Silicon surface texturing by pulsed laser

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Abstract Texturing of silicon surfaces with pulsed laser is made. The method is based on the formation of laser-induced periodic surface structure (LIPSS). The process is temporary characterized through the dynamic reflectance, thus determining the formation threshold of the structure. Relation between the different textures and the spectral reflectance of the samples before and after the treatment is also characterized. The mean value of spectral reflectance decreases up to a 6 %.

Keywords: **Laser. Texturing. Silicon. Reflectance. LIPSS**

Texturado superficial de silicio mediante láser pulsado

Resumen Se realiza el texturado de superficies de silicio con un láser pulsado mediante la formación de una estructura periódica inducida por láser (LIPSS). Se caracteriza el proceso mediante reflectancia dinámica, determinándose el umbral de formación de la estructura. Se caracteriza el nivel de texturado midiendo la reflectancia espectral de las muestras antes y después del tratamiento. El valor medio de la reflectancia espectral disminuye hasta el 6 %.

Palabras clave: **Láser. Texturado. Silicio. Reflectancia. LIPSS**

1. INTRODUCTION

It is very important to reduce the superficial reflectance of silicon solar cells in order to increase their effectiveness. Texturing based on the different reaction rates of certain reagents with the crystalline plane of the silicon structure are typically made for this aim (1). The disadvantage of this method is the introduction of a pollutant medium, which can facilitate impurities inlaying.

An effect induced by pulsed laser radiation, consisting in the formation of a superficial periodic structure which origin is still an object of discussion, is reported in literature since some years ago (2). This effect, known as LIPSS, has been used in this work to create a superficial relief that decreases the reflectance of the silicon used in the manufacturing of solar cells.

This way of making texturing has the advantage of being much more rapid, economic and less polluant than the chemical techniques.

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2. EXPERIMENTAL SETUP

The experimental setup used to make the superficial treatment of the samples and the dynamic reflectance measurements is shown. Two lasers were alternatively used for the treatment in the experiments: GOS 1001 (Wavelength:1064 nm, Pulse energy: 500 J max, Pulse duration: 1 ms) and Lasertec (Wavelength: 1064 nm, Pulse energy: 1 J max, Pulse duration: 0.2 ms). Radiation of Nd laser was guided with and angle of incidence of 90º over the surface of the sample. An He-Ne laser (2 mW power), served as the beam collimator.

To measure the reflectance variation during the process, it was used another He-Ne laser with a 1 mW power that fed into the surface of the sample, just exactly in the treated area, under an of angle about 30º. A silicon photodiode was employed to detect the signal reflected by the sample, which was observed in a Tesla BM56 oscilloscope. The activation of the oscilloscope trigger, by means of the incidence of laser pulsed, was assured by a second detector which captured the Nd-laser pulse.

TABLA. I.– Parámetros de los tratamientos.

TABLE. I.– Parameters of the treatments.

Sample	Laser used	Power density (J/cm^2)	Pulse duration (ms)
Si 1	Lasertec	27	0.2
Si 2	Lasertec	78	0.2
Si 3	GOS-1001	58	1
Si 4	GOS-1001	61	1
Si 5	GOS-1001	68	1

2.1. Description of the experiment

Samples treated were of single crystalline Si (110), which were specularly polished and subjected to a previous chemical cleaning. Optical microscopy of the samples before the laser treatment showed a regular and uniform surface, free of any damages or irregularities.

To apply the treatment, the samples were placed on the movable bearing, making the radiation of the He-Ne collimator laser to fall into the sample. When the energy of the treatment was adjusted and the laser pulse was executed, at the same time, the dynamic reflectance signal was observed in the oscilloscope and the pulse energy was measured in the energy meter.

2.2. Real time reflectance

Real time reflectance was measured during the treatment of the first four samples appearing in table I. The oscillographic records of real time reflectance for different energy values are observed. Figure 1.i shows two representive energy values of the treatment. The reflectance of the Si1 sample with a 26 J/cm^2 energy is observed in figure 1.i.a. When laser radiation falls into, an increase of the reflectance takes place, reaching a maximum value of 100 % at 0.2 ms from the moment the pulse begins to fall into. Immediately the reflected intensity decreases to its initial value of about 80 % at 0.5 ms from the beginning. This temporal increase in the reflectance is due to a rise of the refractive index, as a result of an increase of the surface temperature.

