The potential of rice husk ash for silica synthesis as a semiconductor material for monocrystalline solar cell: a review

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Abstract. The solar cell is a device that can convert solar energy into electrical energy. The solar cell is promising energy because it is environmentally friendly compared to fossil fuel. The essential component in the solar cells is silicon. Silicon is a semiconductor that can absorb sunlight. However, the available solar cells currently have relatively high prices since the semiconductor compiler material requires many processes and expensive. Rice husk ash can be used as a producer of environmentally friendly silicon at affordable prices. The rice husk could produce 87-97% silica and 16-25% ash. In general, the silica content of rice husk ash is 94-96%. The processes for producing silica material as a semiconductor were, such as rice husk ash preparation, greying, leaching, making silicon by reduction, and conductivity test. This review aimed to provide insight into converting the rice husk ash to solar cells.

1. Introduction
Electrical energy in Indonesia uses fossil fuels, such as petroleum, natural gas, and coal. The dependency on fossil fuels will lead to depletion of the amount of fossil fuel. Indeed, increasing coal consumption will make coal mining activities also growing and cause various problems, such as environment, health, and social aspects [1]. Indonesia is a country traversed by tropical equatorial lines that make solar energy development possible in all parts [2]. Indonesia boosts with the largest solar radiation intensity in Southeast Asia with an average power of 4.8 kWh/m² [3]. It has the potential to develop renewable energy that utilizes sunlight by using solar cells. The solar cell is a device that can convert solar energy into electrical energy. A solar cell is promising energy in the 21st century since it is more environmentally friendly than fossil energy. Besides, the solar cell is also cleaner. It does not have a CO₂ pollutant, which can cause the earth to become increasingly hot, more renewable because it can convert solar energy into electrical energy, and also the amount is unlimited [2]. One promising technology is a monocrystalline solar cell. The monocrystalline solar cell is known for its low cost,
ability to create in various fields, potential applications on wearable devices, and sustainable energy building [4].

One of the essential components of a solar cell is silica or silicon dioxide (SiO₂). It is a semiconductor component where it is a component that absorbs sunlight. However, the existing solar cell has a relatively high price since the semiconductor drafting material requiring costly processes and costs. Therefore, it is necessary to substitute the components that have the same function at an affordable price. Ash from rice husk is an environmentally friendly silicone producer with very high silica content. Rice husk burned at 700-900°C will produce high silica with a rate of 87-97% and ash about 16-25% [5]. In general silica content of rice husk ash is 94-96% [5]. Therefore, the rice husk is potentially used as a semiconductor material on the solar cell. The selection of rice husk ash as raw material for silica substitute is in line with paddy production as a significant food commodity in Indonesia. The amount of rice production that continues to increase does not make farmers use all rice crop parts to be taken for its usefulness as a food ingredient. There are some parts of rice plants that are not used as food needs. Rice plants that are utilized or taken by farmers are the inside of rice.

Paddy will be harvested as rice and leave the rice husk or rice chaff, which is underutilized. Part of rice husk that is not used as food is experiencing buildup on land or in rice milling [6]. This pile of rice husk has not been widely used as a beneficial material. Farmers utilize this rice pile for livestock feed, media planting, red stone burning fuel, a mixture in the manufacture of bricks, ceramics, or the rest is discarded [7]. As such, the price of rice husk is low. Silica (SiO₂) is the main content (85-97%) of rice husk [8] which can be utilized for other higher-value uses. This review is expected to be able to provide insight changing the rice husk into solar cells. It is also in-line with government programs through new energy, renewable, and energy conservation to realize high electricity in Indonesia using a solar cell.

2. The Potential of Silica from Rice Husk Ash

There are several agricultural waste ashes that contain silica. Table 1 shows chemical constituent from various agricultural waste ashes. Based on the Table 1, rise husk ash has the highest SiO₂ content compared with other agricultural waste ashes such as Savannah bagasse ash, sugarcane leave ash, oil palm ash and Guinea corn husk ash.

| Chemical constituent | Savannah Bagasse Ash [9] | Sugarcane leave ash [10] | Oil palm ash [11] | Guinea Corn Husk Ash [12] | Rice Husk Ash [13] | Rice Husk Ash [14] | Rice Husk Ash [15] |
|----------------------|--------------------------|--------------------------|------------------|---------------------------|------------------|------------------|------------------|
| SiO₂                 | 77.29                    | 74.74                    | 65.3             | 78.19                     | 82.14            | 93.26            | 96.34            |
| Al₂O₃                | 10.95                    | 1.87                     | 2.5              | 1.35                      | 1.34             | 0.63             | 0.41             |
| Fe₂O₃                | 3.66                     | -                        | 1.9              | 0.84                      | 1.27             | 0.51             | 0.20             |
| CaO                  | 2.09                     | 6.39                     | 6.4              | 3.34                      | 1.21             | 1.96             | 0.41             |
| MgO                  | 1.49                     | 2.42                     | 3.0              | 3.76                      | 1.96             | 0.77             | 0.45             |
| SO₃                  | 0.49                     | -                        | 0.4              | 0.49                      | 0.17             | 0.01             | -                |
| Na₂O                 | 0.38                     | 0.15                     | 0.3              | 0.25                      | 0.14             | 0.01             | -                |
| K₂O                  | 3.16                     | 12.37                    | 5.7              | 7.67                      | 2.09             | 2.85             | 2.31             |

