A ROLE OF DISLOCATIONS AT PROCESSES OF THE MECHANICAL BENDING OF SILICON WAFERS

Sh.M. HASANLI, N.N. MURSAKULOV
Institute of Physics, Azerbaijan National Academy of Sciences,
Baku. Az - 1143, H. Javid av. 33

In this work, peculiarities of mechanical bending and deformation rate of silicon wafers under the influence of applied external forces have been studied. It has been shown that , for all investigated samples ,there are three characteristic sections with various slopes irrespective of the types of operation, orientation and thickness of the wafers. By increasing the applied force (F), the rate of deformation rises, reaches a maximum , and then starts to decrease not monotonically , but spasmodically by further increase of the force F. Experimental results are discussed on the base of the creation of dislocations and their corresponding plastic deformation. Furthermore we have shown that , there is a very good correlation between the density of dislocations and spasmodic decrease of the deformation rate. The analysis of the obtained results confirms the availability of plastic deformation and its inclination to localization during deformation process at room temperature .It should be added that , the spasmodic decrease of deformation rate , can be viewed as a self-organized deformable medium.

Keywords: Semiconductors, surfaces and interfaces, dislocations , deformation rate .

1. INTRODUCTION:

The bending and warping of large-diameter silicon wafers are one of the most difficult problems in manufacturing semiconductor devices and integrated circuits due to the mechanical and high-temperature treatments. In some author’s [1, 2] opinion, the bending of wafers during mechanical cutting is created both by cutter displacement and occurrence of plastic deformation. According to [1], the plastic deformation of wafers during high-temperature processing is due to temperature gradient between edge and center of the wafers. Besides, it is shown, that under identical conditions of thermal processing, the wafer deformation is increased both with number of temperature cycles, and also with temperature rise. The latter can be qualitatively presented as follows: under the influence of thermal processing dislocations are created and as a result, relaxation of thermal strain occurs within the limits of the given sector. During the second thermal processing cycle, the formation of dislocations is considerably facilitated, resulting in their multiplication. The theoretical works [3-4] consider the influence of dislocations on the value of mechanical strength. The work by [4] shows the microplastic deformation in the crystals which is caused by reversible motion of dislocations. Moreover, the plastic deformation is considered to be inclined to localization at all stages of the plastic flow, and only its form changes at different stages. The works [4] slate that the nature of localization of deformation lies in self-organizing processes in deformable medium in the shapes of various sorts of waves. This is possible, because during deformation a flow of energy created by the loading device, runs through the crystal. The process of dislocations at given temperature will depend on: a)value of the applied force, b) value and allocation of local strains on the volume, c) microstructure of the crystal, availability of impurities of other phases etc.

Thus, the short analysis of the articles [1-4] shows, that the wafers' bending and warping may complicate the engineering procedures as photolithography, diffusion epitaxy and etc., and also may change the electrical characteristics of finished semiconductor devices and chips. Therefore, the questions connected with the problem of mechanical strength, and improving semiconductor devices production technology of devices, still remain topical and need to be further investigated.

The present work deals with study of the peculiarities of mechanical bending (W) and bending rate of silicon wafers under the applied force (F), and also their structures after various manufacturing operations.

2. EXPERIMENTAL TECHNIQUE and SAMPLES FOR INVESTIGATION

The investigations were carried out on both n and p-type silicon wafers having diameters of 100 mm and various surface orientations (see table 1). It should be note that, there are different testing methods for investigation of mechanical strength of semiconductor materials such as, torsion's, squeezing, tension, bending etc. among which three or four point contact and axially-symmetric methods occupy a special place. Because, they do not need takings special measures for fastening the samples, and also allow - while testing at room temperature - to receive strains of big value. However, according to [5], at three or four point contact methods of sample testing, the edge effect caused by cutting and grinding can greatly influence on the value of mechanical strength. To avoid this, the work [5] offered the axially symmetric method of plate bending, which is widely used by various researches. In the given work, the experimental results of mechanical bending and deformation rate of silicon wafers were determined by a semi-automatic apparatus designed and made on the base bending methods of hard plates, having symmetrical axis [6]. This method was chosen because it, first, allows to directly test the wafers which are used in the semiconductor devices and large scale integrated circuits production, second, allows to exclude the influence of edge effects on the value of mechanical strength. The experiments were conducted at the room temperature.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

The experimental results of dependency of mechanical bending *(W)* and rate of deformation *V* on the applied force *(F)* after various technological operations are presented in fig. 1-4. The figures 1-4 show that for all investigated samples, three characteristic sections with various slopes can be observed irrespective of types of operations, orientation and thickness' of the wafers (dependence *W=f(F)* for other processes given in the table are observed wears analogous character):

1) the first section (1) – a linear proportionality exists between applied force and bending value. As it is apparent from the figures, the linear dependency for different samples is maintained in the interval of the plate thickness from 0.30 to 0.50(μm).

