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Effect of axial magnetic field on the shape of copper ribbon crystal grown by Czochralski method

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Abstract

During the process of growing ribbon crystal by Czochralski method, Turbulent convection in copper melt was effectively suppressed by applying an axial magnetic field (magnetic induction $B \leq 57\text{mT}$). The changes of thermal fluctuation and flow field were measured and modeled. With the magnetic field increased gradually (from 0 to 57mT), the shape of ribbon crystal became regularly wider. We concluded that the axial magnetic field could promote to form a suitable temperature field for ribbon crystal growth by restraining thermal fluctuation and convection.

Key words : axial magnetic field; ribbon crystal; crystal morphology; Czochralski

1. Introduction

Many silicon sheet growth techniques for solar cell substrates have been proposed in the past few decades [1-5]. The advantages of such techniques which are the efficient use of silicon feed stock with no kerf loss and the elimination of mechanical sawing steps including etching to remove surface damage all focus on reducing costs and translating directly into improved economics. But these techniques also exist many disadvantages, such as high defect density, short minority carrier lifetime, high stress, especially mechanical integrity including flatness, uniform thickness, and surface roughness [6].

The process of growing crystal by Czochralski method under static magnetic fields has attracted much attention from researchers [7-9]. Static magnetic fields have been used as a powerful tool to suppress convection and reduce fluctuation in electrically conducting liquids, thus changing temperature distribution in the melt and the crystal morphology during growth [10]. The mechanical integrity of crystal (flatness, surface roughness) may be improved by applying static magnetic fields.

In this work, we study on the changes in the shape of copper ribbon crystal with and without an axial magnetic field (magnetic induction $B \leq 57\text{mT}$). The results of temperature measurement and numerical simulation both show that the turbulent convection in copper melt was suppressed by applying an axial magnetic field which can provide a suitable temperature field for ribbon crystal growth.

2. Experimental

Fig. 1 shows a schematic of the experimental apparatus used in this investigation of the growth of copper ribbon crystal in an axial magnetic field. A cylindrical water induction coil (200 mm ID, 300 mm OD and 150 mm in height) which could generate 57 mT in magnetic field strength in the square graphite crucible (100 mm in length, 40mm in width, 115 mm in height) was placed outside of the graphite heater (110 mm in length, 50 mm in width, 125 mm in height). The apparatus is different from the conventional CZ furnace, not only the graphite heater is designed to be square to provide a square hot zone for the growth of ribbon crystal, but also crucible and seed crystal will not rotate. The copper ribbon crystal was grown from the copper melt in argon gas kept at 1 atm. The copper seed crystal is 40 mm in width, 300 μm in thickness, 50 mm in length. The pulling rate is 240 $\mu\text{m/s}$. The magnetic field strength ranges from 0 to 57 mT.

With the magnetic field increased gradually, the shape of ribbon crystal became regularly wider. These changes shown in Fig. 2 were recorded by video camera.

In order to determine the accurate temperature distribution, three Pt-Rh thermocouples with a diameter of 0.3 mm, protected by quartz tubes of 4 mm OD, were placed at 10 mm below the melt surface at points A, B, and C, as was shown in Fig. 3.

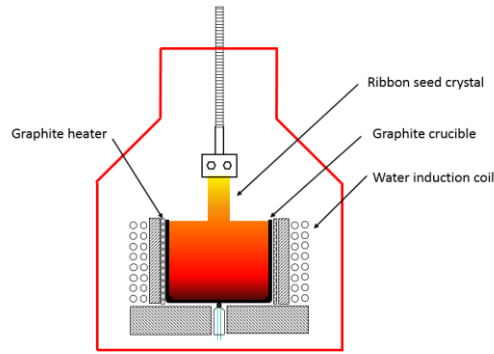


Fig. 1: Schematic diagram of the CZ copper ribbon crystal growth apparatus used in the present investigation in an axial magnetic field application