The high silica content in rice husk ash is potential for further processing into semiconductor material for monocrystalline solar cell. In addition, silica from rice husk ash also has many technological applications in industries such as thixotropic agents, thermal insulators, composite fillers, drug delivery agent, biogenic silica nano-particles, adsorbent and catalyst [16].

3. Silica Synthesis from Rice Husk Ash Extraction

Silica is a compound that is commonly found in rice husk ash. The process of obtaining silica from rice husk ash is by combusting at high temperature, then solubilize with the solvent to remove the non-silicon
compound. The non-silicon contents are leached with the organic solvent, and the last is a downstream process for silica conversion into silicon and purification. The dried rice husk in open dry air and cleaned of impurities.

Based on Agung's study [17], the dry rice husk is made into charcoal and heated in a furnace for 4 hours with a temperature of 700°C. Then, ash was mixed with 10% KOH solution at 85°C and stirred for 90 minutes. The 1 M HCl solution was then added slowly to the silicate solution until it reaches pH 7 to form a precipitate. Based on this method, the silica yield reached 50.97%. HCl's addition significantly affects the purity of silica produced [18]. Their study explained that the addition of 2M HCl could increase silica yield up to 98.49% compared to without HCl addition.

After the solubilization and precipitation, the liquid is leached. Various types of acids can be used in leaching, such as HCl, HF, HI, H₂SO₄, H₃PO₄, C₆H₅O₇, or known as citric acid. The HCl is the most potent acid since it has the highest effectiveness among other types of acids [19]. The average purity level of silica produced is in the range of 91-99%. However, solvents such as HCl, H₂SO₄, H₃PO₄, and HF can pollute the environment and can cause health problems. Therefore, citric acid is used to avoid a harmful effect on the environment [20]. Citric acid is used because it contains carbonyl clusters where they bind to the metal in rice husks form complex compounds so that silica is produced with a high degree of purity [21].

The leaching process can produce wet silica or silicon dioxide (SiO₂). The oxidation process can reduce the wet silica to produce silicon. The oxidation process of silica to silicon occurs only on the surface of silicon (Reaction 1).

\[ \text{Si(s)} + \text{O}_2(g) \rightarrow \text{SiO}_2(s) \]  

(1)

One of the solar cells' surfaces is removed by its oxide layer using hydrogen fluoride. The surface is removed by the oxide layer (etching process); the surface colour changes back to grey as before. This process is carried out so that the diffusion process's donor atoms can be added to P-type silicon crystals. Besides the etching process also serves to give texture to the surface of silicon, the surface structure is formed to increase sunlight absorption and reduce re-reflection. With this process, silicon wafers can absorb maximum sunlight, and the efficiency of solar cells can be improved. The reaction in the etching process, silicon dioxide (SiO₂) reacts with hydrogen fluoride (HF) to form fluorosilicic acid (H₂SiF₆) so that the oxide layer is lost, and the surface of the silicon will be eroded by using acids (Reaction 2).

\[ \text{SiO}_2 \ (s) + 6\text{HF} \ (aq) \rightarrow \text{H}_2\text{SiF}_6 \ (aq) + 2\text{H}_2\text{O} \]  

(2)

4. Silica Reduction Methods

Since the silicon has a melting point of 1414°C, the carbothermal reduction at 2000°C is not recommended for reduction silica into silicon. Therefore, the magnesiothermic reduction has been reported to produce porous silicon structures from silica with a low temperature (500–950°C) also permitting the template-assisted design of silicon structures [22]. The reduction reaction of magnesium with silica produce an interwoven composite product of magnesia (MgO) and silicon (Si) as described in Reaction 3.

\[ \text{SiO}_2 + 2\text{Mg} \rightarrow 2\text{MgO} + \text{Si} \]  

(3)

In order to get silicon, magnesia should be removed and separated in the reaction vessel. However, the side reaction can decrease the silicon yield along with magnesium silicide formation (Reaction 4). Also, Mg₂Si formation not only reduces the yield but also affects the product morphology upon removal that co-occurs through MgO removal in the HCl wash [22].

\[ \text{Si(s)} + 2\text{Mg(g)} \rightarrow \text{Mg}_2\text{Si(s)} \]  

(4)

Nevertheless, Mg₂Si is not thermodynamically stable in the presence of SiO₂. Thus the reaction of magnesium silicide with acid can react spontaneously with air [22]. On the other hand, the essential
factors that need to be considered during the magnesiothermic reduction have been reported from Entwistle et al. [22], as shown in Figure 1.

