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Study of concentric iridescent ring around the laser-induced pits on the solar cell surface

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A B S T R A C T

The laser-induced damage on the surface of monocrystalline silicon (m-Si) solar cells and GaAs/Gesingle heterojunction solar cells are investigated. The solar cells were irradiated by a continuous wave laser at the wavelength of 532 nm. Concentric iridescent ring appeared on the damaged surfaces when observed with an optical microscope (OM) of broad spectrum. The damaged surface film was characterized by X-ray photoelectron spectroscopy (XPS) and the Contour Meter. The laser-induced temperature in silicon was calculated. The formation mechanism of the film and the cause of the concentric iridescent ring were analyzed.

1. Introduction

Today, high power laser processing has gradually become the method of choice to manufacture solar cells [1–3]. Therefore, it is important to explore the mechanism of laser-induced damage to solar cells to improve the manufacturing technology as well as enhance the damage resistance of solar cells. Antipov et al. [4] studied the generation of periodic ring structures induced by continuous wave (CW) laser on thin PbSe films in 2011. Their results indicated that the ring was the result of different defects distribution in materials after laser irradiation. In 2009, Chen et al. [5,6] reported the ring area formed around the erosion pit on stainless steel surface in incipient cavitation erosion. They asserted that the periodical change from red to blue of the iridescent ring was caused by the thermal effect due to the inelastic damage induced by stress waves. Ge et al. [7] reported the same phenomena in 2010, yet they believed that different colors represented different temperatures of the rings. This paper demonstrates that the concentric iridescent ring around the laser-induced pits on the solar cell surface are oxidized films formed at high temperature around the pits, different thicknesses resulting in different colors.

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2. Experimental set-up

Fig. 1 shows the experimental setup. We used a 532 nm CW laser to induce damage to the solar cell, with an output mode of TEM_{00} and its power level changing from 0.35 W to 16 W continuously. A power meter was utilized to measure the real-time laser power. The laser spot was normally focused on the sample by a lens with a focal length of 75 mm. The size of the laser focal spot was defined by the width of the light intensity from the peak to its $1/e^2$ value [8], and was 100 μm in diameter, measured by a spot analyzer.

The 20 mm × 40 mm mono-crystalline silicon (m-Si) solar cells and the 30 mm × 40 mm GaAs/Ge single heterojunction (GaAs/Ge) solar cells [9] were used in the experiment. Fig. 2(a) shows the basic structure of the m-Si solar cell. The anti-reflection coatings are alternated by dozens of SiO_2 layers and TiO_2 layers, and its thickness is about 80 nm. The n-Si is doped with phosphorous (P), while the p-Si is doped with boron (B). The thickness of n-Si is about 0.3–0.5 μm and p-Si is about 300–400 μm. The grid lines are the alloy composed of silver (Ag), titanium (Ti), yttrium (Y), and the rear electrode is made up of Ag, and its thickness is too thin to consider. Fig. 2(b) gives the structure of GaAs/Ge solar cells, which is the same with m-Si samples but made up of different materials. The thickness of GaAs is about 3–5 μm and Ge is about 180–200 μm.

3. Experimental results

As shown in Figs. 3(a) and 4(a), after the irradiation of the 532 nm CW laser (the irradiation power was 1.0×10^4 W/cm^2 and the time

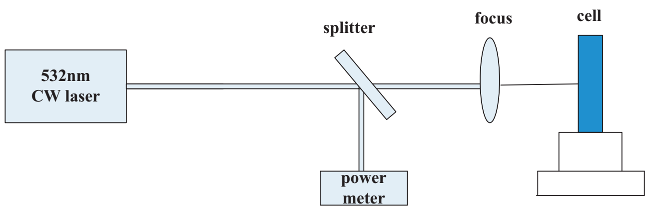

Fig. 1. Schematic diagram of the experimental setup.

was 100 s), concentric iridescent ring appeared on the surface of the solar cells when observed with the OM (Nikon Edipse lv-100D). Fig. 3(b), (c) and 4(b), (c) showed the images taken with monochromatic light under the OM, indicating that the number of the blue stripes was larger than that of the red stripes. Then we used HCl (37%) to erode the surface of the cells, and noted that the iridescent ring disappeared with the revealing of the monocrystalline silicon, as shown in Fig. 5(b). After that the m-Si solar cell was again put under irradiation (with the same irradiation power and exposure time), and the concentric iridescent ring reappeared, as shown in Fig. 5(c). The GaAs/Ge solar cells were processed identically and similar phenomena were observed.

The concentric iridescent ring shows certain experimental regularities. (I) The iridescent rings appears periodically. (II) The iridescent ring has the common central axis. (III) The farther the ring is away from the center, the wider its width becomes. (IV) The color of the ring is related to the observing wavelength and the thickness of the overflowed materials and their oxide materials.