2) the second section (2) - the increase in bending of plates has a monotonic character with increasing of the applied force. 3) the third section (3) - by increasing the applied force, the bending value increases up to destruction. 4) the slopes angles in these section(1,2,3) differ from each other. For example, after grinding process; the value of slopes are: 1) $arctg\alpha_1 = 25$, 2) $arctg\alpha_2 = 11$ and 3) $arctg\alpha_3 = 26.5$ (see fig.1). The comparison of these values indicates that the least slope is observed in the section of monotonic dependency *W= f (F (N)* (section 2). 5) by increasing the applied force *(F)*, the rate of deformation *(V)* rises, reaches a maximum, and then starts to decrease not monotonically, but spasmodically by further increase of the force *F*. 6) At various technological operations, the value of *V* varied in the interval ($1.5{*}10^{-4}$-$2.2{*}10^{-4}$)m/sec.(see fig.1-4).

Table 1

Process	Orientation	Thickness(μm)
After grinding	100	475
After P diff. .	111	480
After B diff.	111	470
After epitax.	100	475
After oxidation	111	500
.After Al contact	111	505

Theoretical dependence of bending value on applied external force calculated by the formula (1) is also presented on the figures:

$$W=3P(1-\nu^2)r^2/(2\pi Eh^3)*\{a^2/r^2[1+(1-\nu)(a^2- - r^2)/(2(1+\nu)b^2)]-(1+Ln(a/r))\} \qquad (1)$$

where *a* -is the radius of fulcrum, *b*- is the radius of around wafer which is related to the sides of an square wafer with the relation $b=b'(1+2^{0.5})/2, r, P, h, \nu$, and *E* are the radius of puanson, the applied load, the thickness of the wafer, Poisson coefficient and Young modulus, respectively. The comparisons of theoretical and experimental values of bending presented in figures (1-4) show that in sections (1) they agree quite well with each other. However, in the second and third sections, strong deviations are observed. From the plots, it is seen that the experimental dependencies *W=f(F(N))* are well-approximated polynomials of 5-th order of form $W=B_0+B_1F+B_2F^2+B_3F^3+B_4F^4+B_5F^5$, where, B_0, B_1, B_2, B_3, B_4 and B_5 are constants and *F* is the applied load. There deviations can be due to the existence of dislocations which are created in the wafers during their bending process which have not been taken into account in the theory. The similar regions are found at squeezing of Si and Ge single crystals and also at tension of various polycrystalline materials [7-9]. In the work by [7], the obtained results are explained by the concept of heterogeneous dislocations created at squeezing of the samples.

It is shown in the work [4] that between the rate of deformation and density of dislocations created during deformation process, these exists the following dependency: $V \cong \sigma Vm\ (Q/E)$ (2) where, σ - internal stress of the wafers ,*Vm* is the velocity of testing machine and $Q \cong \sigma\ L\ b\ \rho_1$ (3) is heat scattering energy of mobile dislocations in unite volume, *L* is the average distance between dislocations, *b* is the Buguer's vector and ρ_1 is the density of mobile dislocations, *E* the energy of fixed dislocations in unit volume is given by $E \cong Gb^2\rho_2$ (4). Where, *G* is the shear modulus, ρ_2 is the density of fixed dislocations.

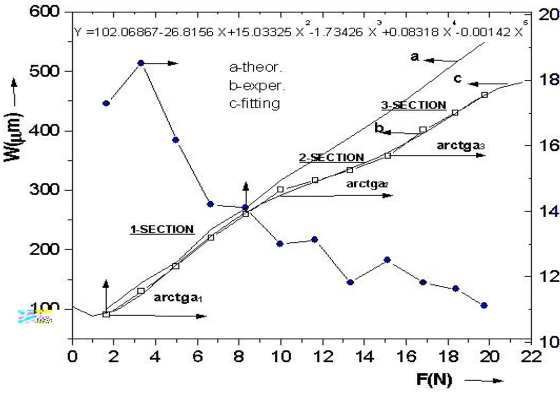

Fig.1. Dependence of the wafer bending and deformation rate on the applied laod after grinding process

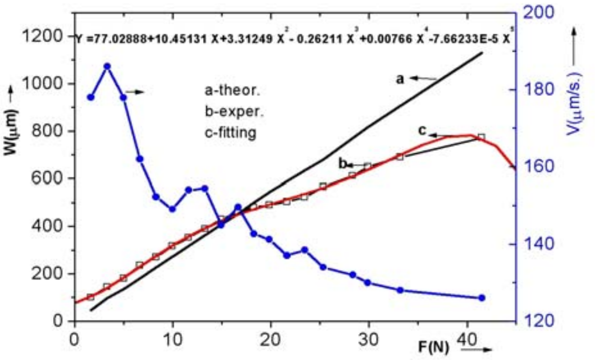

Fig.2. Dependence of the wafer bending and deformation rate on the applied laod after oxidation process.