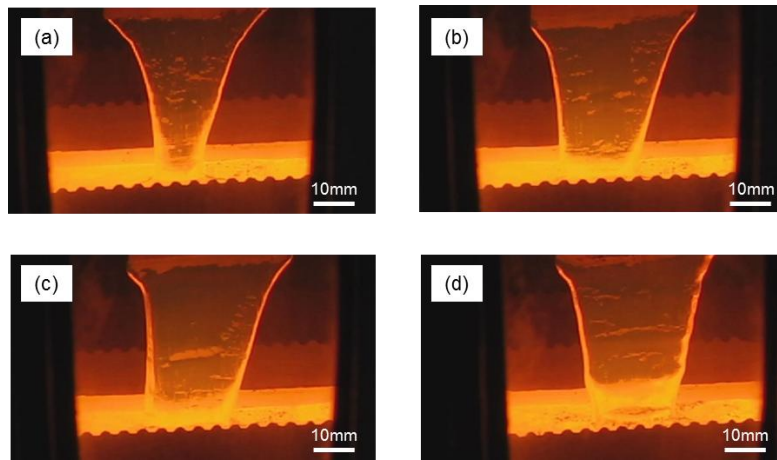


Fig. 2: Effect of applied various magnetic flux densities on the width of ribbon crystals (seed width=40 mm, seed thickness=300 μm , pulling rate=240 $\mu\text{m/s}$): (a) 0 mT (b) 21.6 mT (c) 35.6 mT (d) 57 mT

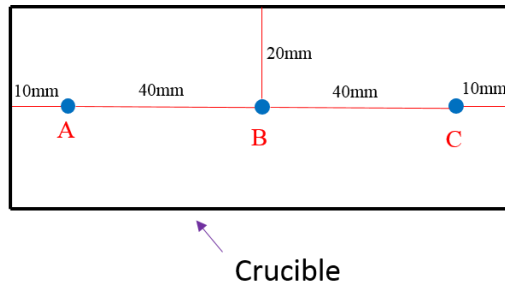


Fig. 3: The locations of three thermocouples in the square graphite crucible

3. Results and discussion

3.1 Crystal morphology

The most obvious effect produced by the presence of an axial magnetic field is the increase of the width of copper ribbon crystal shown in Fig. 2. With the increase of magnetic flux density, the width has increased. These results show that the axial magnetic field may change the temperature distribution in the melt and promote to form a suitable temperature field for ribbon crystal growth.

3.2 Temperature measurement

The results of temperature measurement are shown in Table. 1. The temperature difference between point A and B was 10.7 $^{\circ}\text{C}$ at 0 mT, and 12.6 $^{\circ}\text{C}$ at 57 mT. The temperature difference between point B and C was 3 $^{\circ}\text{C}$ at 0 mT, and 4 $^{\circ}\text{C}$ at 57 mT. These suggest that the axial magnetic field increases temperature gradients in the melt by suppressing

horizontal thermal convection. Compare with the difference of temperature of point A, B, and C with and without the axial magnetic field, we conclude that the axial magnetic field also plays a very important role in restraining vertical thermal convection.

Magnetic field(mT)	Temperature (°C)				
	A	B	C	A-B	C-B
0	1113.0	1102.3	1105.3	10.7	3
57	1107.3	1094.7	1098.7	12.6	4

Table. 1: Temperature distribution in the copper melt with and without an axial magnetic field

3.3 Numerical simulation

Fig. 4 and Fig. 5 show the numerical simulation results of the temperature distribution and flow field with and without an axial magnetic field. Compare with the results of temperature measurement, the changes of temperature distribution are much smaller. Because the error exists in the experiment of temperature measurement, and also numerical simulation has certain error with its idealized model.

