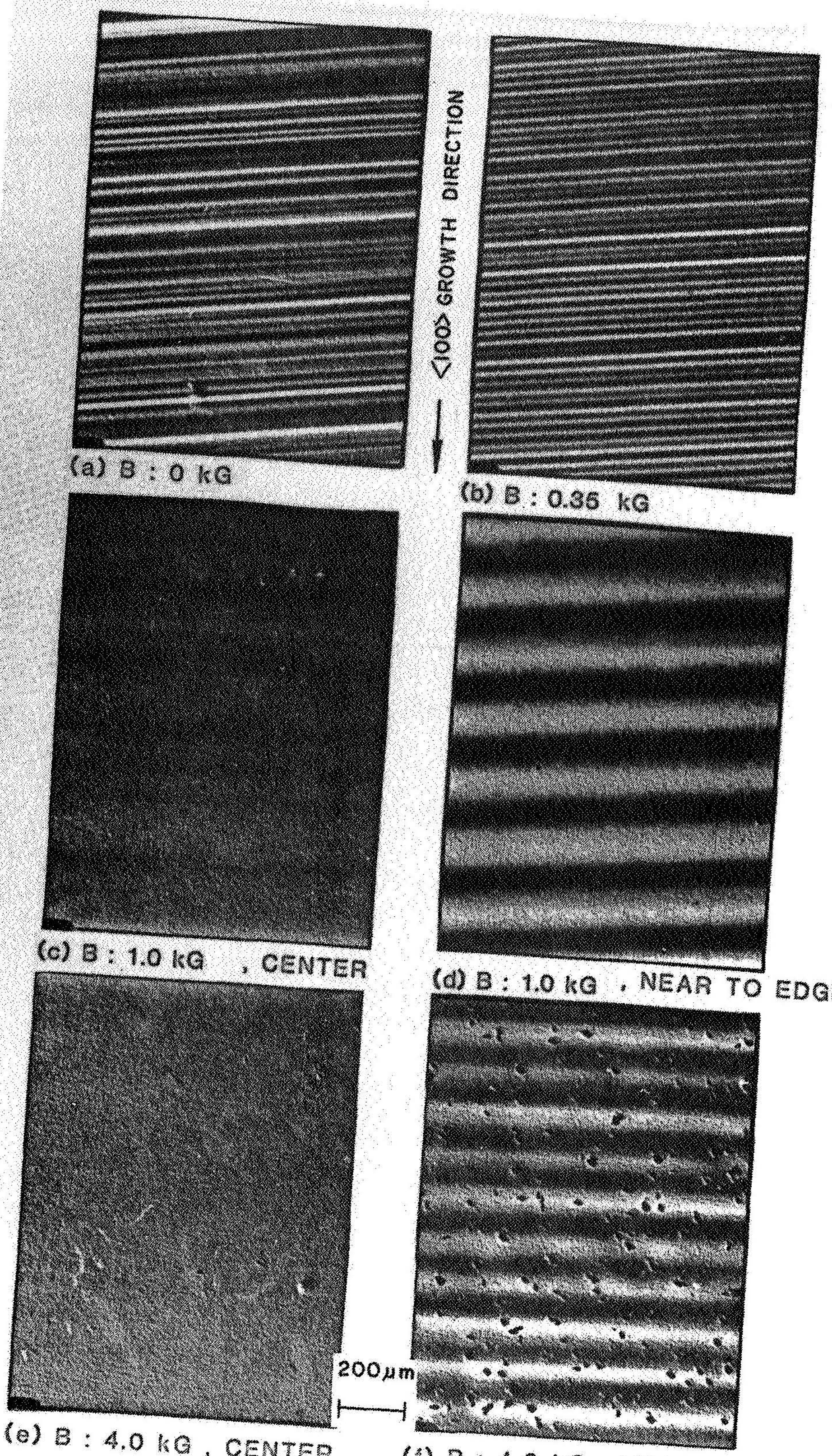


(a) B : 0 kG

(b) B : 0.36 kG

(c) B : 1.0 kG , CENTER

(d) B : 1.0 kG , NEAR TO EDGE

(e) B : 4.0 kG , CENTER

(f) B : 4.0 kG , NEAR TO EDGE

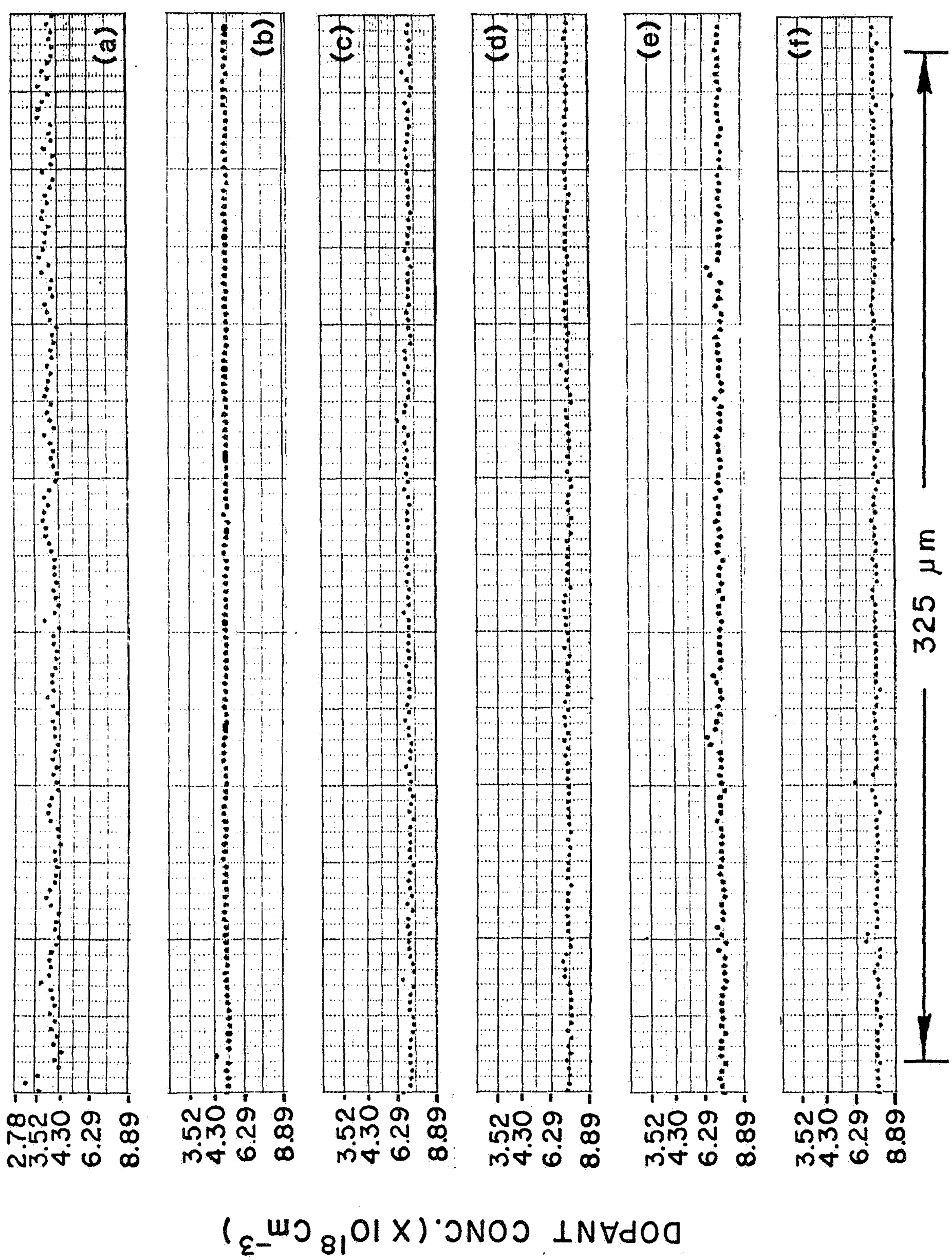


Figure 5

Figure 6

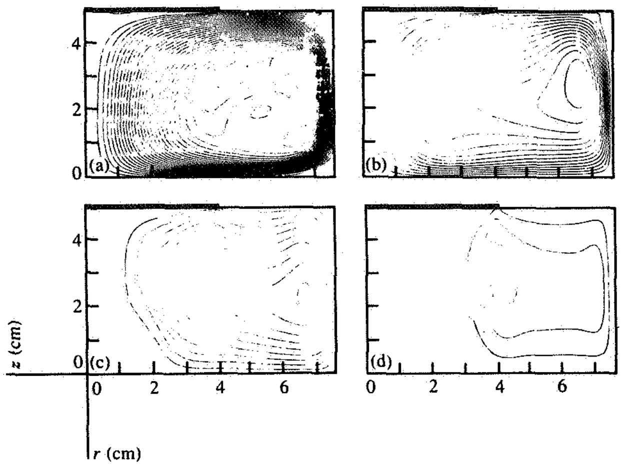
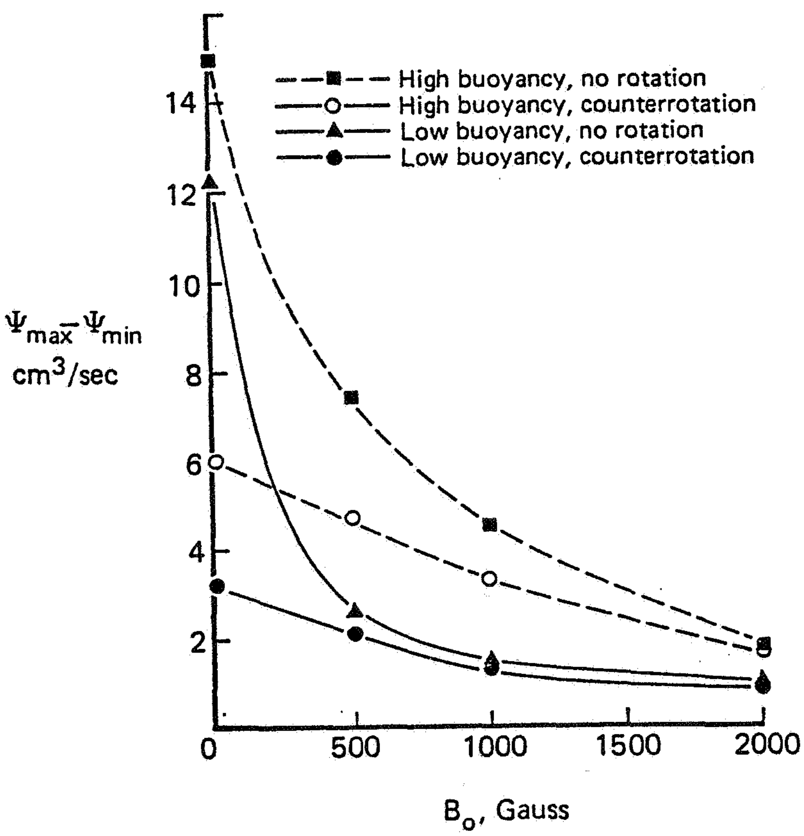


Figure 6 Meridional circulation patterns for the simulations of high-buoyancy flows without rotation: a) $B = 0$; b) $B = 0.05$; c) $B = 0.1$; and d) $B = 0.2$ T. Contour spacing $= 0.5\ cm^3/s$.

Figure 7



Effect of magnetic field intensity on the strength of the meridional circulation.

DISCUSSION

LESK: Why does a magnetic field increase the viscosity?

WITT: According to the three-finger rule, you have the charge moving in one direction, which gives the charge, and you have the normal magnetic field, and then you have the right angles of force. The Lorentz force in this case always acts normal to the direction of propagation and that is interpreted as affecting the viscosity.

LESK: Why not try and force the liquid back where it came from by applying a current?

WITT: If you apply an electric current and you introduce a magnetic field then you get turbulence. You can use that for effective mixing in the melt if you want to.