The following is an explanation of the experimental data mentioned above from the standpoint of buildup and motion of dislocations under influence of the applied force F. In the first section (1), under the external force F, the wafer bends and deforms, resulting in the creation of dislocations. They move on various slip planes and then are unorderly situated on them. Increasing the value of *F* further, results in an increase in both concentration and density of mobile dislocations on these planes. Therefore, according to the formula (3), the increase in density of the mobile dislocation will give rise to the increase in *Q* energy scattering into heat, and as a result, the wafer will heat up. Heating the wafer, in turn, will promote a rise of new dislocations and an increase of their density. In this case according to the formula (2) the wafer's deformation rate will also increase. The given idea is confirmed by experimental results of dependencies of deformation raate on the value of the applied force (see fig. 1-4). Due to the easy and reversible motion of dislocation at large distances, the observed resilient deformation of wafers takes place in order words, the linear proportionality W= f *(F)* is consistent in section (1). In section (2) with a further increase of the applied force, the number of dislocations and simultaneously, their motions rate will increase in different crystallographic directions. For this reason, in certain crystallographic directions, an accumulation of dislocations occurs. Stored dislocations elastically interact between themselves, creating obstacles for the motion of other dislocations. The further movement of dislocations is impeded and as a result, the density of fixed dislocations is enlarged. Thus, the obstacle experience major pressure and the wafer is plastically deformed. Apparently, the availability of a plastic deformation is the reason for observed monotonic enlargement of the wafer's bending (see fig.1-4). It should be underlined, that in accordance with the formula (4), with the increase of fixed dislocations density, their energy *E* also increases, and according to the formula (2), the rate of wafer's deformation should also decrease. This statement is confirmed by the experimental results shown in fig.(4). As it is seen from the figures, despite increasing the value of F, both the slope of the second section and the wafer deformation decrease. Thus, the decrease in the rate of deformation is not monotonous but it is in spurts. The saltatory change in deformation rate is apparently, connected with the fact that part of dislocations stored at hindrances, under certain conditions are able to overcome their barrier and move further. As a result, the saltatory motion of dislocations takes place resulting in the saltatory change of the wafer's deformation rate. It should be noted that, the hindrance to the motion of dislocations and saltatory change in deformation rate might be caused by the availability of impurities and other defects in the wafer and thereby inhibit the motion of dislocations and promote formation of dislocation avalanches. In the third region, by increasing the external force further, the number of dislocation is increased and the process of dislocation accumulation is continued. At the same time, part of dislocations having opposite sign may annihilate which causes a partial relaxation of the internal stresses. Besides a part of dislocations may move from one slip plane to the other one, and then, the number of dislocations on the latter maybe increased, resulting in the hardening of the wafer and increase of its bending and consequently in the decrease of deformation rate. The increase of accumulation of the dislocations in certain crystallographic direction and their interaction through the neighboring slip planes may cause stresses in separate directions. At values of stress larger than the wafer's breaking point, some cracks may be formed in it. However, the process of a crystal fracture will depend on the kinetics of the cracks growth.

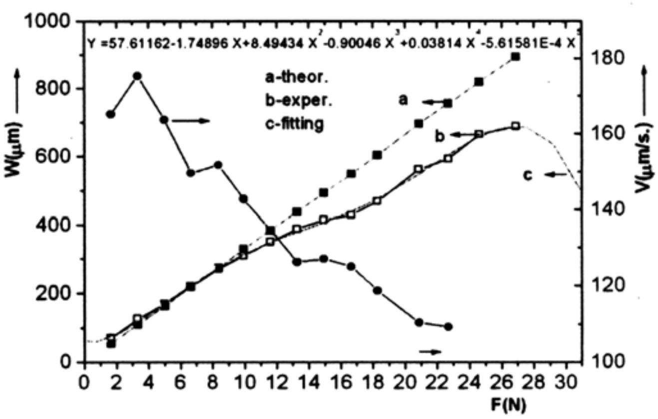

Fig.3. Dependence of the wafer bending and deformation rate on the applied load after epitaxy process

