Processes in Semiconductor Materials After Laser Cutting.

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Abstract

The results of laser - semiconductor interaction are presented. The characteristic zones are investigated after laser affects the semiconductor substrates by method of electro-physical (dynamic and static) perfomances of diagnostic structures.

It has been found that:

1. Near of area of interaction of a laser radiation with a material of the target, the hot electrons generated by laser radiation, causes changes of properties of a material. It causes increase of reverse currents of the diodes. The magnification of reverse currents of the diode is observed which depends on supply voltage and distances between laser cut and diode. The distance between edge of the diode and edge of the laser cut with which begins increase of reverse currents of the diodes in Si: for supply voltage was 8,2 V – 5 μ, 20 V - 26 μ; in HgCdTe : for working voltage (0,1 V) the distance was 18 μ.
2. The laser radiation causes temporary increase of reverse currents of the diodes on distances from 2 μ and more (measurement of a reverse currents of the diodes on distances 36 and 78 μ have shown reduction of a reverse currents, in time about 400 minutes).
3. Our experimental data allow us to develop criteria of definition of parameters of laser radiation for laser cutting of semiconductor materials on distances in some microns from elements of the integrated circuits.

The basic criteria of a choice of laser radiation:

1. Repetition frequency of laser pulses;
2. Volume of destruction of a material for one pulse.

The laser source for these experiments was an UV laser at 0,34 μ wavelength with 7 ns pulses, laser fluency was more than 1,1 J / cm ^{2} that corresponding to minimum energy density required to forming pits.

The diagnostic structures included p-n junctions (Si, HgCdTe) or source of MOSFETs (Si).

Our experimental data showing that the powerful high-speed laser tools for cutting of materials are of limited usefulness for semiconductor materials.

Keywords: laser interaction, semiconductor, laser microcutting, laser microdrilling.

Introduction

Photons of laser radiation being absorbed in a material of the semiconductor and to cause generation of free carriers. Free carriers interacting with atoms of a crystal lattice, give back them the energy. The depth of penetration of laser radiation is defined as:

$L_1 = 1/\alpha$ [1], (1),

Where α (λ) - coefficient of absorption of a material of a target on wavelength of laser radiation.

The thermal fluctuation of atoms breaks periodicity of a crystal lattice, thus, increases probability of interaction hot electrons with atoms of material.

The heated up material evaporates and (or) passes in a liquid phase, which through the mechanism heat diffusion (D-coefficient), transfers heat to distance:

$L_2 = \sqrt{Dt}$ [1], (2),

Where t – the pulsewidth of laser radiation.

Thus, around of area of interaction of laser radiation the area with the changed properties of a material is formed. However, not all free carriers (hot carriers) interacted with atoms of a crystal lattice directly on distance L_2.

The part of hot carriers is distributed in volume of a semiconductor material further distances L causing local heating of a material (Joule heating [1]).

Distance, on which density of diffusion of free carriers is sufficient for breakdown of material, is much more than L_1 and L_2.

It is function by dependent from quantity of absorbed photons by a material of a target with energy greater than width of the forbidden gap.

The experimental definition of given distance is offered by the authors in given article.

