Solar Energy Materials & Solar Cells 136 (2015) 44–47

Contents lists available at ScienceDirect

Solar Energy Materials & Solar Cells

journal homepage: www.elsevier.com/locate/solmat

New potential for reduction of kerf loss and wire consumption in multi-wire sawing

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ARTICLE INFO

Article history:
Received 11 November 2014
Accepted 13 December 2014
Available online 14 January 2015

Keywords:
Wafering
Multi-wire sawing
Kerf loss
Wire consumption
Removal mechanism
Wire abrasion

ABSTRACT

Wafer production with multi-wire sawing leads to a high consumption of wire and a relatively high offcut (kerf loss) of high purity silicon material. In this paper a new approach to reduce these costs in order to achieve a more cost efficient wafering is developed. Investigations of wire behavior during multi-wire sawing have been carried out at commercial multi wire-saws for large-scale production. Virgin and worn wire samples as well as silicon bricks were analyzed with regard to wear condition and diameter. These analyses revealed that material removal (abrasion) occurs mainly at one side of the wire. This suggests that no rotation of the wire around his longitudinal axis takes place during slicing. Because of these findings, a method was developed which is based on a wire with a non-circular cross-section. By this approach, a better exploitation of silicon material and wire can lead to a better cost-effectiveness of wafer and hence solar cells.

1. Introduction

Thick film silicon modules are still the most prevalent solar cells. By means of multi-wire sawing, silicon columns (bricks) are cut into thin wafers (150 × 180 μm, 156 × 156 mm²), which form the mechanical platform and exhibit the photonically active material for this type of solar cells. In Fig. 1 multi-wire sawing is illustrated schematically. The amount and distance of the wire guide rolls can vary according to the type of multi-wire saw, but the basic mode of operation is the same. A virgin wire wound from the supply spool is directed by the wire guide rolls. These rolls have several hundred parallel grooves whereby the single wire of several hundred kilometers is winding and thus creating a wire web. A take-up spool collects the used wire which had been running through the web. This so-called unidirectional slicing mode is widely spread in PV (photovoltaics) wafer manufacturing.

The brick is pushed slowly (mm/min) through the fast moving (m/s) wire web and gets sliced into wafers. In Fig. 2 the cutting of slices (wafer) is sketched. It is done by an abrasive (mostly silicon carbide) which is suspended in a carrier fluid which is evenly distributed on the wire web. The mixture of abrasive and carrier fluid is called Slurry. Further details of the mechanisms of multi-wire sawing are described in Ref. [1].

Because of the high consumption of slurry (including abrasive) and wire, the sawing cost is about 30% of the wafer production [1]. Beside the high amount of production costs, a high amount of silicon material (up to 50%) is lost as kerf loss due to multi-wire sawing [2]. A lot of research and improvements have been done to solve these problems and to achieve a cheaper wafer production. Important approaches are:

- In Fig. 2 it can be seen, that the size of the kerf is similar to the size of the wafer thickness. Thus, one approach to reduce the kerf loss is to reduce wire diameter and the abrasive size [1–3]. In experiments a kerf loss of less than 100 μm has already been achieved using a wire with small diameter and small abrasive sizes [2]. However, in large-scale production a too small wire diameter is risky, because a thin wire increases the probability of wire breakages. Due to a wire break during multi-wire sawing, usually the majority of the actually sliced wafers are lost due to superficial imperfections or even mechanical ruptures.
- The behavior of slurry during wire sawing has been investigated and improved [4,5] and are a steady topic of research and development programs in all major slicing companies and institutes.
- Using the two above mentioned approaches, the high rate consumption of abrasive and silicon during multi-wire sawing can only be minimized but not overcome due to its intrinsically nature as the machining method. Therefore approaches of

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http://dx.doi.org/10.1016/j.solmat.2014.12.020
0927-0248/

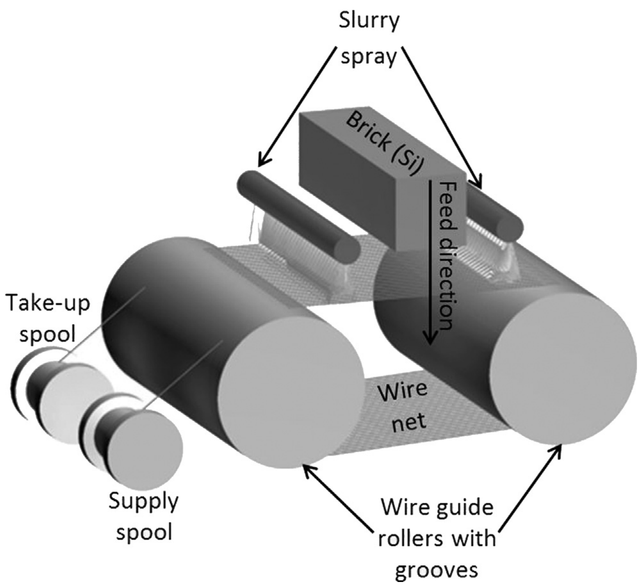

Fig. 1. Schematic diagram of multi-wire sawing.