From the analysis of experimental results are revealed the following peculiarities of mechanical bending and rates of deformation of silicon wafers after diverse manufacturing operations:

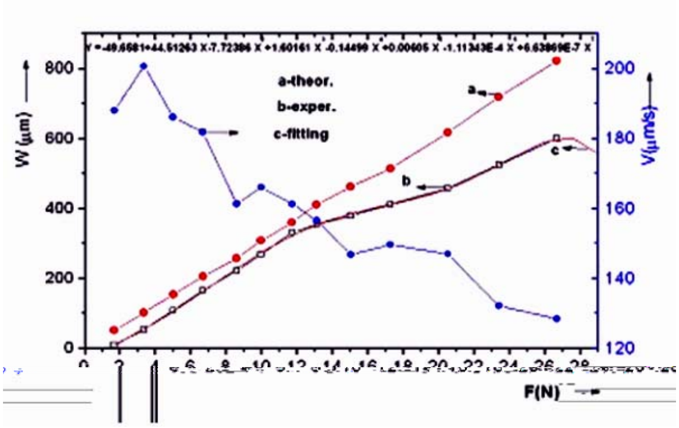

Fig.4. Dependence of the wafer bending and deformation rate on the applied load after phosphor(P) diffusion process.

1) Irrespective of the type of operation, orientation and tickness of wafers on curves *W=f(F)* are observed. three characteristic section with various slopes, a) the section (1)-a linear proportionality exists between *W* and *F*. б) the section(2) of monotonic dependence *W=f(F)*, c) the third section (3) by increasing the applied force, the bending value increases up to destruction.

By increasing the applied force *F*, the rate of deformation rises, reaches a maximum, and then starts to decrease not monotonically, but spasmodically by further increase of the force *F*.

Experimental results are discussed on the base of the creation of dislocations and their corresponding plastic deformation.

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Ş.M. Həsənli, N.N. Mursakulov

SİLİSİUM LÖVHƏSİNİN MEXANİKİ ƏYİLMƏSİ PROSESİNDƏ DİSLOKASİYALARIN İŞTİRAKI

Bu məqalədə xarici qüvvələrin təsiri altında silisium lövhəsinin mexaniki əyilmə və əyilmənin deformasiya sürətinin xüsusiyyətləri tədqiq edilmişdir. Göstərilmişdir ki, bütün tədqiq edilən nümunələr üçün texnoloji proseslərin növündən, kristalloqrafik orientasiyasından və lövhələrin qalınlığından asılı olmayaraq müxtəlif meyilli üç xarakterik oblast müşahidə edilir. Tətbiq edilmiş qüvvənin (F) qiyməti artdıqca deformasiya sürəti artır, maksimuma çatır və qüvvənin sonrakı artmasına müvafiq olaraq sıçrayışla azalır.

Eksperimental nəticələr əyilmə deformasiyası zamanı dislokasiyaların yaranması ilə izah edilir. Bundan başqa dislokasiyaların sıxlığı ilə deformasiya sürətinin sıçrayışla azalması arasında yaxşı korrelyasiya olmasını göstərmişdir. Alınmış nəticələrin analizi plastik deformasiyanın otaq temperaturunda mümkünlüyünü və deformasiya prosesi zamanı onun lokallaşmaya meylli olmasını təsdiq edir. Bu mülahizələrə onu əlavə etmək lazımdır ki, deformasiya sürətinin sıçrayışla azalmasına deformasiyaya uğrayan mühitin öz-özünü tənzimləməsi kimi baxmaq olar.

Ш. М. Гасанли, Н.Н.Мурсакулов

РОЛЬ ДИСЛОКАЦИЙ В ПРОЦЕССАХ МЕХАНИЧЕСКОГО ИЗГИБА КРЕМНИЕВЫХ ПЛАСТИН

В этой работе изучались особенности механического изгиба и скорости деформации кремниевых пластин под действием приложенных внешних сил. Показано, что для всех исследованных образцов, независимо от вида технологических операций, кристаллографической ориентации и толщины пластин наблюдаются три характерных областей. При увеличении приложенной силы (F), скорость деформации растет, достигает максимума, и затем начинает уменьшаться не монотонно, а скачкообразно с дальнейшим увеличением приложенной силы F. Экспериментальные результаты объясняются на основе зарождения дислокаций в процессе изгиба. Кроме того, показано, что, имеется хорошая корреляция между плотностью дислокаций и скачкообразным уменьшением скорости деформации. Анализ полученных результатов подтверждают возможность при комнатной температуре пластической деформации, и стремление ее к локализации в течение процесса деформации, а также скачкообразное уменьшение скорости деформации, может рассматриваться как самоорганизация деформируемой среды.

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