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Separation of backsheets from waste photovoltaic(PV) modules by ultrasonic irradiation

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Abstract. With the rapid development of the photovoltaic industry, the global installation of photovoltaic modules has increased significantly. However, there are few reports on the recycling of photovoltaic modules' backsheets. In this study, we employed customized ultrasonic instrument and compound solvents to recover backsheets from crystalline silicon PV modules. This investigation showed that the backsheets of end-of-life PV modules could be separated successfully by ultrasonic irradiation. At a temperature of 50℃, the backsheet could not be separated in formic acid and acetic acid regardless of the ultrasonic power and concentration, but the effect in acetic acid was better. At a ultrasonic power of 720W and a temperature of 70℃, although the backsheet could be completely separated in butanone, the silicon wafer was damaged to varying degrees due to the swelling of EVA.

1. Introduction

In recent years, renewable energy, represented by solar energy, has received increasing attention from more and more countries due to the increasing energy and environmental issues. Since the 1990s, solar cell technology has been vigorously developed all over the world. The lifespan of PV modules is usually 25-30 years [1], so in the near future, there will be a large amount of end-of-life photovoltaic modules that need to be recycled. According to the World Renewable Energy Association, the number of end-of-life photovoltaic modules will reach 1,000 tons, and by 2038, 195,7099 tons [2]. Therefore, how to recycle and dispose of end-of-life photovoltaic modules is of great significance.

As of 2017, crystalline silicon PV modules accounted for about 90% of the total solar cell market share [3]. This was mainly due to the high conversion efficiency of silicon-based solar cells and the mature production process. As shown in Figure 1, the main components of crystalline silicon photovoltaic modules are tempered glass, encapsulant, silicon wafers, backsheet and metal ribbons [4]. The role of tempered glass is to protect the silicon cell, with good light transmittance and mechanical strength. Ethylene vinyl acetate (EVA) is usually employed as encapsulating material for its excellent moisture-proof and adhesion properties [5]. The backsheet is a polyvinyl fluoride composite film (TPT), which has three layers; the middle layer is polyethylene terephthalate (PET), and the other two layers are polyvinyl fluoride films [6].

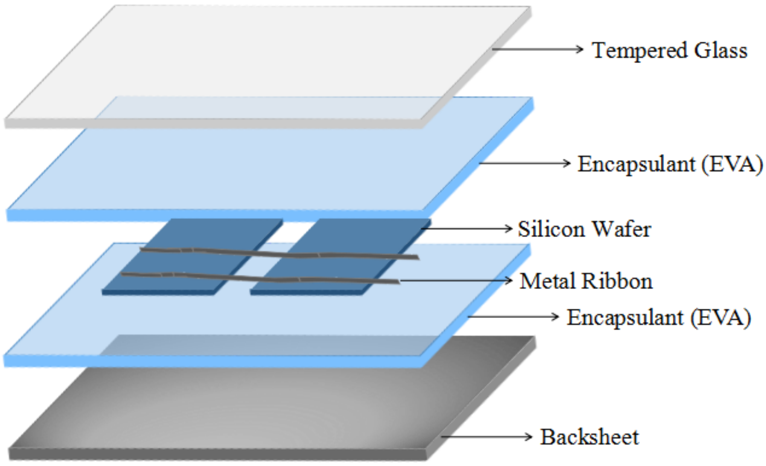


Figure 1. Typical structure of crystalline silicon photovoltaic modules.

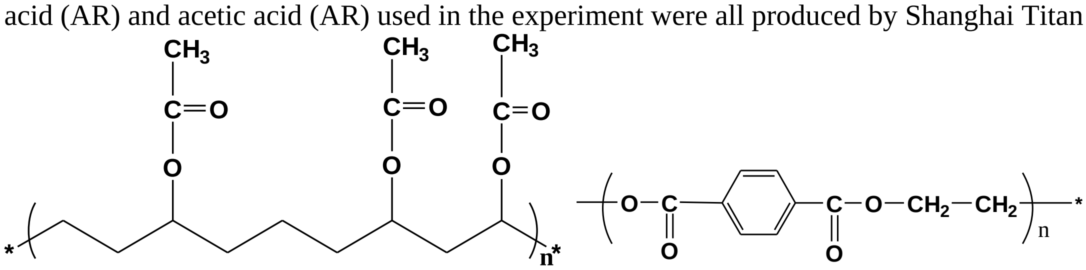
So far, there have been many reports on disposing of the backsheets from crystalline silicon photovoltaic modules at home and abroad, but the scope of research is relatively narrow, mainly including chemical and heat treatment. Jeongeun et al. used a special designed fixture to heat the photovoltaic module at a rate of 15℃/min to 480℃ to obtain a complete silicon wafer [7]. Heat treatment usually removes the backsheet and EVA film directly. Although the efficiency is high, it will produce a large amount of harmful gases, and the high temperature will damage the silicon wafer and affect the recycling [8]. The chemical method mainly includes organic solvents and nitric acid, both of which have a long processing time and generate a large amount of waste liquid, which is not suitable for industrial applications.

