Measurement of Velocity and Temperature Field at the Low Prandtl Number Melt Model of the CZ Crystal Growth

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Abstract : A physical model of the Czochralski method for silicon single crystals is designed to measure the change of velocities and temperature profiles in the melt. Wood's metal(Bi 50%, Pb 26.7%, Sn 13.3%, Cd 10%, m.p. 70°C) is used to simulate the silicon melt in the crucible. To measure the local velocity change, electromagnetic probe is adopted as a velocity sensor. The output voltage of the sensor shows linear relationship to the velocity of the melt.

1. Introduction

The ever increasing application of semiconductor based electronics creates an enormous demand for high quality semiconductor single crystals. The volume of silicon production, the most commonly used material, is about 3000 metric tons a year. The Czochralski(CZ) system is usually used to produce silicon single crystals due to its high productivity. The silicon single crystal grown by CZ method shows, however, microscopic fluctuations of oxygen concentration along radial and axial directions and this is thought to be due to the instability of flow in the melt[1]. The temperature higher than 1420°C and limitations of variation of process variables in the CZ system make it difficult to perform an experiment in the real system. Therefore numerical study and cold model study using transparent fluids such as silicon oil and water were mainly performed. But the numerical study has its limitations and transparent fluids have transport properties such as viscosity and thermal conductivity much dissimilar to those of silicon. In this study, Wood's metal(Bi 50%, Pb 26.7%, Sn 13.3%, Cd 10%, m.p. 70°C) melt was used to simulate the silicon melt.

For the purpose measuring temperature velocity variations in the melt, a cold model system composed of Wood's metal melt, a crucible, a rotating plate, a heater and temperature and velocity sensors was constructed and the temperature and velocity variations at various points were measured. As many data must be acquired to analyze the variations of flow velocity and temperature, a plug-in DAQ device was used.

2. Experimental Procedures

The schematic side view of the cold model system is depicted in Fig. 1. In this figure, the crucible, thermal insulator, rotation plate and rotation axis is rotation and the other parts are stationary. The characteristics of rotation device are the control of rotation rate using an electrical method, which reduces vibration of the rotation axis, and the large deceleration ratio of the gear to support the load of Wood's metal. The crucible is made of Aluminum alloy to protect the reaction of Wood's metal with the crucible. Cylindrical band shaped heater was used to maintain the crucible wall temperature nearly constant and the power to this heater was PID controlled.

