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Horizontal Pulling of Silicon Single Crystals

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This report presents the recent results of the development study on the horizontal ribbon growth method, being implemented in the development program on the photovoltaic solar energy conversion system under the Sunshine Project sponsored by the Japanese Government. In the study, the objective is placed to develop a production method to grow silicon single crystal ribbon in good quality suitable for substrate material of highly efficient solar cells and at extremely high growth rate advantageous for substantial cost reduction.

At the first stage of our basic study, the horizontal pulling method, which was initially investigated by Bleil in the manner that a crystal ribbon is pulled from the free melt surface to a nearly horizontal direction, continuously solidifying at the growing edge in a wedge form while removing the heat of solidification by a cooling means, was improved basically by introducing gas-cooling and large wedge factor n (length to thickness ratio). As previously published, it has been demonstrated theoretically (see Fig. 1) and experimentally that silicon single crystal ribbons can be grown at extremely high growth rates (the maximum was 0.69 cm/sec for single crystal and n=50.3, and 1.41 cm/sec for polycrystal and n=330).

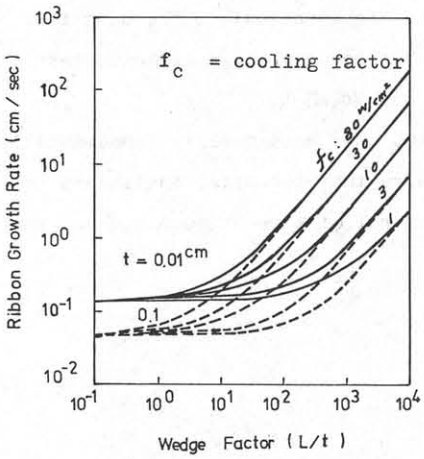
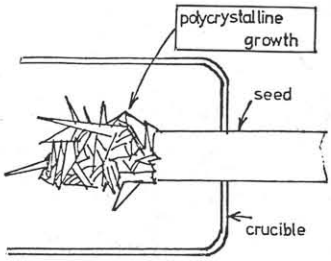


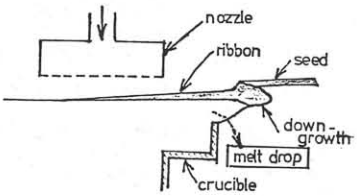
Fig. 1. Calculated ribbon growth rates.

At the second stage of the basic study, to establish the fundamental conditions for stabilizing the operations of the process was intended, because a number of experiments have made clear that the following several kinds of troubles have happend to disturb each step of the operations; seeding, sprouting and steadystate growth. The main troubles experienced are illustrated in Fig. 2.

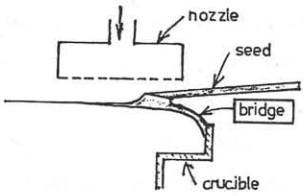
In recent experiments employing these improvements, silicon single crystal ribbons of 5 m long have been demonstrated to grow in reproducible manner, which means, we believe, that stable continuous pulling has become possible.



(a)



(b)



(c)

Fig. 2. Troubles encountered in pulling operations:
(a) polycrystalline growth,
(b) melt drop,
(c) bridge.

Preliminary evaluation study showed that the silicon ribbons grown by the improved horizontal growth method have good physical properties substantially equivalent to the conventional CZ crystals, and that the characteristics of the solar cells fabricated from those ribbons are identical to the ones from the monitor CZ wafers; typically, the photovoltaic conversion efficiencies of 10 - 11 % have demonstrated with AR coating and at AM 1.

These results show that the grown ribbons have good quality fundamentally suitable for substrates of solar cells and also that technical conditions to grow thinner and wider ribbons in precise control of size at much higher growth rates should be explored further.