In this study, the end-of-life crystalline silicon photovoltaic module was ultrasonically separated using a mixed solution of various organic solvent and water. Meantime, the effects of power and temperature on the separation of the backsheets were evaluated and optimized in order to develop a green and efficient method for the disposing of the backsheets from crystalline silicon photovoltaic modules.

2. Experimental

2.1 Materials and chemicals

Crystalline silicon photovoltaic modules with dimensions of 125*135*2 mm, which obtained from Ranruo optoelectronic Co.,Ltd., Dezhou were disposed in this research. The chemical structures of encapsulant and backsheet were shown in Figure 2. The butanone (AR), benzyl alcohol (AR), formic acid (AR) and acetic acid (AR) used in the experiment were all produced by Shanghai Titan company.



Ethylene vinyl acetate copolymer (EVA) Polyethylene terephthalate copolymer (PET)

Figure 2. The chemical structures of encapsulant and backsheet.

2.2 Devices and methods

Industrial-grade ultrasonic cleaner (CH-12M, Weineng, China) was used in this research, its schematic illustration is shown in Figure 3. The power of ultrasonic cleaner is 720W (adjustable), the frequency is

28Khz, and the heating power is 1000W; 12 transducers are installed at the bottom. When the ultrasonic cleaner was filled with enough water, the container containing the solvent and the PV modules was placed in the washer for ultrasonication. The disposing of backsheets was carried out at different temperatures (30, 50, 70°C) and ultrasonic powers(180W, 360W and 720W).

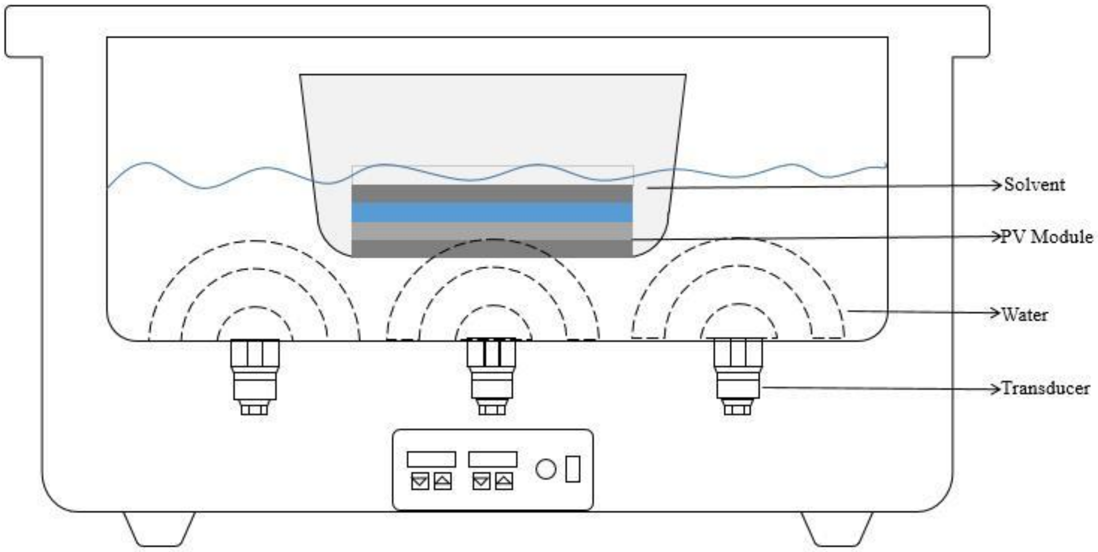


Figure 3. The schematic of the ultrasonic cleaner.