**Figure 1.** The magnesiothermic reduction process and summary of critical design factors [22].

Based on Figure 1, the critical parameters that should be able to provide valuable reaction conditions on product properties. Several factors considered for magnesiothermic reduction have been reported by Entwistle et al. [22] such as ramp rate of 1-4°C/min, reaction temperature range of 500-900°C, reduction time between 0.5-12 hours and the molar ratio between 1.5-3. The heat accumulation that occurs at the reaction temperature can cause the reaction to approach or even exceed the melting point of silicon. This usually occurs in spherical porous macropore products with pore sizes of about 200 nm [23][24]. Both of these effects occur due to the nature of the interwoven silicon aggregates or the magnesia product phase. In lower temperatures, magnesia phases with a range size of 2–50 nm formed interwoven with silicon. Increasing temperatures can cause the aggregation of magnesia crystallites into the macropore range ~ 200 nm [22].

The isolation of silicon from rice husk ash can be done by using a metallothermic method using aluminium reducing agents at a temperature of 650°C for 3 hours. This method produces silicon with a purity level of 46.72% [25]. This value is different from the silicone obtained when receiving acid treatment. The purpose of acid treatment in silicone extraction is to remove the impurities. However, the use of hydrochloric acid can pollute the environment. Therefore, organic acids are used to purify silicon. One organic acid that can be used to refine the silicon is citric acid [21].

Solar cells are made on a single crystal or multiple crystal silicon base material, but the most crucial requirement is purity. In order to obtain high purity, silicon raw materials must go through a purification step in which the silicon is converted into silane. A single crystal solid is made by melting silicon, and into the melt, a single crystal seed attached to a lever is dipped and pulled while it is slowly rotated. Meanwhile, multiple crystals of silicon are formed immediately after the refining stage.
5. Silica Coating to Monocrystalline Solar Cell

Silicon from rice husk ash can be used as a semiconductor material that is coated onto the solar cell by layering. Figure 2 shows the difference in silicon distribution structure in several solar cells, such as monocrystalline, polycrystalline, and amorphous layer.

![Silicon distribution structure in solar cells](image)

**Figure 2.** The different structure of silicon for monocrystalline silicon solar cell (a), polycrystalline silicon solar cell (b), and amorphous silicon (c) [26].

Based on the distribution of the silicon structure above, the monocrystalline silicon structure can be used as a surface coating for monocrystalline solar cells, as shown in Figure 3. Silicon can be found in the antireflective coating and n-type layer at solar cell instrument.

![Coating structure layer](image)

**Figure 3.** Coating structure layer of monocrystalline solar cell [26].

All the component that layered the solar cell instrument has its type of material and function. The material will define the function of the layer. The typical material for each layer and its function showed in Table 2.

**Table 2.** The layer structure of monocrystalline solar cell [27].

| Layer                  | Typical material        | Function                                           |
|------------------------|-------------------------|----------------------------------------------------|
| Superstrate            | Glass                   | Provide structural stability and protection        |
| Antireflective coating | Silicon nitride         | Minimize light reflection                         |
| Front-side contact     | Silver or aluminium     | Collect electrons                                  |
| N-type layer           | Monocrystalline silicon | Transport electron and generates electron-hole pairs |
| Back surface field     | Heavily doped silicon   | Block electrons from back-side contact             |
6. Electrical Conductivity Test of Silicon From Rice Husk Ash

Electrical conductivity is one of the essential characteristics to determine the electrical properties of a material. Electrical conductivity (s) itself is the ability of a material to conduct electric current. The material can be categorized into three based on their electrical properties: conductors, insulators, and semiconductors. The range of electrical conductivity values in conductor materials is more than 10\(^8\) S/cm, semiconductor materials between 10\(^{-9}\) S/cm – 10\(^3\) S/cm, and insulator materials less than 10\(^{-9}\) S/cm [27]. The electrical conductivity can be measured using the LCR-meter, an instrument used to measure inductance (L), resistance (R), and capacitance (C). Measurements using LCR-meter will determine the conductance value (G) of the sample printed pellets. The conductance value (G) is obtained from the standard resistance value (R) [28]. Various electrical conductivity values from several materials shown in Table 3.

