PHYSICAL AND TECHNOLOGICAL PRINCIPLES FOR OBTAINING A NANOMETRIC RELIEF OF THE SURFACE AT THE PROCESSING OF HARD BRITTLE MATERIALS

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ABSTRACT. Hard brittle materials, including the minerals diamond and leikosapphire are used in microelectronics for printed microcircuit substrates. The quasi-plastic grinding allows a surface of high quality with roughness 1 - 10 nm to be modeled without polishing. The acoustics oscillations generated of the blank at the processing could be used to control of the processing process and quality of the processed surface of the materials used in electronics.

ФИЗИЧЕСКИ И ТЕХНОЛОГИЧНИ ПРИНЦИПИ ЗА ПОЛУЧАВАНЕ НА НАНОМЕТРИЧЕН РЕЛЕФ НА ПОВЪРХНОСТТА ПРИ ОБРАБОТКАТА НА ТВЪРДИ КРЕХКИ МАТЕРИАЛИ

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РЕЗЮМЕ. Твърди крехки материали, включително диаманти и лейкосапфири се използват в микроелектрониката за производство на платки. Квазипластичното шлифоване позволява моделирането на повърхности от високо качество с грапавост 1-10nm, без полиране. Акустичните колебания, генерирани от загатовката при обработка, могат да бъдат използвани за контрол на процеса и качеството на обработената повърхност на материалите за електронната техника.

A traditional method for processing of hard brittle materials is mechanical grinding with free or connected abrasives. The roughness of the obtained surface after such a processing is about 200 nm and the subsurface layer is broken. In order lower roughness to be obtained (0,2 – 10 nm depending of the area of application of the microcircuit bases), the blank is usually polished in attacking medium, which is labor-consuming and unproductive.

An alternative and perspective method of the mechanical processing of hard crystal materials is the grinding in regime of quasi-plasticity (Теплова Т. Б., 2005). The quasi-plasticity has to be understood as revealing the plastic properties of the surface layer of the hard brittle materials at certain conditions of processing. The technology is based on the mechanical action on the surface subjected to processing at the tool feed of a part of the micron. A decrease in the brittle destruction has been observed at a decrease in the mechanical action intensity, in the surface layer (SL) of the hard materials.

Processing in a regime of quasi-plasticity can be obtained at provision of rigidity of the construction of the elastic processing system (EPS) and a relative isolation against external disturbances. As a result, the blanks from brittle materials could be mechanically processed in an adjustable regime to obtaining of processed surfaces with nanometric relief.

T. G. Bifano and T. A. Dow have made researches in the processing in the regime of quasi-plasticity on equipment PEGASUS (Bifano. T.G., Blake. P., Dow, T.A., and Scattergood, R.O., June.1988).

As a result of the researches carried on a big quantity of amorphous glasses, monocrystals and modern ceramic materials by the authors has been formulated a hypothesis for the processing in regime of quasi-plasticity, which main point consists in the fact that if the feed is enough small, all the materials, regardless of their hardness and brittleness during the mechanical surface processing go through a transition of brittle to quasi-plastic destruction regime.

In order the task to be solved, the CNC machine module АН12f4 (Коньшин А.С., Сильченко О.Б., Сноу Б.Д., 27.04.2001 г) has been developed. It is with a sufficient rigidity at the cutting-in feeds providing grinding of the hard brittle materials in a regime of quasi-plasticity. The main technological parameters of the machine module are presented in Table 1. The machine module realizes a dynamic pulse action of the grains of the rotating tool on the surface of the crystal, subjected to processing, which is a result of the composition of two vectors: the vector of the compressive stress, determined by the potential compression energy and the vector of the tangential stress, determined by the kinetic energy.