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The initial data used by the authors:
1. The natural limit pulsewidth is the moment of emission of particles from material at action of laser radiation, which absorbs radiation.
2. The standard time – of – flight techniques had shown, that the important factor was merely the number of photons and not the pulse duration [2].
3. The value of coefficient of absorption of semiconductor materials is high in the field of ultraviolet (UV), it have allowed us to choose for experiments of a pulse UV laser at 0,34 μ wavelength with 7 ns pulses.
In figure 1 the curves of changes of diameters of throats of laser craters in Si (melting temperature Si is 1420^0 C), for repetition frequencies 100 Hz and 10 Hz, and the curve of change of a diameter of throats of a laser craters for a semiconductor material InSb with melting temperature 525^0 C versus number of pulses is shown [3].
The analysis of the form of curves (repetition frequencies 100 Hz) allows allocating three characteristic stages of formation of a laser crater:
First stage. The processes arising in the target results in distribution of thermal area around the point of interaction. The power of each incoming pulse (repetition frequency 100 Hz) is high enough to increase the temperature of heated area up to melting point around of crater. The process of removal of a liquid phase from crater results in increase of recrystallized materials around of laser crater. The dynamics of melting (diameters of throat of laser craters) of target material in different semiconductors is not the same. More fusible materials give faster increase of diameter of a laser crater.
The process of increase of diameter of a crater ceases, when interaction of the laser beam with walls of a laser crater become insignificant. About it speaks equality of diameters of craters for different semiconductor materials.
It is where the second stage of formation of a crater begins. All material is thrown out of an interaction range in a liquid phase and in ionized state.
The third stage. When the pressure of evaporation of the material is not enough for full depletion of liquid phase (having a reflection coefficient close to 1) from the laser crater, part of materials in a liquid phase stay on walls of a crater. We observe the reduction of diameter of the laser crater. It creates conditions for self - focusing of laser radiation, which results in a deepening of a laser crater.
The curve of change of diameters of a laser craters in Si at repetition frequency 10 Hz shows, that the time gap between pulses of laser radiation long enough to terminate all processes in Si. It results in almost complete absence of area with the thrown out material around of a laser crater. The area of recrystallized materials arises after the first two pulses and further does not occur it of change. The profile of a laser crater repeats distribution of radiation density in a beam zone.
In experiments we used laser radiation with energy in a pulse of 2 kW.
For allocation of an electronic component arising at laser cutting, we have carried out experiment, when distance between the diode on Si and line laser cutting, much more exceeded safe distance.
On distance 150 μ from the diode, which was under a voltage 100 V, we made of a laser cut. The current – voltage characteristics of reverse – biased diode initial and after laser cut is shown in figure 2.
From figure one can see, that, not looking on very large distance between p-n junction and edge of a laser cut, the reverse current has increased.
In our experiment we used p-n junctions made on a Si (100), substrate concentration 3.6 x 10^{15} cm^{-3}. The size of a window p-n junction was 100 x 100 μ^2.
The average power in a pulse was 2 kW, diameter of a light spot was 20 μ on a surface of silicon. The depth of a cut was approximately 20 μ.

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In figure 3, we are submitted current – voltage characteristics of reverse - biased diodes on silicon versus distance between edge of the diodes and the chains of laser craters forming laser cut (distances are specified in figure) [4, 5, 6].
We can see that voltage of beginning of the raised reverse currents, depended from distance at constant of breakdown voltage.
Parameters of laser radiation: density of energy 8,2 J / cm^2, diameter of a crater 12 μ , depth of a crater 80 μ .
In our experiment we used p-n junctions made on an n - Si (100), substrate concentration 3.6 x 10^{15} cm^{-3}. The size of a window p-n junction was 40 x 40 μ^2.
The measurements were carried out after removal of products of combustion of silicon from a surface that composed no more than 60 minutes from time of a beginning laser cutting.
Change current – voltage characteristics of reverse - biased diode on silicon at time versus distance between edge of the diode and edge of the laser cut are shown in figure 4.
Designations: initial - curve 1; after laser cutting on distance 8,7 μ through 30 seconds - curve 2. The measurement current – voltage characteristic of reverse - biased diode through 50 minutes has shown complete restoration of physical properties of the diode.

Repeated laser cutting on distance 2 microns were resulted in significant displacement current – voltage characteristic of reverse - biased p-n junction - a curve 3.
Approximately through 50 minutes the process of change current – voltage characteristic of reverse - biased p-n junction stopped - curve 4.
The experiment was made with repetition frequency of following of laser pulses 100 Hz, the power in a pulse was 2 kW, width of a laser cut - 20 μ. The depth of laser cut was about 20 μm.
In our experiment we used p-n junctions made on a Si (100), substrate concentration 3.6 x 10^{15} cm^{-3}. The size of a window p-n junction was 100 x 100 μ^{2}.
In works [4, 5, 6], we have shown, that the increase of reverse currents of the diodes is not connected to the superficial centers of generation - recombination, located near to silicon - oxide border.

Discussion

The analysis of experimental data shows, that at formation of craters the free carriers, generated by laser radiation, go out on the large distances from a place of laser interaction. Density free carriers on distance in 150 μ were enough to change structure of a material by an electrical field in diode.
The changes in a material near to area of interaction of laser radiation with a material of a semiconductor target without the application of an electrical field have revealed the following laws:
First, the laser radiation causes temporary increase of reverse currents of the diode on distances from 2 μ and more (measurement of return currents of the diode on distances 36 and 78 μ have shown reduction of reverse currents up to initial sizes at time about 400 minutes [5, 6, 7]).
The similar changes of reverse currents of diodes are described in work [8].
The annealing of diodes at temperatures 600^0 C, resulted in restoration of the diode. The seen changes in covering oxide at given heat disappeared.
Our experiments with heating of diodes after laser cutting have shown faster reduction of currents down to initial levels.
Secondly, there are around of a place of interaction of laser radiation with a material of the semiconductor, a zone, in which there are irreversible changes current – voltage characteristics of reverse - biased diode on silicon.
The borders of the given area, depending on the enclosed voltage, are determined by a method of measurement of reverse currents of diodes, are published in works [4, 5, 6, 7] and the moment of a beginning of increase of reverse currents of the diodes in Si: for supply voltage was 8,2 V – 5 μ, 20 V - 26 μ; in HgCdTe: for working voltage 0,1 V it was 18 μ.
The similar results are received by the authors and at laser cutting near to analog MOS - devices [4, 5, 6, 7] on Si.