The behavior of the Si2 sample, treated with 78 J/cm^2 energy is observed in figure 1.i.b. The maximum reflectance value reached in this case is similar to the one reached in the former case. However, immediately, a decrease to a minimum value takes place, lower than the reflectance the sample used to have before the treatment.

According to our point of view, the decrease in the reflectance up to values that are lower than the initial ones, is the result of the formation, in the surface, of an electronic plasma that absorbs the radiation strongly. As the power density increases, the generated plasma increases its density, therefore, radiation absorption is greater. In the first sample, the energy of treatment was insufficient to provoke the thermoionic radiation which can cause formation of plasma.

On the other hand, in Si2, it can also be seen that reflectance does not recover its initial value, not even after the treatment has concluded, but a nonreversible decrease takes place. This decrease in reflectance increases with energy, and it is related to changes that occur in the morphology of the surface, as we can see the formation of LIPSS for these energies, one that can not yet be seen in Si1.

Taking into account the theoretical model proposed in (3), surface temperature of silicon being subjected to a treatment with different energies, was estimated. It was proved that to reach melting point in surface, power density values of 78 J/cm^2 were needed. When treating the Si2 sample with this value, a final decrease of reflectance to a 5 % is observed. This decrease is related to morphological changes which could be fundamentally determined by the rapid crystallization of the surface in case a liquid exists. The fact that we find, precisely for this energy density value, a final decrease of the reflectance, agrees with the proposed value estimates in (3).

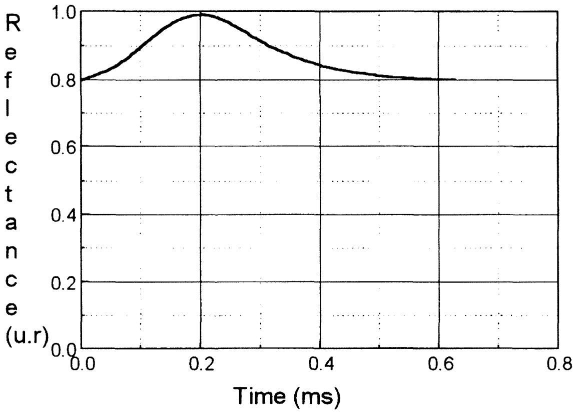
According to these results, the appropriated doses for the study carried out with GOS-1001 laser were chosen, as well as a technological system which allowed the treatment in larger areas (about 1 cm^2) and with a higher pulse quality.

2.3. Optical microscopy

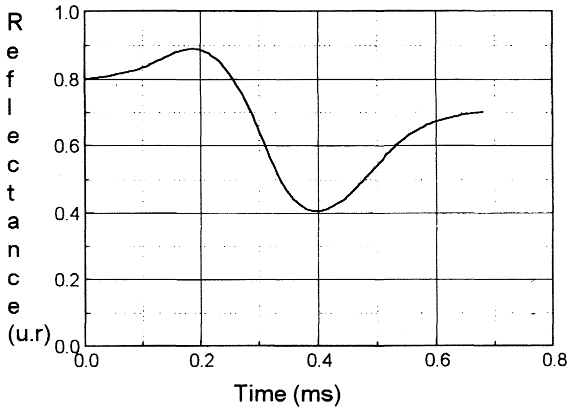
Structure formed by effect of laser radiation consists of a set of craters distributed in a quite regular form and, in some cases, linked by channels that seem to communicate the irregularities of the surfaces. Density and depth of the structure increase as the laser energy increases. The sequence of micrographies observed shows qualitatively the variation of the texturing characteristics with the increase of power density.

As we can see in figures 1.iiig., decreases in the cavities formed in silicon after treatment, are shorter than the rest of the figures, where a greater definition of irregularities is observed. This shows that as pulse energy increases the texturing thick increases too, although the distance between the observed craters remains almost constant.

1.i.