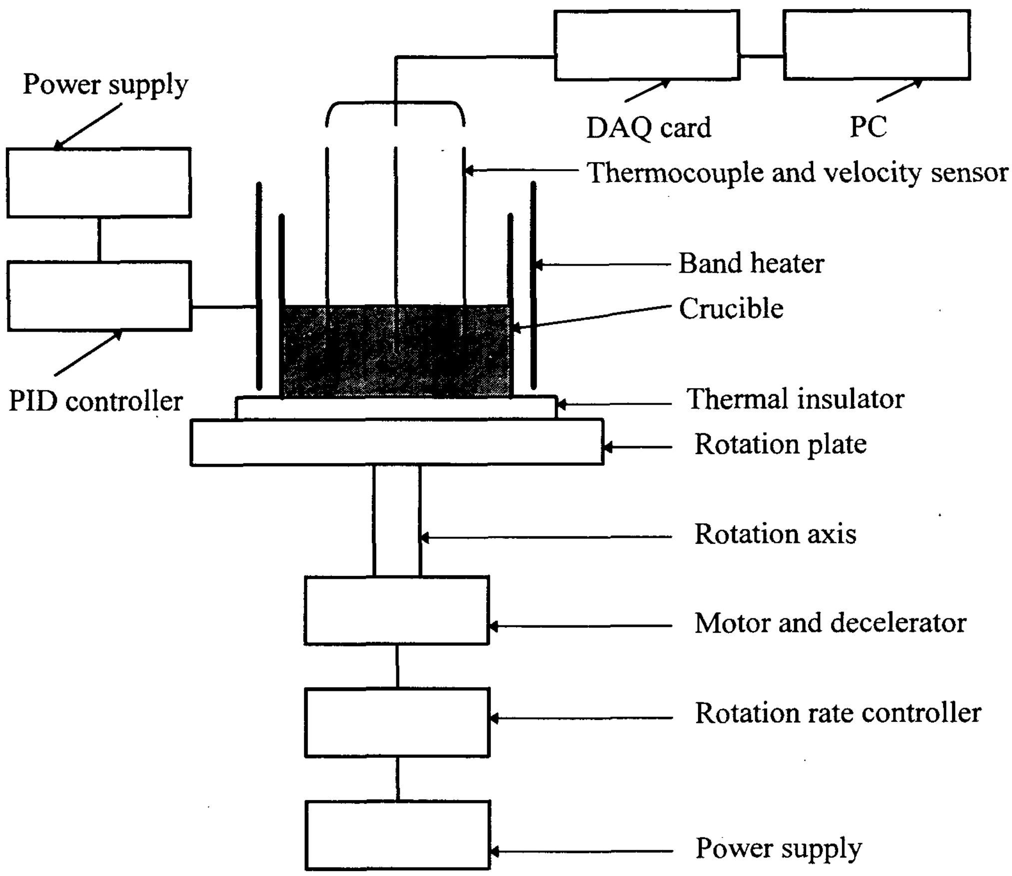

Fig. 1. Schematic diagram of the cold model system.

The most important part of this cold model system is the velocity sensor called incorporated magnet probe. The use of flow visualization methods(interferometer) is excluded on account of the opacity of the Wood's metal. Various sensors, such as the Pitot-Prandtl tubes[2], with a working principle founded on pressure difference measurements, are ineffective due to metal solidification within the manometric tubes. The incorporated magnet probe, developed by C. Vives is based on the fundamental study of a liquid metal flow around a permanent magnet of cylindrical shape[3]. This is illustrated schematically in Fig. 1 and relies on the principle that a conductor moving within a magnetic field will generate an electric field. Referring to Fig. 1, when immersed in a moving conductor a potential difference develops between the tips A and B of the leads connected to a nanovoltmeter. The theory of this device, treated elsewhere, predicts that the potential difference is proportional to the magnitude of the velocity vector perpendicular to the line AB(a second pair of leads with tips C and D provides a voltage proportional to the orthogonal velocity vector) and independent of the physical properties of the liquid. Unlike the hot film probe used by Murthy and Szekely[4], the device is insensitive to temperature as long as the temperature is well below the Curie point of the permanent magnet. This response of the probe to velocity fluctuations is nearly instantaneous.

With this velocity probe and the K-type thermocouple, the velocity and temperature variation at various points within the melt with the passage of time were measured. The temperature and velocity data were acquired using a DAQ card and were analyzed using PC.

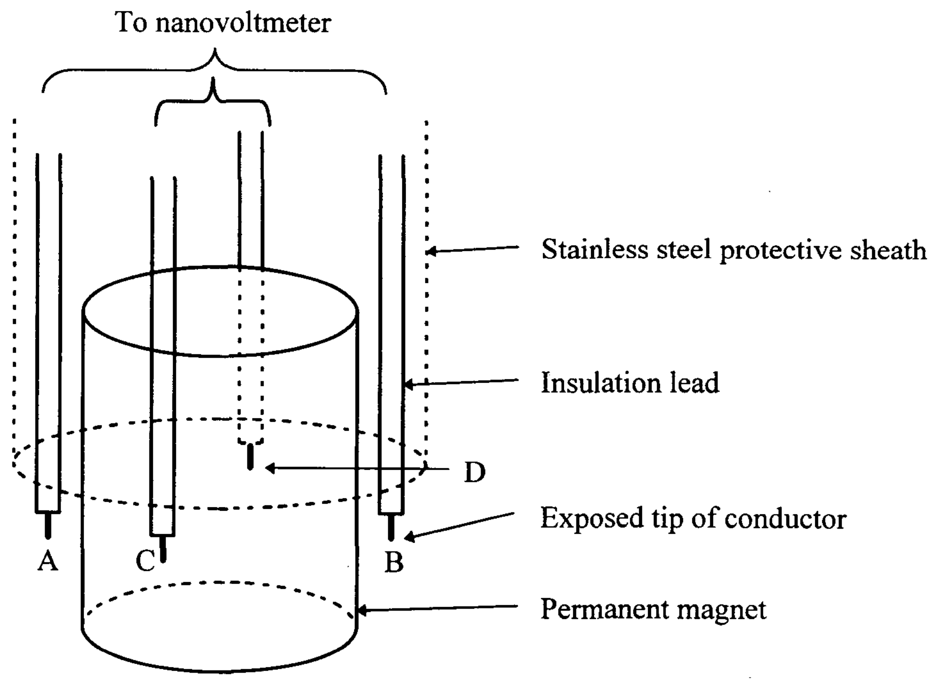

Fig. 2. Shape of the incorporated magnet probe for measuring velocities.

3. Discussion and Summary

A cold model system using the Wood's metal which has dynamic and thermal similarity with the real CZ system was developed. The temperature and velocity distribution were measured using K-type thermocouple and incorporated magnet probe, respectively. The voltage induced at the tip of the velocity probe was in the order of microvolt. This model study on the CZ system reveals the spatial velocity distribution in the melt which has high electric conductivity.

4. Acknowledgments

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5. References

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