The main point in the process of quasi-plastic destruction of the processing material surface layer could be explained by the physical mesomechanis developed by the academician V. E. Panin (Панин В.Е., 1998) of Russian Academy of Sciences. It relates the dislocations on a micro-scale level to the integral mechanical characteristics of the processes occurring on macro-scale level, taking into consideration the composition of the material, its texture and loading conditions. In the papers in mesomechanics it has been grounded that during the process of quasi-plastic destruction, on mesolevel the loaded material forms structures able to realize quasi-plastic deformation "slip-turning". A model of dimensions-adjustable and non-defect processing of hard texture materials by cutting is suggested on the basis of the theories of academician V. E. Panin and the papers by O. B. Silchenko (Коньшин А.С., Сильченко О.Б., Сноу Б.Д., 27.04.2001 г). The main point in the model is as follows. The deformed rigid body is a multilevel, self organizing system, in which the micro-, meso- and macro- levels are mutually related. At external action of a rhythmic field in the elastic processing system on micro-level occurs action of the cutting tool grain on a point of the processed surface. On mesolevel occurs swinging of the mesovolume steadily disturbing it slipping stability. The out-breaking of the surface section occurs on macro-level.

Table 1.

No	PARAMETER	QUANTITY
1	Number of the controllable axes	6
2	Number of the positions for mounting of the cutting tool and control and measuring means (revolving head)	3
3	Number of spindles	3
4	Digital set and realization of movement • Axes X, Y, μm; • Axis Z, μm; • Axes A, B, grad	0.05 0.05 0.0001
5	Maximal value of movement • Linear axis X, mm; • Linear axis Y, mm; • Linear axis Z, mm; • Circular axis A, grad; • Circular axis B, grad;	1000 300 10 90 unlimited
6	Range of working feed, mm/min	0.06 ÷4500
7	Range of the spindle rotating frequency, rpm	3000 ÷ 6000
8	Number of the places in the changeable cassete	15
9	Number of the simultaneously processed products	5
10	Roughness of the processed surface Rz, μm	0.032 ÷ 0.05
11	Diameter of the diamond tool, mm	250
12	Total power, kW	7

A regime of quasi-plastic surface processing of brittle materials could be provided by a special choice of such parameters as pressure force and speed of the tool movement in parallel to the surface of the crystal, subjected to mechanical action. At certain values of the contact stresses, in the surface layer appears a state of strain different of the energy needed for a brittle destruction. The regime of quasi-plastic destruction has to be in the range of energies exceeding the elastic energy corresponding to the limit of Payerls and to be less than the energy value corresponding to the stresses of brittle destruction. At the surface processing prevailing becomes not the brittle, but the quasi-plastic flow.

During the process of the surface grinding, the processing material heats and the thermal expansion value could become commensurable to the value of the tool feed, which can cause brittle destruction of the processing blank. Apart from that, thermal-elastic stresses appear in the material, which are conducive to the defects distribution and to the possible material destruction. If the temperature distribution into the sample and dependence of the thermal expansion of the material of the processing blank on the temperature alteration are known, the integral thermal expansion of the sample could be determined, compared with the deformation of the elastic processing system and the pressing force could be adjusted so that the out-break with two free surfaces of the sample surface subjected to processing to be averted. This way, at consideration of the heat processes accompanying the processing in regime of quasi-plasticity is possible to be formulated thermal criteria dependencies determining the conditions under which the processing process will not turn from quasi-plastic cutting into a brittle destruction. In particular, the criterion of brittle thermal destruction characterizes the material resistance to brittle thermal failure. The stresses emerging during the material processing under the action of the normal component of the cutting force should not exceed the limit of the slip strength of the material, which mathematically could be expressed as follows:

$$\sigma_{process} = \frac{E \cdot \beta_0}{2 \cdot (1-\mu)} \cdot \left[\Delta T + \frac{k \cdot \Delta T^2}{2} \right] < \tau_s \qquad (1)$$

where $\sigma_{process}$ – stresses appearing during the process of the material processing as a result of the action of the normal and tangential component of the cutting force of the processing tool; τ_s - limit of the slip strength; μ - Poisson's ratio; E - Yung's modulus, Pa; $\Delta T = T - T_0$; T - temperature of the sample, ^oK; T_0 - medium temperature, ^oK; β_0 - coefficient of linear thermal expansion at 20^oC. Here the dependence of the coefficient of linear thermal expansion on the temperature is taken into consideration. On first approximation $\beta = \beta_0(1 + k\Delta T)$, where k is the factor of proportionality, reflecting the alteration of the thermal-expansion coefficient of the material caused by the temperature.