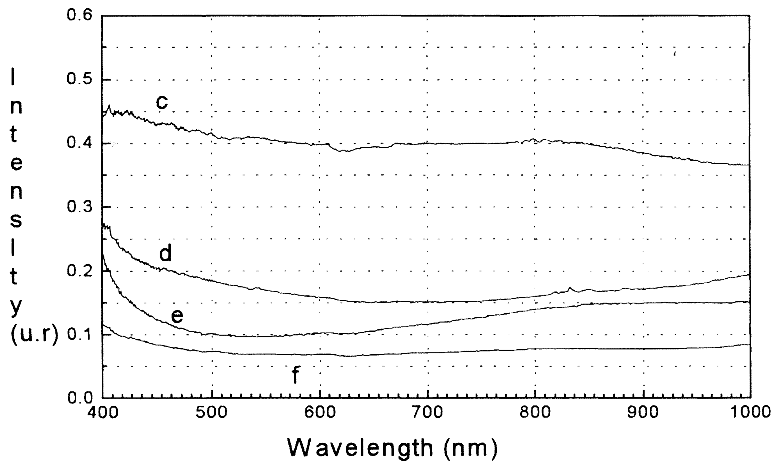


a



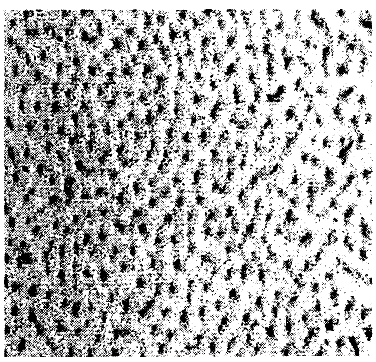
b

1.ii.

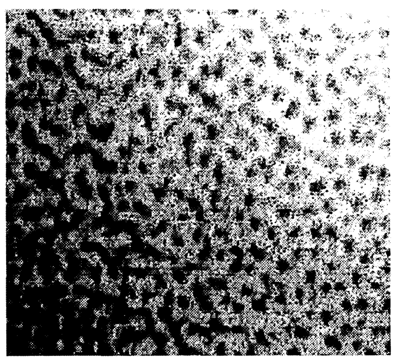


1.iii.

g)



h)



i)

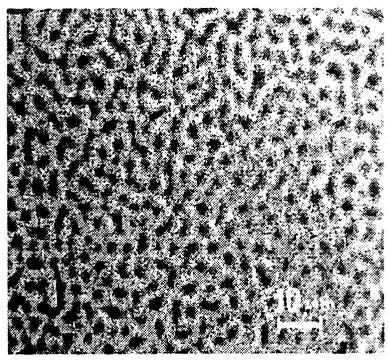


FIG. 1.— i) Real time reflectance oscillographic records for different power density values (a) Si 1 sample, (b) Si 2 sample. ii) Spectral reflectance of Si samples textured with different power density (a) not treated Silicon surface, (d) Si3, (e) Si4 and (f) Si5. iii) Variation of texturing with the increase of pulse energy.

FIG. 1.— i) Oscilogramas de la reflectancia en tiempo real para diferentes muestras. (a) muestra Si 1, (b) Si 2. ii) Reflectancia espectral de las muestras de Si texturadas con diferentes valores de energía (d) muesta Si 3, (e) muestra Si 4, (f) muestra Si5. iii) Variación del texturado con el incremento de la energía.

2.4. Spectral reflectance

Measurements of the spectral reflectance in a range from 400 to 1000 were taken to Si5, Si6 and Si7 samples (Table I). Curves *c* in figure 1.ii., represent the spectral reflectance of the nontreated sample; and *d*, *e* and *f* belong to Si3, Si4, and Si5 samples, which were treated at 58, 61 and 68 J/cm^2. Reflectance values, which represent a decrease of about 50, 62 and 75 % respectively, are observed. These reflectance values agree with the results shown by the optical microscopy, so that as the treatment energy increases, the reflectance of the surface diminishes in this range of the spectrum.

3. CONCLUSIONS

- The possibility of making surface texturing of crystalline silicon with Nd-laser pulses was proved.
- An increase of laser energy provokes a greater texturing depth, although its period does not change.
- Spectral reflectance of Si5 has a value of approximately 6 %. This value is similar to the best records reported in literature (4).

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