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A method to recycle silicon wafer from end-of-life photovoltaic module and solar panels by using recycled silicon wafers

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ABSTRACT

This paper details an innovative recycling process to recover silicon (Si) wafer from solar panels. Using these recycled wafers, we fabricated Pb-free solar panels. The first step to recover Si wafer is to dissolve silver (Ag) and aluminium (Al) via nitric acid (HNO_3) and potassium hydroxide (KOH), respectively. The next step is to remove anti-reflection coating (ARC) and emitter on the surface by using an etching paste which contains phosphoric acid (H_3PO_4). Wafers onto which the etching paste was applied were heated for 2 min at 320, 340, 360, 380, and 400 °C. The recycled wafers showed properties with the thickness of over 180 µm, resistivity of 0.5–4 Ω cm, which are almost identical to those of commercial virgin wafers. Furthermore, the solar cells manufactured with the recycled wafers showed an efficiency equivalent to that of the virgin cells. Pb-free solar panels were fabricated with the solar cells by using 60Sn-38Bi-2Ag solder to assemble the solar panels. Thermal cycling test based on the standard IEC 61215 were performed on the solar panels in order to confirm their stability.

1. Introduction

Global warming has compelled the energy sector to move toward low-carbon energy resources, the photovoltaic (PV) component of which will play an important part [1]. This development is due to the much lower CO_2 emissions of crystalline silicon PV installations (23–81 gCO_2-eq/kWh) compared with those of electricity generation from fossil fuel (400–1000 gCO_2-eq/kWh) [2]. Globally, the capacity of PV installations has increased from 39 GW in 2010, to 177 GW in 2014, [3] thereby making the price of electricity derived from PV technology to become competitive with that of electricity from fossil fuel [4–6]. With the increase in installations, however, the number of solar panels reaching their end-of-life (EoL) stage will rise steadily [4]. The estimated cumulative amount of PV waste by 2017 is 870 t, which will increase by 1,957,099 t by 2038 [4]. To limit the negative impact of the forecasted growth in PV waste, the European Union (EU) commission has recently decided to include PV panels into the new Waste of Electrical and Electronic Equipment (WEEE) directive, [7] the legislation that encompasses the recycling of electronic wastes. For these reasons, PV manufacturers, distributors and internet/distance seller have the legal obligation to ensure take-back and recycling, which includes the related financing, reporting and administration, of their discarded products within European borders [8]. This regulation encourages them to establish a sustainable supply system of raw materials from EoL panels. The system will make it possible to increase the competiveness of solar panels by enabling the use of recycled materials [9–11], which can reduce the energy consumption for manufacturing wafers [12].

Silicon has a special role in the PV supply chain, namely as the raw material for poly-silicon; the material for the ingot process; and the wafer of solar cells. The price of the Si increases as we go from raw material to wafer [13]. For this reason, we focused on developing a method to recycle Si wafers from the solar panel, when the solar panel is no longer in use. In addition, the solar industry in the EU has started regulating the use of hazardous materials on the basis of the Restriction on Hazardous Substances (RoHS) directive, [14] which was updated in July 2011 as RoHS 2 [15]. This directive imposes deadlines for applications of exemptions in cases where technical reasons are provided. Although solar panels are currently exempted from the RoHS, [15] they will be subjected to regulations in the next few years unless the exemption is renewed. A review of the RoHS directive is expected to take place by mid-2021 at the latest [16]. These regulations encourage the PV industry to develop lead (Pb)-free solar panels. For this reason, we are focusing on developing Pb-free solar panels using recycled silicon wafers.