2.3 Analytical method

When the treatment time was the same, the separation rate (S) is used to evaluate the separation effect according to the following formula:.

$$s = \frac{A}{B}$$

where A is the total area of separated backsheet, and B is the total area of the backplane($125*135mm^2$).

3. Results and discussion

3.1 Effect of power

Figure 4 shows the separation of PV module backsheets at different ultrasonic powers (720W, 360W,180W). The experiments were conducted at 50°C, the solvent concentration is 50%. For benzyl alcohol (Fig. 4(a)) and butanone (Fig. 4(b)), the separation effect was enhanced with the increase of ultrasonic power. As shown in Fig. 4 (a), when the ultrasonic power was 720 W, the backsheet could be completely separated within 210min. As the ultrasonic power was decreased to 360w or 180w, the separation was less effective, there was almost no separation of the backsheet. This may be due to the better solubility of benzyl alcohol, and as the power increases, the OH radicals generated by the cavitation of the aqueous solution became more and more, and the dissolution of EVA in benzyl alcohol was promoted [9]. When 50% butanone was employed (Fig. 4(b)), the separation of the backsheet was almost the same in the first 60 minutes, but there was a huge difference later. The separation rate increased significantly with the increase of ultrasonic time and power. After 240 minutes, the separation rates were 67.59% (360w) and 6.54% (180w), respectively. At a power of 720w, the separation rate increased sharply with the increase of the disposing time, and the backsheet was completely separated in 210 minutes. Its explanation may be that, first, butanone itself is a strong solvent, and secondly, as the power increases, the cavitation rate increases, the molecular collision speed increases, and a large impact force is applied to the interface, which may cause molecular chain breakage [10]. In formic acid (Fig. 4(c)) and acetic acid (Fig. 4(d)), the separation rate of backsheets was poor at different power levels, and almost no separation was found. The low separation rate is mainly due to the week diffusion and permeability of molecules and poor solubility of EVA at low temperature. Compared with formic acid, the separation rate of backsheet in acetic acid was better. This may be owing to the fact that the structure of acetic acid is similar to that of EVA (both contain 2 carbon atoms), which has a higher affinity and better compatibility than formic acid [11].

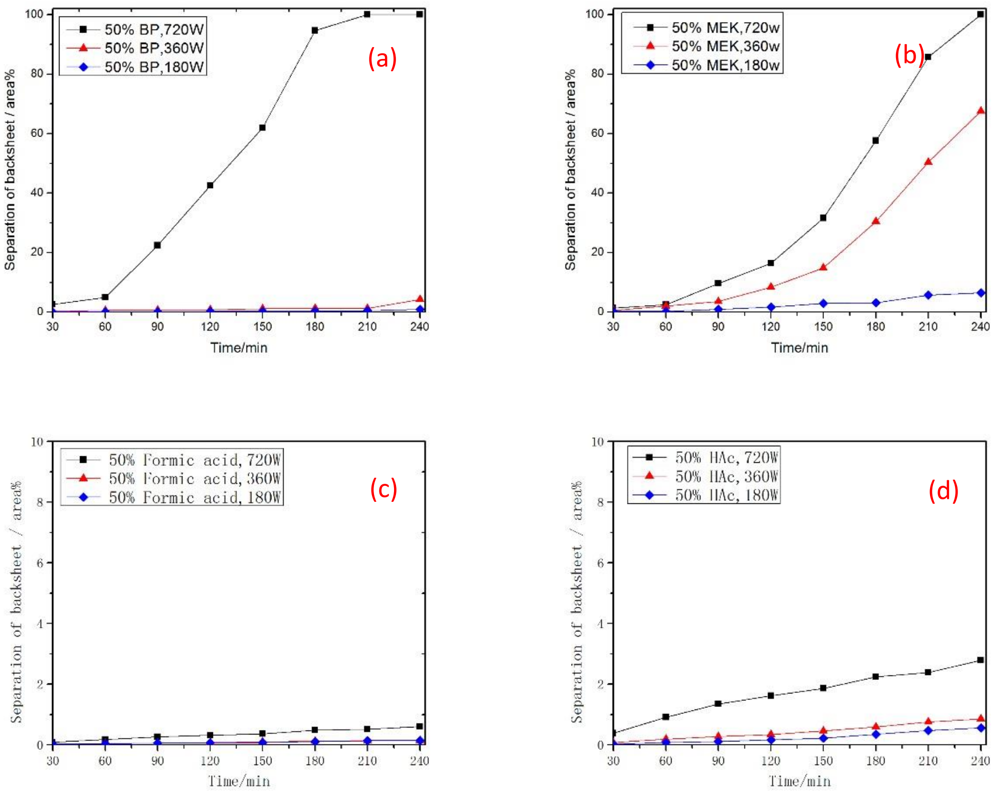


Figure 4. The separation of PV module backsheets as a function of the ultrasonic power, treatment time, and types of solvent: (a) BP, (b) MEK, (c) Formic aid, and (d) HAc (concentration: 50%, temperature:50℃).

