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Laser surface treatment of multicrystalline silicon for enhancing optical properties

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ABSTRACT

To minimise reflection from the flat surface, the multicrystalline silicon wafers were textured. This means creating a roughened surface so that incident light may have a larger probability of being absorbed into the solar cell. Due to grains of random crystallographic orientation, most of the texturing methods used for monocrystalline silicon are ineffective in case of multicrystalline silicon. Therefore, in the present paper a new approach to surface texturisation was developed. Texturisation of multicrystalline silicon wafers was carried out by means of laser surface treatment. Then, a special etching procedure was applied to remove laser-damaged layer. The reflectance of produced textures was measured by PerkinElmer Lambda spectrophotometer with an integrating sphere. The topography of laser-textured surface was investigated using ZEISS SUPRA 25 and PHILIPS XL 30 scanning electron microscopes. The laser treatment and etching in alkaline solution ensured obtaining texture of regular structure that was insensitive to random crystallographic orientation of different grains. The laser processing parameters were adjusted by performing a number of experiments for different values of processing parameters. It is a new approach to texturisation problem of multicrystalline silicon.

1. Introduction

Taking into account rapidly growing demand for energy and the fast depletion of deposits of conventional sources of energy, the development of new sources of energy has become a challenge to today's world. Moreover, what is even more important is that the use of fossil fuels such as coal and crude oil, being nowadays prevailing sources of energy, leads to unacceptably high concentration of harmful gases in the atmosphere. This, in turn, leads to ozone depletion and global warming that may destructively influence natural environment (Goetzberger and Hoffmann, 2005; Rodacki and Kandyba, 2000; Green, 2000).

One of the most important alternatives for conventional source of energy is solar energy. It is referred to as solar radiation that reaches the earth. Solar energy can be converted directly or indirectly into other forms of energy such as heat and electricity. A direct conversion of solar energy into electricity is performed by photovoltaic devices referred to as solar cells. The main drawback in the use of photovoltaic technology is the intermittent and variable character of solar light. However, this technology has many significant advantages

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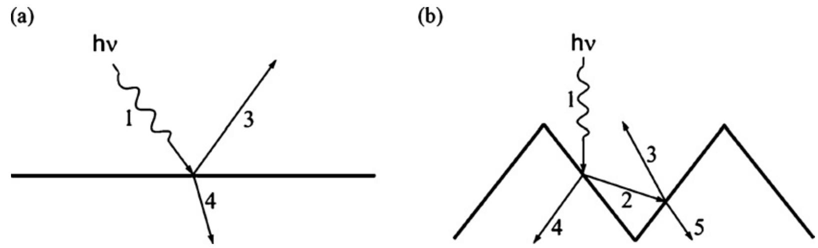

Fig. 1 – The influence of surface texture on light reflection: (a) planar surface and (b) textured surface. (1) Incident light, (2 and 3) reflected light and (4 and 5) absorbed light (Goetzberger and Hoffmann, 2005; Klugmann, 1999).

compared with conventional sources of energy. It is pollution free and clean, has no moving parts, produces no noise and requires very little maintenance. It does not require connection to a power grid since it can operate as a standing alone system. It is very promising alternative as far as environment protection is concerned since the use of this technology may significantly reduce chemical, radioactive and thermal pollution. Therefore, it may be helpful in reducing the greenhouse effect. In addition, it may be treated as a renewable and virtually inexhaustible source of energy in the context of expected duration of sun activity (Green, 2000; Nijs et al., 2001; Klugmann, 1999).

As a consequence, it is very attractive new technology for power generation. So far, it is not competitive with conventional sources of energy because of high production costs of solar cells but experts predict that with mass production and improvement in technology the unit price will drop and the significance of this technology in the energy production will systematically increase in future (Klugmann, 1999). In order to decrease production costs of photovoltaic systems intensive research in the area of multicrystalline silicon solar cells is carried out. It is one of the most environmental-friendly material of high abundance in the crust of the earth. It is competitive material for photovoltaics compared with monocrystalline silicon due to relatively low production cost and acceptable efficiency of cells (Dekkers et al., 2004; Hauser et al., 2003; Panek et al., 2005; Park et al., 2002; de Wolf et al., 2000; Dobrzański et al., 2007; Dobrzański and Drygała, 2007).

Electrical current is produced in the solar cell as a result of interaction between the incident sunlight and semiconductor that the cell is made of. Sunlight is composed of photons whose energy corresponds to their wavelengths. The flux of incident photons is generally separated into three disjoint parts: reflected photons, photons passing through the cell and absorbed photons. The influence of surface texture on light reflection is depicted in Fig. 1. Only absorbed photons of energy greater than the energy gap of semiconductor that cell is made of may generate electricity. During the operation of solar cells, optical losses appear that deteriorate light to electric conversion. Optical losses consist in reflection of the part of incident light from the front surface of the cell. As a result a smaller number of photons can generate electron–hole pairs and contribute in a photovoltaic conversion decreasing solar cell performance. When the flux of incident photons (1) reaches the planar front surface (Fig. 1a) it is divided into the absorbed (4) and reflected flux (3). To minimise the number of photons in reflected flux, surface texturing is accomplished. Texturing consists in expanding the front surface by roughening (Fig. 1b). In that case, the flux of incident photons (1) is again divided into absorbed (4) and reflected flux (2). However, because of the slope of textured surface, reflected flux (2) has another chance to bounce the front surface once again. As a result, the reflected ray (2) reaches the surface again and the second absorbed flux (5) can penetrate into the bulk of material. Consequently, the probability with greater amount of incident light to be absorbed is increased (Goetzberger and Hoffmann, 2005; Klugmann, 1999).

There are many publications relevant to the increase of incident sunlight absorption by means of surface texturisation (Dekkers et al., 2004; Hauser et al., 2003; Panek et al., 2005; Park et al., 2002; de Wolf et al., 2000). However, most of the texturing methods used for monocrystalline silicon appear to be ineffective for multicrystalline silicon. Therefore, we take up in this paper the research on texturisation of multicrystalline silicon by means of laser technology. Laser processing may be applied in the production of crystalline solar cells in the areas such as doping, scribing, cutting, drilling, joining of cells and laser fired contacts (Dobrzański et al., 2007). The principle of laser processing consists of material removal resulting from laser-induced melting and evaporation (Dobrzański and Drygała, 2007; Abbott et al., 2005; Klimpel et al., 2007; Major, 2002). The interaction between laser beam and material depends on both the laser type and its parameters. Therefore, they must be selected to match specific properties of material under processing (Allmen and Blatter, 1995; Bonek et al., 2007; Jackson and O'Neill, 2003; Jackson and Robinson, 2007). In the present paper, laser-textured surface of multicrystalline silicon has been studied. Microstructure and reflectivity of various textures as well as their influence of electrical properties of solar cells have been evaluated.

2. Experimental

Material used as a substrate was "as cut", p-type, boron-doped multicrystalline silicon wafers manufactured by casting method. Experiments were carried out on wafers of thickness ~330 μm, area 5 cm × 5 cm and resistivity 1 Ω cm. Damage on the surface induced by wire-cutting was removed by etching in 20% KOH solution at 80 °C. Typically, about 11 μm of distorted material were etched away creating damage-free surface.

To minimise reflection losses from the front surface, texturisation of wafers by means of ALLPRINT DN50A Q-switched