![Table 3. Comparison of electrical conductivity values of various materials.](image)

| Materials          | Electrical conductivity (S/cm) | References |
|--------------------|--------------------------------|------------|
| Zeolit A1T         | 1.059 x 10\(^{-6}\) - 2.848 x 10\(^{-6}\) | [29]       |
| Zeolit A2T         | 1.226 x 10\(^{-6}\) - 2.911 x 10\(^{-6}\) | [29]       |
| Zeolit A3T         | 1.287 x 10\(^{-6}\) - 3.040 x 10\(^{-6}\) | [29]       |
| LiTaO\(_3\)        | 1 x 10\(^{-5}\)                | [30]       |
| ZnO                | 0.28 x 10\(^{-3}\) – 0.3 x 10\(^{-3}\) | [31]       |
| Quartz Sand        | 1.2 x 10\(^{-8}\)              | [32]       |
| Rice Husk Ash      | 0.208 x 10\(^{-7}\) – 1.48 x 10\(^{-7}\) | [33]       |

Based on Table 3, several materials have various conductivity values. The lowest conductivity value in quartz sand material of 1.2 x 10\(^{-8}\) S/cm, while the highest conductivity value was obtained in Lithium Tantalate (LiTaO\(_3\)) material of 1 x 10\(^{-5}\) S/cm. The value of conductivity in rice husk ash is still low because it has not received special treatment to increase rice husk ash [34].

7. Rice Husk Ash Silica in Wide Application

Rice husk ash is an alternative source to produce silica with good quality in large quantities. Silica production on an industrial scale is generally based on mechanical, physical, chemical, and energy-intensive thermal operations at high temperatures using large amounts of acids and producing significant volumes of waste. Conventional silica production is based on the reaction between sodium carbonate and quartz at high temperatures. Once sodium silicate is formed, silica is deposited and reacted with sulfuric acid. It uses high energy levels and produces large amounts of liquid waste and greenhouse gases. The utilization of rice husk ash into silica as a semiconductor material in the monocrystalline solar cell has several advantages compared to the use of inorganic silica from quartz sand. Silica from rice husk ash is environmentally friendly, cost-friendly, energy-efficient, and simple, so it is very likely to be developed further and commercialized in the industry [35].

Silica can be the primary material for the semiconductor section in the solar cell. The semiconductor is a material that has a level of conductivity between an insulator and a conductor. The main parameter that makes up the semiconductor with other materials is the bandgap energy. The energy bandgap determines the difference between the valence band and the conduction band section, which determines the amount of transition energy needed to make the electron band from the valence band conduction band [18]. Semiconductors have bandgap energy (E\(_g\)) between 0-4 eV, while isolators have bandgap energy above 4 eV, and conductors have bandgap energy below 0.5 eV [18]. Semiconductors are developed as materials supported by electric currents due to leaps from excited electrons. According to the photovoltaic principle, solar cells are made from silicon crystalline base material because of their abundant presence, non-toxic nature, and high conversion efficiency [36].

Rice husk ash has the main component in amorphous silica with a high content, which is 83-90%. The silica application that can be extracted from rice husk ash is of high value and potential to be widely applied. One of the main is to make semiconductor components of the monocrystalline solar cell. The
use of silica from rice husk ash can be widely applied in several kinds of solar cells for monocrystalline solar cells and the non-silica next generation, like the dye-sensitized solar cell (DSSC). The DSSC uses dye and TiO$_2$ for the next-generation photovoltaic energy conversion. In addition, DSSC has required silica in a more developed form and requires additional treatment such as the coating on gold, further crystallization, and oxidation. It can also be used for the manufacture of silica gels, silicon chips, synthesis of activated carbon and silica, the production of light construction materials and insulation, catalysts, zeolite, materials for lithium-ion batteries, graphene, energy storage, capacitors, carbon capture, and drug delivery vehicles. The use of rice husk ash for the future is currently being widely discussed and developed. It is highly recommended to be used as a potential resource of low-cost precursors for silica production as a value-added material for practical applications [37].

8. Conclusions

Rice husk ash can be used as an alternative to silica, a raw material for semiconductors in monocrystalline solar cells. The purity and conductivity of the silica from rice husk ash are similar to that of other materials. This review shows the advantages of using silica as a raw material for making semiconductor material for monocrystalline solar cells. Silica from rice husk becomes a promising material with low initial cost since it is an agricultural waste that has not been utilized. Also, rice husk is an organic materials and the ash/silica for making the solar cells semiconductor is therefore eco-friendly. The purification using hydrochloric acid produced 96-98% silicon from rice husk ash. However, hydrochloric acid adversely affects the environment. Therefore, citric acid can be used as an alternative for raw materials. The citric acid for manufacturing semiconductor solar cells is environmentally friendly and can be produced in high purity. This review provides platform for future research to obtain high purity silica from rice husk as an alternative eco-friendly material and sustainable renewable energy sources.

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