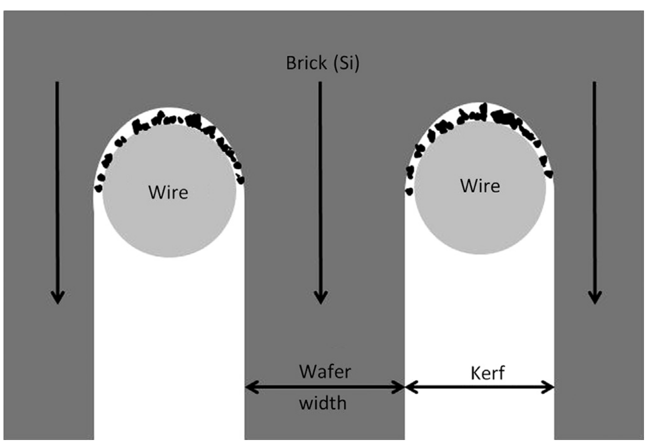

Fig. 2. Cutting of wafer by pushing a brick into a web of wires which are coated with abrasive.

recycling slurry [6,7] and kerf loss silicon [8,9] have been investigated.

- Alongside free abrasive, also fixed abrasive wire (mostly with diamond abrasive particles) is investigated and reported to be sporadically introduced in PV mass production [10–14].
- Another approach is the abrasive electrochemical method based on a multi-wire saw system. Here, multi-wire sawing is combined with wire electrical discharge machining [15].

This paper shows a new approach to improve multi-wire sawing focusing on the interaction wire and slurry. It can be combined with the already existing improvements to achieve a cheaper wafer production. The origin of this improvement was an investigation of wire behavior during multi-wire sawing. The investigation has been carried out directly at large-scale production, whereby new findings have been achieved.

2. Method

Single wire cuts on a bench-scale have been carried out to investigate wire behavior and sawing mechanism, [16–18]. The results presented in this paper have been gathered from wire samples which have been produced due to incision experiments directly at multi-wire saws from large-scale production. To investigate a wire after different operating times, the multi-wire sawing process was interrupted. Subsequently, the partially sliced brick was removed from wire web. At one side of the web which is in proximity to the supply spool, the wire has incurred a comparably small operating time. The closer the wire is moving towards the take up spool, the larger is the operating time and thus its wear. Representative samples of the wire are then cut out of the web. Taking into account the position of each wire sample within the web and the dimension of the brick, the cut-out wire parts could assign a length at which the wire was slicing silicon. This operation length of a wire is given by the number of passes through the brick multiplied by the transversal section of the brick.

The wires commonly used in multi-wire sawing consist of (cold) drawn high purity steel, coated with brass and having diameters between 100 and 140 μm. Focused Ion Beam (FIB) combined with Scanning Electron Microscope (SEM) and Energy Dispersive X-ray analysis (EDX) have been employed to examine the brass coating and its influence on abrasion and wear.

An incision experiment has been carried out at two different types of multi-wire saws purchased from MeyerBurger/CH. Thereby smaller wire saws with a wire web width of 0,3 m (ca. 1000 parallel wires slicing as many as wafers) and larger wire saws with a wire net width of 1 m (ca. 3000 parallel wires slicing as many as wafers) were used. Because of the dimension of the used bricks, the maximum operation lengths on these saws are 120 m or 450 m, respectively. By using different saws, different kinds of wires and wire guide rolls were used as well.

Virgin wires and used wires from incision experiments with specific operating times and accordingly defined operation lengths were thoroughly cleaned before surface investigations with SEM and EDX were performed. By cleaning the used wires, the sticking slurry has been removed. For further investigations the used wires were prepared metallographically by polishing the longitudinal section and subsequent etched using the HNO_3-solution.

Circularity was measured using a digital passameter from Union Tool CO/JP as a gauge which was especially equipped with a mechanical gear to account for a uniform rotation of the thin and flexible wire, and thus to measure the circularity of the examined wires. The measurement was done by rotating the wire 720° around its longitudinal axis wile measuring the diameter ca. 500 times per turn.

3. Results

All examined wires exhibited a one-sided abrasion. In Fig. 3, SEM images of the particularly stressed front, the flank and the unstressed back are shown.

The linear grooves at the back of the wire are remains of the drawing process during manufacturing of the wire. Virgin wires are showing the same appearance. EDX analyses confirm that also the thickness of the brass layer (thinner than 1 μm) at the back of a used wire is comparable to the thickness at a virgin wire.

At the front, the brass layer is worn after a few meters of operation length. The overlapping craters at the stressed front are due to the indenting of abrasive particles (SiC) into the steel wire. The indenting causes the wire abrasion. During investigations of the abrasion at the wire front, no evidence of crack formation could be seen. The abrasion appears rather more ductile. Fig. 4 shows a cross-section with an altered surface at the wire front and a cross-section with the smooth back. Due to etching with HNO_3-solution, the linear texture can be seen. Independent of the operation length, the stressed wire front appears similar. At the flank less indenting occurs, but some deeper craters than at the front were found.