The Development of Mono-sized Micro Silicon Particles for Spherical Solar Cells by Pulsated Orifice Ejection Method

Wei Dong[1,a], Satoshi Masuda[2,b], Kenta Takagi[2,c] , and Akira Kawasaki[2,d]

[1]Micro Powder Research Institute, Aramaki, Aoba-ku, Sendai 980-8045, Japan
[2]Department of Materials Processing, Graduate School of Engineering, Tohoku University, Sendai 980-8579, Japan
[a]w-dong@material.tohoku.ac.jp, [b]masuda@stu.material.tohoku.ac.jp, [c]ktakagi@material.tohoku.ac.jp, [d]Kawasaki@material.tohoku.ac.jp

Abstract

Mono-sized silicon particles were effectively fabricated by a novel way named pulsated orifice ejection method (POEM). The particles are with very narrow particles size distribution and very small standard deviation of mean particle size. There are two different types spherical silicon particles were found. One consists of many grains mainly in random boundaries. The other consists of two or three grains with only twin orientation relationships, even single crystal in cross-section was also found within this type of spherical silicon particles.

Keywords : POEM, Silicon, Spherical particles, OIM

1. Introduction

Accompanying the development of photovoltaic industry, the cost reduction and high efficiency of crystalline silicon solar cells, which dominate almost 90% of the PV production, are faced with most important tasks. In overcoming these problems, an idea of making spherical silicon solar cells is advocated [1]. Compared with silicon wafer, spherical silicon solar cells, which can be fabricated from melted silicon without the cutting and polishing processes commonly required in silicon wafer fabrication , are considered to be of high-efficiency and low-cost [2, 3].

However, the technology for the mass production of small mono-sized silicon particles, which is regarded as the key to the application of sphere silicon particles for solar cell, has not been established so far. On the other hand, a pulsated orifice ejection method (POEM) allows the preparation of particles with very narrow particle size distribution and very small standard deviation of the mean particle size. So far, several materials with melting points less than 600 K, such as Pb-Sn, Sn-Ag, Bi-Sb have been successfully produced [4-7]. The aim of the present research is to prepare spherical silicon particles with small standard deviation experimentally by POEM and clarify the microstructure of the obtained silicon particles by means of orientation imaging microscopy (OIM) observation.

2. Experimental and Results

This apparatus mainly consists of a high temperature furnace, the part for particle formation and the driving part consisting the piezoelectric actuator. In preparing silicon particles by POEM, high purity silicon grains with the size of about 3 mm were filled in the tundish. Air was first eliminated by vacuuming the inner part of the chamber and the tundish up to less than 2×10^{-2} Pa and then back-filling with high purified Ar until the pressure of Ar in the chamber reaches 0.1 MPa. The tundish was heated to 1723 K, and that is about 40 K above the melting point of silicon. The temperature was then maintained for 30 minutes. The rectangular pulse waves generated by a function generator are used for controlling the output wave of a power amplifier, which was applied to the piezoelectric actuator to drive the rod in reciprocating motion in corresponding with the rectangular waves. Nearly equal amount of molten silicon droplets were then squeezed from the orifice by a reciprocating action of a rod provided by piezoelectric actuator. Molten silicon droplets become spherical due to the surface tension, and solidify during the process of dropping. Mono-sized silicon particles were then obtained. OIM technique was used to reveal crystallographic orientation distribution between grains in silicon particles.

Fig.1 shows SEM micrographs of mono-sized silicon particles obtained by POEM. The mono-sized silicon particles with the diameter of about 300μm can be classified into two kinds according to their obtained shape. One is of a jagged surface with small protrusion, as shown in Fig .1(a). The other one has a smooth surface of lemon-like shape, as shown in Fig. 1(b). They are referred to as the grape-fruit type and lemon type silicon particles respectively in this paper.

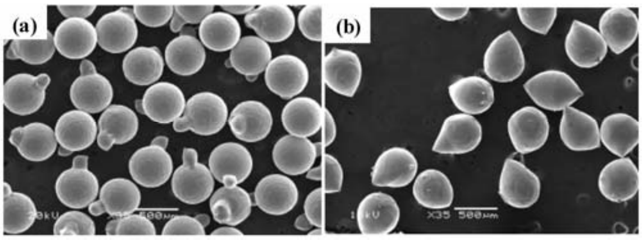

Fig. 1. SEM micrographs of monosized silicon partiles obtained by POEM: (a) grape-fruit type and (b) lemon type.

