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Review

Evolution and present status of silicon carbide slurry recovery in silicon wire sawing

H.S. Gopala Krishna Murthy

No. 3438, 2nd Cross, Girinagara 4th Phase, Bangalore 560085, India

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ABSTRACT

Recovery of used slurry from wire sawing of silicon wafers is important from both cost and environmental aspects of silicon wafer manufacturing. The mechanisms proposed for wire sawing of silicon wafers are briefly reviewed to help understand the nature of used slurry. Various processes that have been proposed for recovering slurry are reviewed and the merits and deficiencies of such processes are discussed. The basic physical principles and the various unit operations used in the recovery process are described. Criteria for selection of appropriate recovery processes are given. Commercially important processes in use in the industry for recovery of used slurry are examined in light of the consolidation trend in the Industry. The advantages and increased trends of using of in-house processes against out-sourced processes are brought out.

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E-mail address: hsgkmurthy@gmail.com

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1. Introduction

The Solar PV market is growing at a rate of nearly 25–50% since the year 2000 and this is likely to continue due to the steep drop in the cost of modules (Mehta, 2013). The global PV module production capacity in 2015 is estimated to be about 60 GW though the demand would be about 50.0 GW. Of this crystalline Silicon (c-Si) and thin-films have 90% and 10% market share respectively. Because production is higher than demand, prices of modules are low and therefore industry focus is on reducing cost per Watt peak (Wp) (ITRPV, 2015a). This is achieved by (a) improving yields at all stages of the PV module production process, (b) reducing materials and consumables, including silicon and (c) improving cell and module efficiencies. These are crucial at present as the current low price barely matches manufacturing cost and the industry is struggling to survive.

Silicon wafers are produced by cutting single crystalline or multi-crystalline ingots using wire sawing technology. While some disruptive technologies are being proposed to replace wire sawing, (Feinstein, n.d.) they are still in the early stages of development and may take many years to become commercially viable.

In the conventional wire sawing process, slurry of Silicon Carbide abrasive (SiC) dispersed in a liquid vehicle, usually Poly Ethylene Glycol (PEG) is employed. Both these are expensive with prices increasing further with growth in demand. In the manufacture of wafers, cost of slurry comes next only to cost of silicon, and accounts for nearly a third of the total cost. As a result of sharp reduction in selling price of wafers, wafer manufacturers are under tremendous pressure to reduce manufacturing cost. One way for this is to use diamond coated wire for sawing, thereby totally eliminating the need for silicon carbide slurry. Diamond wire sawing process is compared with slurry based process in a recent review (Photon International, 2011). As surface texture of diamond cut wafers is very different from normal slurry sawn wafers, downstream users have to modify their processes to use diamond wire sawn wafers. Details of surface textures of slurry and diamond wire sawn wafers are described in literature (Bidiville et al., 2010; Chen et al., 2010). Using diamond coated wire, cutting rate could be 2–3 times over the rates of conventional slurry based wire sawing. Hence, throughput from a diamond wire saw could be much higher, bringing down cost of ownership. Also, diamond wire process presents a distinct possibility of recovering kerf silicon by a simple process though with current low price of polysilicon this may not be important. According to the International Technology Roadmap for Photovoltaics (ITRPV) (ITRPV, 2015b) in the years to come, diamond wire technology would be used for cutting mono wafers whereas slurry based process would be preferred in multicrystalline (mc-) wafer production. The main reason for this is that (mc-) wafers cut with diamond wire are fragile and hence break relatively easily overshadowing other advantages of diamond wire sawing. Probable reasons for such fragility are presented in a thesis by Hao (2012). Recently Anspach et al. (2014) have demonstrated that production from conventional slurry based process could be increased by nearly 200%, wire consumption could be reduced by 45% and slurry requirement could also be reduced by 40% by using structured wire. Thus wire sawing of silicon with slurry would continue to be important in the industry. Consequent to this recovery and reuse of slurry used in wire sawing would be crucial for wire sawing economics.

2. Business of used slurry recovery

Neesse (2006) reviewed SiC-Recycling in Wafer Sawing Operations in 2006. Three major slurry recovery companies SiC Processing AG (SiC, n.d.) of Germany, CRS Reprocessing Services (CRS, n.d.a) of USA and Metallkraft AS (Metallkraft, n.d.) of Norway are in the market today. (There are several Chinese, Japanese and Korean reprocessing companies also, but information on them is scarce). These companies have established several facilities in the past for recovery of slurry from wire saw wafer manufacturers. Recently price of poly and downstream products like wafers, cells and modules crashed consequent to huge capacities established, particularly in China and other South Asian countries. The PV industry was plunged in to a deep crisis because of excess capacity and very low prices. This resulted in many companies closing down (Eric Wesoff, n.d.), particularly in the USA and Europe. Major manufacturers consolidated their activities also, placing an emphasis on creating complete in-house facilities starting from raw materials for poly making to finished modules. Cost reduction by sheer scale of operations was also achieved particularly in China. Efforts were also made to reduce cost of manufacturing by reducing materials consumption, improving efficiencies at each stage and recycling materials wherever possible. Such efforts have resulted in reduction of manufacturing cost of silicon PV modules to less than 50 cents per peak Watt (Greentechmedia, n.d.). Still as reported in (PV, n.d.), the latest selling price of PV modules is just about 60 to 65 cents per peak Watt. With such thin margins, survival of module manufacturers depends on how they cut their cost of manufacture further.

Many wafer producers such as REC Wafer, Norway, Bosch Solar, Schott Solar and Q-Cells, Germany and BP-Solar, USA who were unable to compete with the East Asian competitors, closed their operations. Some units developed their own in-house slurry recovery processes as a part of consolidation (SiC, 2013). These developments have impacted slurry recovery companies who are facing serious problems today: SiC Processing has filed for insolvency; Metallkraft has closed all its activities except in Singapore; and SRS Reprocessing Services has shifted its emphasis to other business sectors; thus giving impetus to in-house slurry recovery becoming prominent.

3. Scope of the present study

In this paper, an attempt is made to study the principles behind the recovery of used slurry, various technologies available for this purpose and their relative advantages and disadvantages. This study is based on information available from various sources such as patent literature and brochures or websites of slurry recovery service providers. Certain information presented here is based on real-life experience of the present author in operating a slurry recovery system for more than a decade. It is hoped that the present work would be useful to those already doing slurry recovery or those wishing to start recovery operations.

As the wire saw process is well-known, no attempt is made here to describe it. The ITRPV road-map envisages usage of thinner wires of down to 80 μ diameter and production of thinner wafers of 100 μ in future. Today, the industry uses 120 μ wire and produces 180–200 μ thick wafers. So far, attempts to reduce thickness of wafers further have led to higher breakage annulling the gains of reduced thickness.

4. Slurry after wire sawing

The most important role in wire sawing process is that of slurry. Silicon carbide which is the preferred abrasive can be either green or black with very little differences between the two variants in wire sawing. Particle size distribution is very important and SiC powder with a narrow distribution of particle size is used. Details of the effects of size of abrasive used in wire sawing are given by Anspach and Lawerenz (2009). Important point to note here is that