3.2 Effect of temperature

The effect of temperature on the separation of PV module backsheets was investigated at a concentration of 50% and a power of 720W. It could be seen from Figure 5 that the separation rates increased significantly at 70℃ compared with the rates obtained at 50℃; when temperature reached 70℃, all the backsheets could be separated smoothly within 240 minutes. Among the four solvents, the backsheet was better separated in benzyl alcohol and butanone (all stripped within 240 min), whether it was 50℃ or 70℃. When 50% benzyl alcohol was employed, the separation rate of backsheets within 30min was 22.35% at 70℃, it could be completely separated within 90 minutes, and the wafer remained intact. This can be attributed to the fact that the benzyl alcohol structure contains a benzene ring (non-polar), and the polarity of the vinyl acetate is also weak, so the affinity between the two is large, and it is easy to dissolve EVA. Furthermore, as the temperature increases,the molecular thermal motion is enhanced, so the separation effect is better. Although the PV module backsheets could be completely separated within 120 min when heated at 70℃ in butanone, the silicon wafer was damaged to varying degrees (as shown by the solid line in Figure 5); when the temperature was 50℃, the separation rate of backsheet reached 100% in 240 min but the wafer remained intact. The cracking of silicon wafer at 70℃ was attributed to the swelling force of EVA, which is a result of the swelling rate of the EVA being greater than the dissolution rate [12]. The separation rate obtained in formic acid was similar to that obtained in acetic

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acid. When the temperature was higher(70℃), the backsheet can be completely separated within 240 min; when the temperature was lower (50℃), there was almost no separation effect. At 70℃, the back sheet could be completely peeled off in acetic acid within 120 min, so the effect of acetic acid was better than that of formic acid.

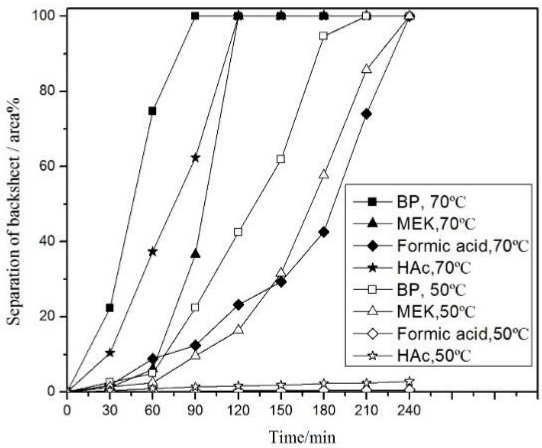

Figure 5. The separation of PV module backsheets as a function of temperature and treatment time(concentration: 50%, ultrasonic power: 720 W).

4. Conclusions

In summary, the backsheets of end-of-life PV modules was separated by ultrasonic irradiation successfully. Furthermore, the most suitable conditions for separation were investigated by varying the solvent concentration, experimental temperature and ultrasonic power. Based on the research, the following conclusions can be made.

(1) When the solvent temperature was 50℃, the separation rate of the back sheet increased with the increase of ultrasonic power. Only in butanone and benzyl alcohol, the backsheet could be completely separated within 240 minutes. At a temperature of 50℃, the separation effect in formic acid and acetic acid was poor (almost no separating), but acetic acid was superior to formic acid.

(2) With the increase of power, the separation effect of the backsheet in 50% benzyl alcohol was obviously enhanced, and it could be completely separated within 210 min; this indicated that the influence of ultrasonic power was greater than the solvent concentration.

(3) When the temperature was 70℃, the backsheet can be separated in solvents with a concentration of 50%; however, in the butanone solvent, the silicon wafer was damaged to varying degrees, mainly due to the swelling of the EVA.

(4) Butanone was the most effective solvent for separating the backsheet of end-of-life PV modules by ultrasonic radiation.

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