At the surface processing of a material is necessary the operational regime to be chosen in such a way as the temperature in the processing area not to exceed the calculated value of the limit temperature. There are dependencies determining the allowable ranges of temperature alterations at processing in quasi-plasticity regime of different materials. It is possible processed surfaces with nano-metric roughness without macroscopic defects to be obtained if rational regimes of surface processing at quasi-plasticity regime are chosen.

Photos of processed surfaces of diamond and leikosapphire are presented in fig. 1. There could be seen the quality of the processed surface of a diamond sample (fig. 1a, R_z = 8nm) and leikosapphire (fig. 1b, R_z = 2nm on separate surface areas) and R_z = 20nm (fig. 1c). Fig. 1d and fig.1e show a grinded surface of a natural diamond with diamond inclusions in counter.

In order the processing in regime of quasi-plasticity to be realized, after obtaining a full contact of the blank and the grinding tool, the contact stresses have to be kept constant in the limits $(0.1 \div 10)10^5$, Pa depending on the properties of material (elasticity coefficient, Poisson's ratio, coefficient of thermal conductivity), conditions of heat abstraction, type of the machine and rigidity of the system “tool-blank”.

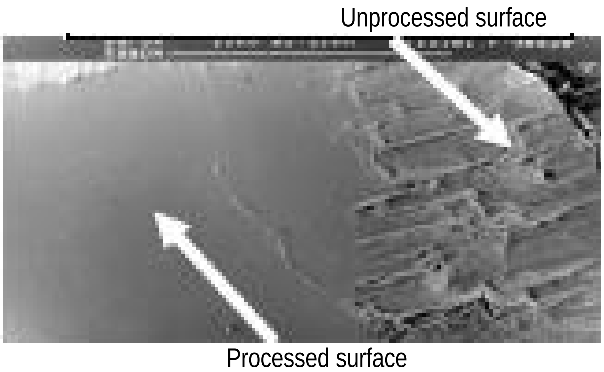

Fig. 1a

Fig. 1b

Fig. 1c

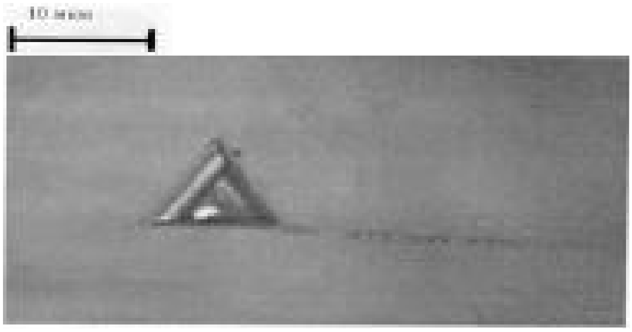

Fig. 1d

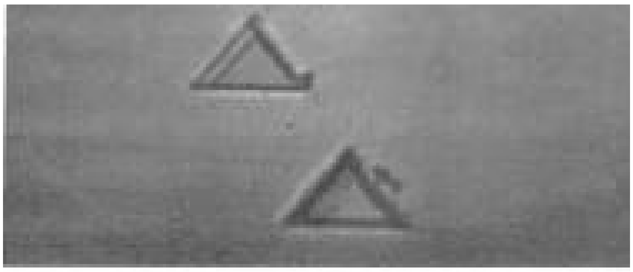

Fig. 1e

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