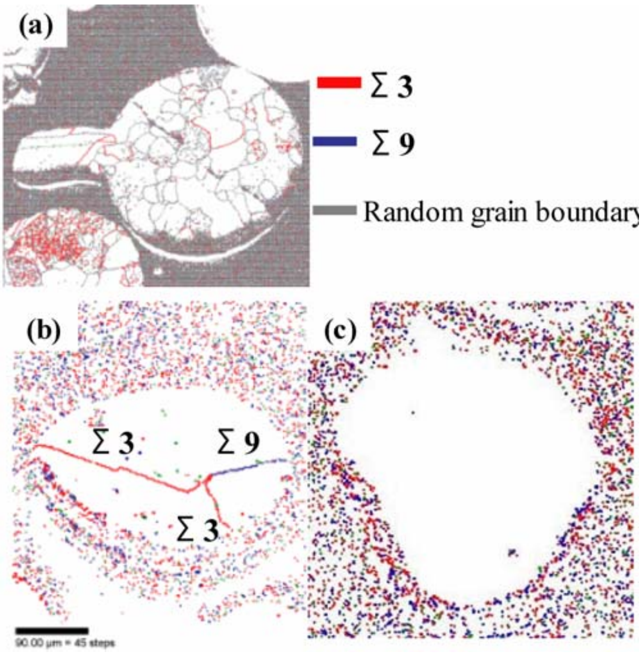

Fig. 2. Grain boundary character distribution of monosized silicon particles: (a) for grape-fruit type, and (b) for lemon type.

The results of OIM analysis for grape-fruit type and lemon type silicon particles are shown in Fig.2(a) and Fig. 2(b) respectively. Grain boundary character distribution expressed by lines in Fig.2(a) for the grape-fruit type silicon show that this type of silicon particles is polycrystalline, which consists of many grains mainly in random boundaries. On the other hand, grain boundary character distribution in Fig.2(b) for lemon type show that this type of silicon particles consists of only two or three grains with Σ3 or Σ9. Twins, in the coincidence site lattice(CSL), are a subset of Σ3 [8]. The occurrence of Σ9 grain boundaries is attributed to the geometric interaction of twin related variants [9]. That means only twin orientation relationship between grains was found to exist in this type of silicon particles. Even single crystal in cross-section as shown in Fig. 2(c) was also found within this type of silicon particles.

3. Summary

Mono-sized silicon particles with narrow particle size distribution have been successfully prepared by pulsated orifice ejection method (POEM). The results of OIM show that the grape-fruit type silicon particles are polycrystalline, which consists of many grains mainly in random boundaries. For lemon type, the silicon particles consist of only two or three grains in twin orientation relationship only and sometimes single crystal along its cross-section.

4. References

1. R. Bishconti and H. Ossenbrink: Sol. Energy Mater. Sol. Cells, **48**, p.1 (1997).
2. C. Okamoto, K. Tsujiya, T. Minemoto, M. murozono, H. Takakura and Y. Hamakawa: Jpn. J. Appl. Phys, **44** p. 8351 (2005).
3. T. Minemoto, C. Okamoto, S. Omae, M. Murozono Tsujiya, H. Takakura and Y. Hamakawa: Jpn. J. Appl. Phys, **44**, p. 4820 (2005).
4. M. Asano, N.Nagai, A. Kawasaki and R. Watanabe: J. Jpn. Soc. Powder Powder Metallurgy, **43,** p.1273. (1996).
5. Y.Kuroki, A. Kawasaki and R. Watanabe: J. Jpn. Soc. Powder Powder Metallurgy, **38**, p. 700 (1991).
6 K. Ichiki, M. Asano, A. Kawasaki, R. Watanabe and M. Miyajima: J. Jpn. Soc. Powder Powder Metallurgy, **44**, P. 7005 (1997).
7. Masuda, K. Takagi, Y. S. Kang and A. Kawasaki: J. Jpn.Soc. Powder Powder Metallurgy, Vol. 51(2004), p. 646.
8. V. Randle: JOM, **50**, p. 56 (1998).
9. P. Lin, G. Palumbo and K. T. Aust: Script Mater., **36** p. 1145(1997).