The anti-reflection coating is transparent to visible light, and it has little effect on the formation of rainbow ring. After the laser irradiation, Si/Ge overflowed and was oxidated into SiO_2/GeO_2. The film producing the coaxial ring is made up by the generated oxides.

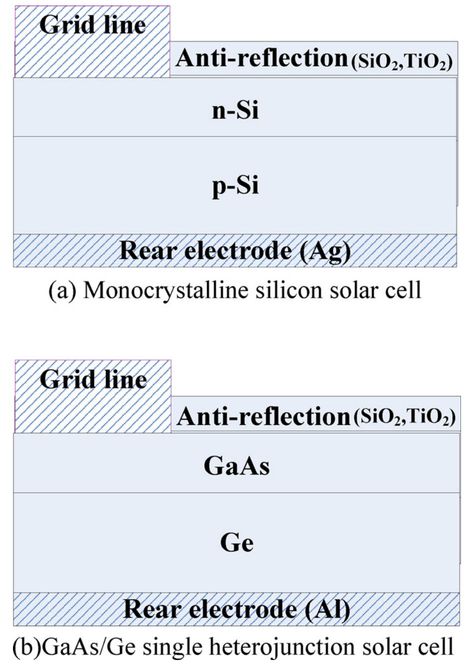

Fig. 2. Structure diagram of solar cells. (a) Monocrystalline silicon solar cell. (b) GaAs/Ge single heterojunction solar cell.

4. Mechanism analysis

4.1. The formation mechanism of the surface film

We intend to analyze the mechanism of laser-induced damage with the example of m-Si. In our experiment, the energy of the

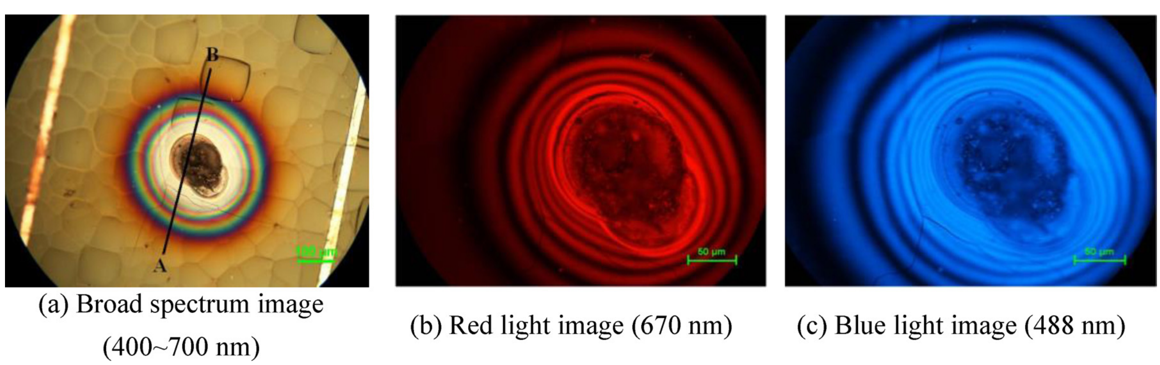

Fig. 3. The OM images of the m-Si solar cell surface observed with different light. (a) Broad spectrum image (400–700 nm). (b) Red light image (670 nm). (c) Blue light image (488 nm).

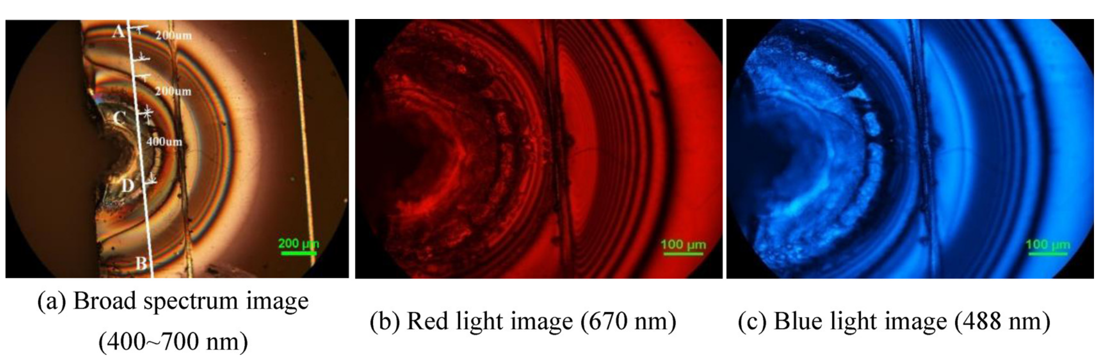

Fig. 4. The OM images of the GaAs/Ge solar cell surface observed with different light. (a) Broad spectrum image (400–700 nm). (b) Red light image (670 nm). (c) Blue light image (488 nm).