New technology of silicon production for photovoltaic and electronics

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Funded from the IPP programme, the National Renewable Energy Laboratory (NREL) and Russian scientists initiated a joint research project to implement a new chlorine-free methods of solar-grade silicon and electronics production [1]. Today, semiconductor-grade polysilicon is mainly manufactured using the trichlorosilane ($SiHCl_3$) distillation and reduction. The feed-stock for trichlorosilane is metallurgical-grade silicon, the product of reduction of natural quartzite (silica). This polysilicon production method is characterised by high energy consumption and large amounts of wastes, containing environmentally harmful chlorine based compounds. In the new method, solar grade polysilicon is manufactured of monosilane synthesised on the basis of metallurgical-grade silicon and ethanol as the feedstock materials. The basic processing stages are:

1. The reaction of metallurgical-grade silicon with ethanol at the 280 °C in the presence of a catalyst:

$$Si + 3\,C_2H_5OH \xrightarrow{catalyst} Si(OC_2H_5)_3H + H_2$$

2. The catalyst enchanted disproportion (i. e. simultaneous oxidation and reduction) of triethoxysilane will lead to the production of monosilane and tetraethoxysilane:

$$4Si(OC_2H_5)_3H \xrightarrow{catalyst} SiH_4 + 3\,Si(OC_2H_5)_4$$

3. Dry ethanol and secondary products such as high purity SiO_2 or silica sol can be extracted by hydrolysis of tetraethoxysilane. Ethanol will be returned to stage 1:

$$Si(OC_2H_5)_4 + 2H_2O \rightarrow SiO_2 + 4\,C_2H_5OH$$

4. Monosilane is decomposed pyrolytically to pure silicon and hydrogen:

$$SiH_4 \xrightarrow{850°\,,\,900°C} Si + 2\,H_2$$

This low-temperature chlorine-free process provides a substantial reduction of energy consumption (90 kWh per one kg of polysilicon vs. 300 kWh required for one kg of polysilicon produced by conventional trichlorosilane method).The silicon yield (polysilicon and its main byproduct, silica sol) is in the range of 80% to 90% vs. 6% to 20% for the trichlorosilane method. Compared with the trichlorosilane method, the price of polysilicon is reduced from $60/kg to $40/kg (pilot production: 3 ton/year) and then to $15/kg (at 1 000 ton/year production rate).

Most of new technological processes and techniques has been developed, all of them tested at the industrial level. A new efficient and environmentally benign method of manufacturing of monosilane, the basic feedstock for solar-grade silicon has been patented in USA [2] and Russian Federation [3].

The Experimental study of mono-crystalline silicon ingots prepared of polysilicon manufactured by the new method has shown an excellent purity of the polysilicon feedstock. Specific resistance of mono-crystalline silicon after 5 to 8 runs of zone melting exceeds 10 000 Ω cm and the lifetime for minority charge carriers is not less than 1 000 μs which demonstrates an extremely low content of electrically active impurity in silicon samples prepared using the new manufacturing method. This high purity silicon can be used in electronic industry for manufacturing of ICs, IR detectors, high power transistors and thyristors.

Industrial applicability of the new cost-efficient low-temperature chlorine-free solar-grade silicon manufacturing method has been experimentally proved.

With the proposed manufacturing technology implemented, the price of solar PV modules is expected to be reduced down to 2 US$/Wp in 2 years period (pilot production) and further, down to 1 US$/Wp in the next 3 years (large-scale production). Substantial waste and pollution reduction.

References:

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