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Hidden values in kerf slurry waste recovery of high purity silicon

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ABSTRACT

Slurry waste is a byproduct generated from the slicing process of multi-crystalline silicon ingots. This waste can be used as a secondary resource to recover high purity silicon which has a great economic value. From management perspective, the ever increasing generation of kerf slurry waste loss leads to significant challenges to the photovoltaic industry due to the current low use of slurry waste for silicon recovery. Slurry waste, in most cases, contains silicon, silicon carbide, metal fragments and mineral-oil-based or glycol-based slurry vehicle. As a result of the global scarcity of high purity silicon supply, the high purity silicon content in slurry has increasingly attracted interest for research. This paper presents a critical overview of the current techniques employed for high purity silicon recovery from kerf slurry waste. Hydrometallurgy is continuously a matter of study and research. However, in this review paper several new techniques about the process of high purity silicon recovery from slurry waste are introduced. The purpose of the information presented is to improve the development of a clean and effective recovery process of high purity silicon from slurry waste.

Contents

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1. Introduction

The photovoltaic (PV) industry has grown over the past decade at a remarkable rate [1]. For the year 2013, the global PV module production reached 39.8 GW (Fig. 1).

For the year 2014, GTM Research expected to reach the range of 40 to 50 gigawatts (GW) for worldwide installations. In addition, this expectation has motivated PV module suppliers to increase their manufacturing capacity for the same year. The same consequence is likely for producers of polysilicon, wafers and cells.). Therefore, the year 2014 is considered the start of a new growth phase for the PV industry [2].

Furthermore, the mono-crystalline and multi-crystalline silicon wafer-based technologies accounted for about 90% of the total production in 2013. The share of multi-crystalline technology is now about 55% of total production. Material usage for silicon cells has been reduced advantageously during the last 10 years because of higher efficiencies and thinner wafers Fig. 2.

The wafers used by the photovoltaic industry are mostly produced by multi-wire slurry sawing. Multi-wire sawing is the main slicing technique of the photovoltaic industry at the present time. It consists on slicing ingots with a wire using slurry poured on the wire web and running at high speed (10–15 m/s). The slurry contains silicon carbide (SiC) powder and oil, generally polyethylene glycol (PEG) [3,4].

Over 90% of the solar cells produced worldwide are based on crystalline silicon wafers. For meeting the annual growth target in the Si-based PV industry, the sufficient silicon availability is a must. Hence, considerable efforts, for developing high purity silicon recovery processes from kerf slurry waste, are of great importance [5].

Another point of attention is to increase the recycling of high purity silicon from disposed slurry waste. Unfortunately, low amount of this material is recycled in despite of its high cost and high demand (for the solar cells based industry for example).

This review compares the relative efficiency and bottlenecks of potential technologies, expediting identification of the major knowledge gaps and future research requirements with regard to the high purity silicon recovery from kerf slurry waste [6].

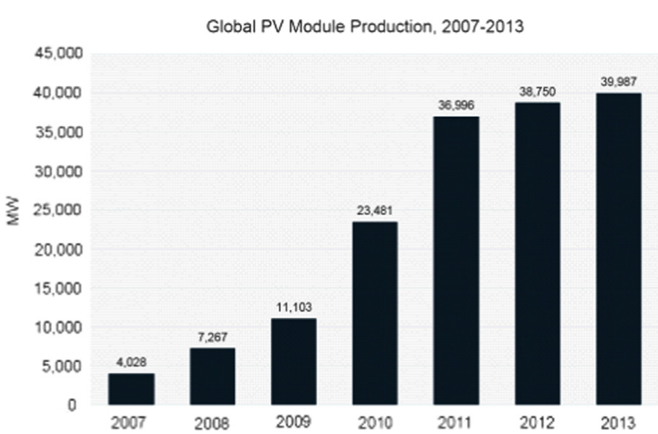

Fig. 1. Global PV module production from 2007 to 2013.

2. Solar-grade polycrystalline silicon production

The production of pure silicon is costly but needed the photovoltaic industry therefore developing new processes are of high interest. Some alternatives are the traditional Siemens chemical process and upgrading metallurgical grade silicon materials and silicon scrap.

The processes applied in order to purify metallurgical grade silicon to solar grade silicon are divided into two categories. The first category, called the chemical route, is related to the purification of silicon by means of the Siemens process, consisting of decomposing trichlorosilane (Eqs. (1) and (2)). The second one is known as the metallurgical route and involves obtaining solar-grade silicon directly from metallurgical silicon [7,8].

$$Si(s)+3HCl(g)=HSiCl_3(g)+H_2(g) \tag{1}$$

$$2HSiCl_3(g)+H_2(g)=Si+SiCl_4+2HCl \tag{2}$$

2.1. The metallurgical-grade silicon route process

The purification and upgrade of metallurgical-grade silicon is a very effective approach with regard to production expenses of SoG-Si. Metallurgical grade silicon (MG-Si) is the raw material for pure silicon production. Commercially, its production involves the reduction of silicon oxide (quartz) with carbon in submerged arc furnaces (Fig. 3). The process can be express as:

$$SiO_2+2C=Si+2CO\ (g) \tag{3}$$

MG-Si usually contains 99.0 wt% of impurities, some elements counting for them are Fe, Al, Ti, Mn, C, Ca, Mg, B, and P.

A key process for the metallurgical route is the directional solidification step due to the difficulty to remove impurities such as Boron and phosphorus which implies the use and research of

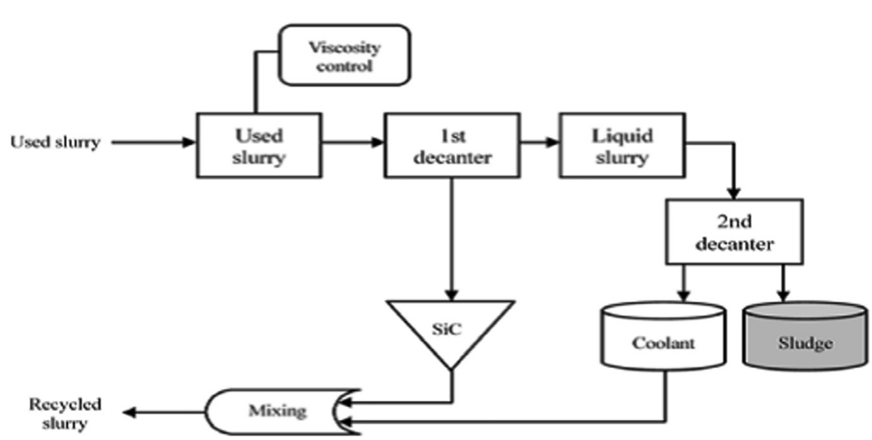

Fig. 2. Slurry recycling system.