Conclusions

1. Distance, on which density of free carriers is sufficient for occurrence degradation of a semiconductor material, which is expressed as electrical and thermal breakdown of a part of the diode, is much more long, than area of distribution of thermal heating. It depends from quantity absorbed of photons in a material of a target with energy of greater than width of the forbidden gap and quantity of free carriers in an initial condition of material.
2. The received experimental data we used to developed criteria of definition of parameters of laser radiation for laser cutting of semiconductor materials on distances in some microns from elements of the integrated circuits.

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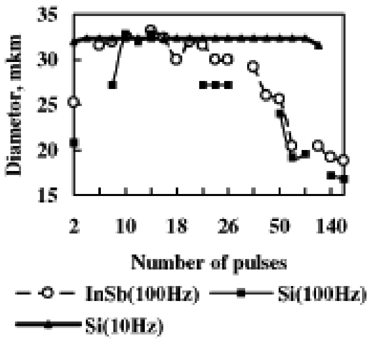

Figure 1. Diameters of throats of laser craters versus number of pulses for two semiconductors with different melting points (T_{InSb}= 525^0 C and T_{Si}= 1420^0 C) number of pulses at repetition frequencies 100 Hz and diameters of throats of laser craters in silicon versus number of pulses at repetition frequencies 10 Hz.

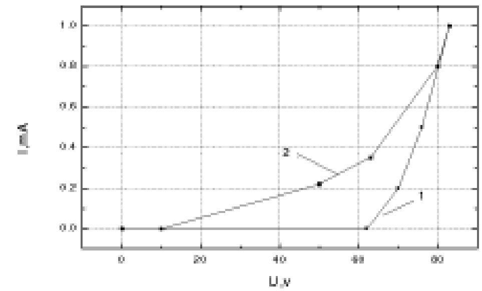

Figure 2. Current-voltage characteristics of reverse-biased diodes on Si which was under a voltage 100 V at laser cutting on distance 150 mkm. Designations: curve 1 - Reverse branch Current-voltage characteristics of the diode initial; 2 - Reverse branch Current-voltage characteristics of the diode after laser cutting.

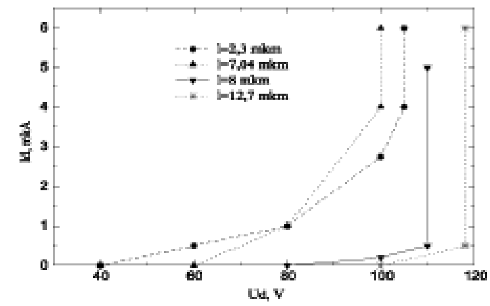

Figure 3. Current-voltage characteristics of reverse-biased diodes on Si versus distance (L) between edge of the diode and edge of laser cut. On an insert the distances are specified.

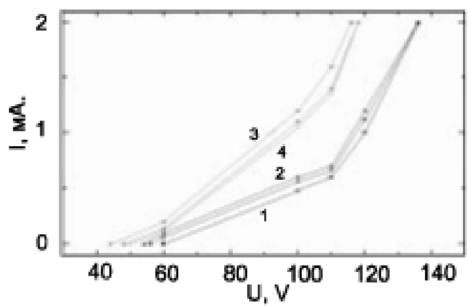

Figure 4. Current-voltage characteristics of reverse-biased diodes on Si versus distance (L) between edge of the diode and edge of laser cut at time.

1 - Initial Current-voltage characteristics of reverse-biased diodes.

2 - The characteristic of the diode after the laser cutting on distance 8,7mkm from p-n of transition (through 30 s)

3 - Current-voltage characteristics of reverse-biased diodes after the laser cutting on distance 2 mkm (through 30 s), intermediate curves - Current-voltage curves of the diode measured through 10 mines after laser cutting.