PREPARATION AND CHARACTERIZATION OF SILICON RIBBONS

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ABSTRACT. Silicon deposits are made on different substrates by injecting silicon powder in a plasma torch (Ar+H₂). The self-supported deposits are then subjected to recrystallization by zone melting to improve their grain size and some electronic properties.

1. Introduction

In case of most electronic devices and integrated circuits the cost effectiveness is not a strong requirement at the materials level. However, the silicon (Si) solar cells differ in this manner, where Si is responsible for nearly 30% of the cost of a cell. Moreover, the single crystal Si solar cells are too expensive for large scale terrestrial use by at least a factor of 10 [1]. Many techniques for cheap elaboration of polycrystalline Si are being actively investigated. Numerous advancements in techniques of Si sheet and ribbon formation have led to considerable cost reduction [2], avoiding slicing operations and material losses. A possibility of obtaining low-cost Si ribbons is through the plasma-spray technique where the starting material is Si powder which could be directly obtained from purification of impure Si. Some work on plasma-sprayed Si layers has been reported in the past [3,4]. Rapid growth of such layers and improvement of their crystalline and electronic properties (eg., by zone-melting) are being studied in our lab in view of low-cost solar cells. 5cm X 5cm Si ribbons have been obtained at a growth rate of 300 microns/min, and are then subjected to recrystallization by zone melting. The experimental details and some properties of the ribbons are reported here.

2. System description

2.1 THE PLASMA SPRAY GUN

A water-cooled METCO 7MB plasma spray gun with tungsten and copper electrodes is used. Ar and H₂ are used as primary and secondary gases in the plasma flame. The electrical discharge power between the two electrodes and the flow rates of gases can be controlled. The gun is mounted on a scaled track so that it can be moved and fixed at any distance from the substrate.
2.2 THE FLUIDIZED-BED DISTRIBUTOR FOR SILICON POWDER

A fluidized bed (METCO 4MP) powder distributor is used to inject the silicon powder into the plasma flame. The distributor is pressurized by Ar injected from the top and bottom into the distributor so that the Si powder inside it is held in a semi-suspended or even floating state. Another circuit of carrier gas (which is also argon) through the distributor takes the Si powder away to the plasma flame. The powder feed rate can be controlled by changing either the pressure within the distributor or the carrier gas flow rate. The fluidization of Si powder assures an injection of powder into the plasma flame at a precise rate. It also offers a good mixing of Si with the dopant B$_2$O$_3$ powder.

3. Experimental details

3.1 OBTAINING SILICON DEPOSITS

3.1.1. Silicon powder and boron doping. The ultra pure, undoped Si powder supplied by ETHYL corporation (USA) is used (powder size <180 microns after sieving). The doping is done by adding B$_2$O$_3$ powder to Si and thoroughly mixing. Further mixing takes place in the fluidized bed distributor. Adding 2.5 mg of B$_2$O$_3$ in 1 kg of Si gives a calculatory doping of $10^{17}$/cm$^3$. Slightly varying amounts of B$_2$O$_3$ are added in different attempts to see the effectiveness of this kind of doping.

3.1.2. Plasma torch projection. An electric arc is created between the two electrodes of the gun, while the flux of H$_2$ + Ar is directed into the torch creating a plasma flame. Si powder from the distributor is injected into the plasma just in front of the gun nozzle. The powder is melted and accelerated by the hot plasma towards the substrate [5]. The gun is slightly moved to get deposits of uniform thickness. Different substrates such as alumina, poly- and single-crystalline Si, ceramic silicon nitride are used. In the case of polished alumina substrates the deposits got detached soon after the projection (self-supported ribbons). The optimal conditions found were a gun-substrate distance of 12cm and arc power of 380A at 55V. The substrates had to be pre-heated for about 3 minutes before the introduction of the powder. Heating is continued even after the powder injection is stopped to prevent the cracking of the deposits by any thermal shocks. This post-heating is done with the gun power gradually reduced.

3.2 ZONE-MELTING OF THE SAMPLES

The self-supported ribbons (5cm X 5cm) were subjected to zone-melting (Fraunhofer Institut, Freiburg, FRG). A liquid zone is created in the ribbon by two tungsten lamps (2500W) kept above and below the ribbon. The lamps are then gradually moved scanning the whole sample. The "supported" deposits made on substrates other than Al$_2$O$_3$ were subjected to "large area heating" in which the whole surface is melted at the same time with the depth of the molten zone depending on the lamp power.

4. Characterization and results

4.1 MICROSTRUCTURE

The plasma-sprayed ribbons have many surface voids and pores (Figure 1). Their grain