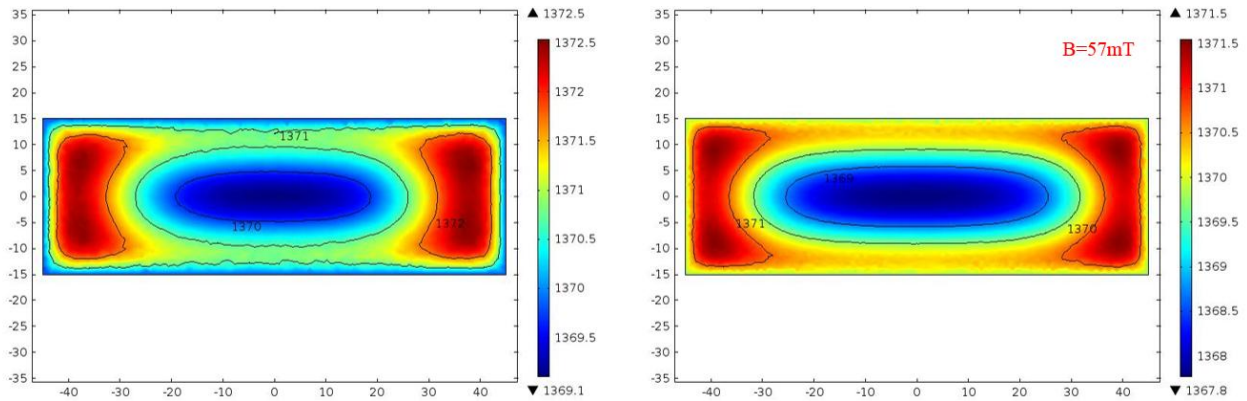


Fig. 4: The numerical simulation results of the temperature distribution with and without an axial magnetic field (magnetic induction $B=57\text{mT}$)

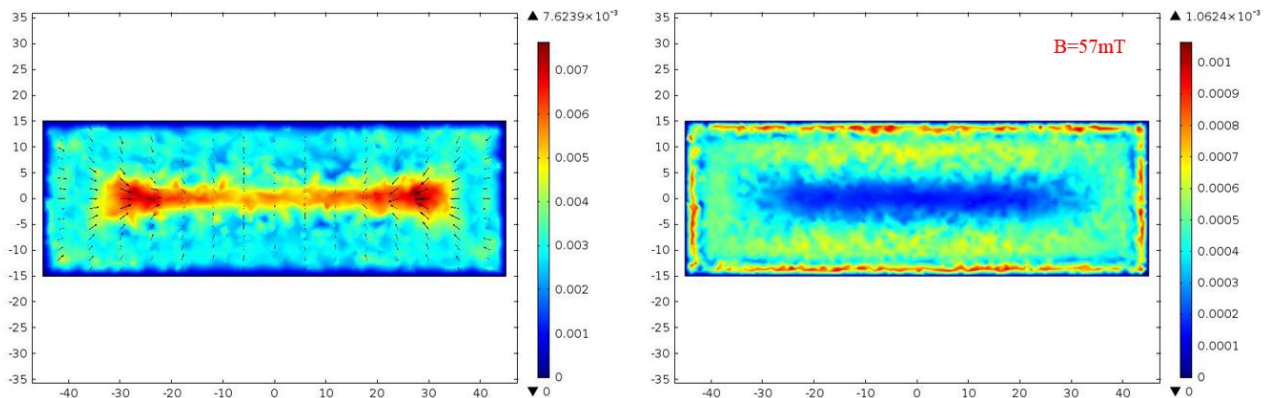


Fig. 5: The numerical simulation results of the flow field with and without an axial magnetic field (magnetic induction $B=57\text{mT}$)

4. Conclusions

Copper ribbon crystals were grown under the presence of an axially symmetric vertical magnetic field. With the magnetic field increased gradually (from 0 to 57mT), the shape of ribbon crystals became regularly wider. All the results of crystal morphology, experiment measurement and numerical simulation show that turbulent convection within a copper melt is effectively suppressed and temperature fluctuation in the melt is reduced by applying an axial magnetic field.

Acknowledgment

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