The first step to recycle Si wafer is separation of the different layers

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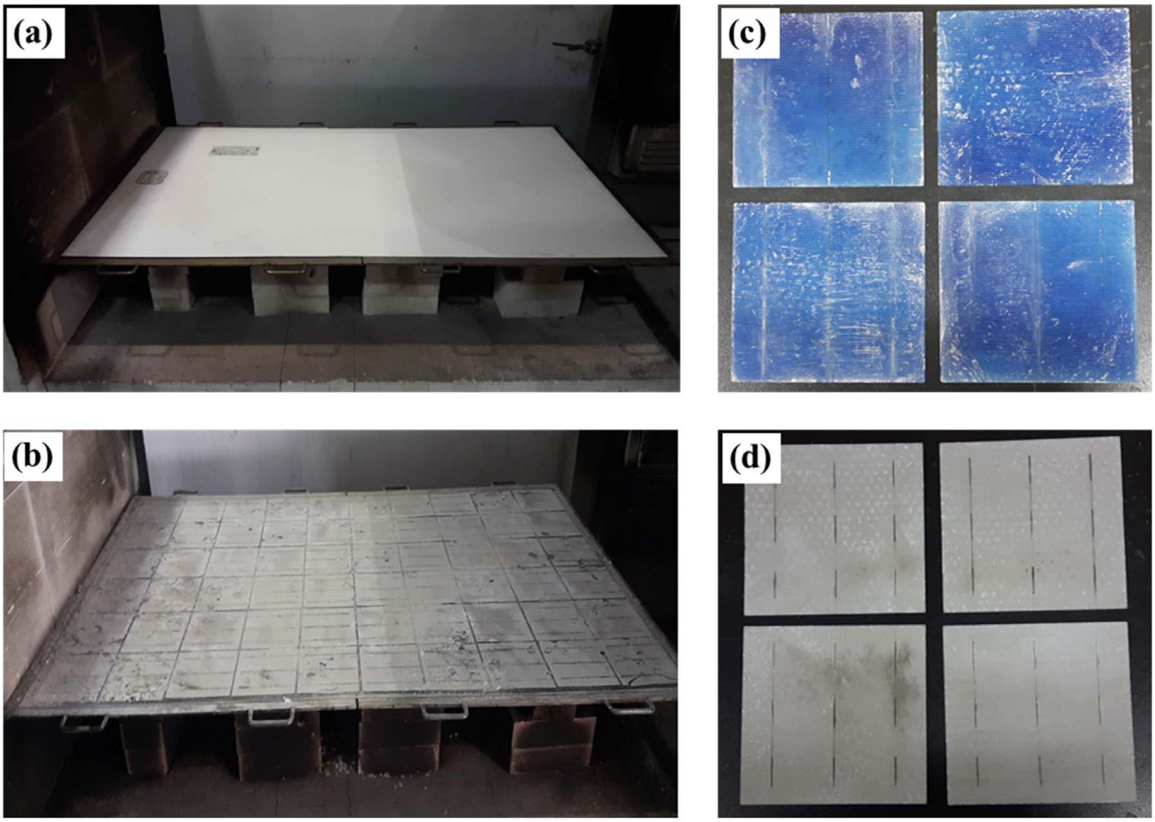

Fig. 1. Solar modules in a furnace to separate each layer via thermal process: (a) before thermal process; (b) after thermal process; (c) the front surface and (d) back surface of solar cells after thermal process.

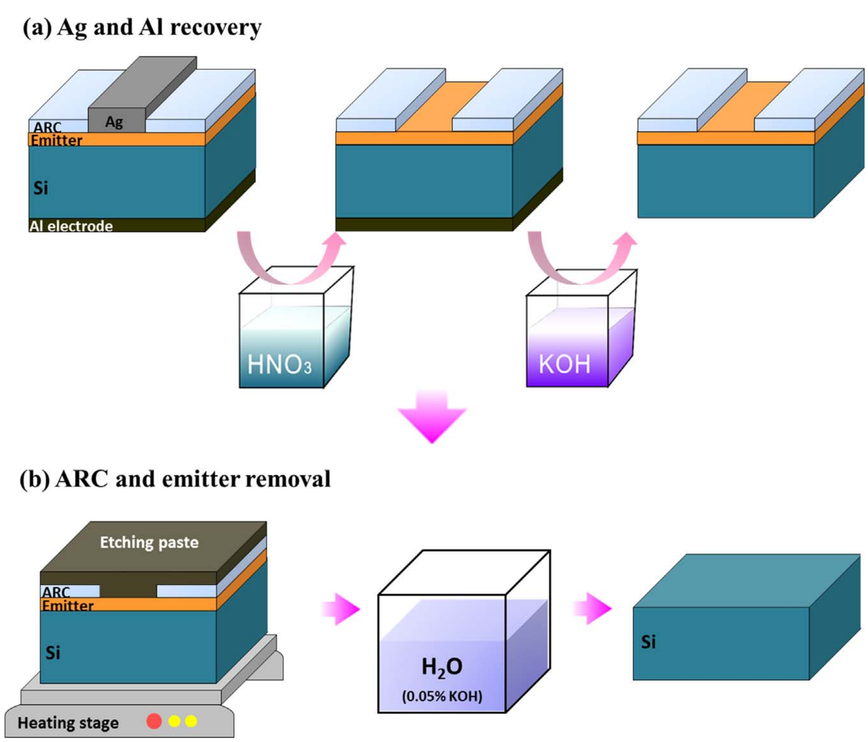

Fig. 2. Schematic diagram of recycling processes to remove the Ag, Al, ARC and emitter layer from the wafer surface.

of the solar panels without damage to the Si wafer. Kang et al. [9] reported a procedure to separate solar panels via toluene. The solar panel was immersed in organic solvent at 90 °C for about 2 days. A method to thermally separate the individual layers was developed in 1998 by the research group of Frisson [17]. Similarly, Klugmann-Radziemska et al. performed the separation of the glass and polymer layers from solar panels by using a thermal process [18]. To recover the silicon wafers efficiently, we have also developed a thermal method [19]. This method is consisted of a specially designed fixture, which helps to efficiently release gases from EVA and back sheet. The solar