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Polishing substrates of single crystal silicon carbide and sapphire for optoelectronics

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As a result of research of polishing single crystal materials it is shown that the material removal rate of the processed material depends on the volumetric wear coefficient and friction path length of element of the processed surface on the surface of lapping. It is found that the polishing flat surfaces of the optoelectronic elements of single crystal silicon carbide is advantageously carried out by using polishing slurry of the powders based on MAX-phase Ti_3AlC_2 and colloidal nanoparticulate systems, and single crystal sapphire — using suspensions of diamond micron powders of cubic boron nitride powders and MAX-phase Ti_3AlC_2. Nano-polishing surfaces of elements of the single crystal sapphire should be performed using the colloidal nanoparticulate systems. It is also shown that the polishing efficiency of the single crystal silicon carbide and sapphire is inversely proportional to the transfer energy, the maximum value of which corresponds to a the minimum roughness.

Keywords: optoelectronic elements, polishing flat surfaces, silicon carbide, sapphire

Исследование полирования монокристаллических материалов показало, что производительность съема обрабатываемого материала зависит от коэффициента объемного износа и длины пути трения элемента обрабатываемой поверхности по поверхности полировальника. Установлено, что полирование плоских поверхностей оптоэлектронных элементов из монокристаллов карбида кремния целесообразно осуществлять с использованием полировальной суспензии порошков на основе MAX-фазы Ti_3AlC_2 и коллоидных систем наночастиц, монокристаллов сапфира — с помощью суспензии из алмазных микропорошков, порошков кубического нитрида бора и MAX-фазы Ti_3AlC_2. Нанополирование поверхностей элементов монокристаллического сапфира должно осуществляться с использованием коллоидной системы наночастиц. Показано, что производительность полирования монокристаллов карбида кремния и сапфира обратно пропорциональна энергии переноса, максимальное значение которой соответствует минимальной шероховатости.

Полірування підкладок монокристалічного карбіду кремнію та сапфіру для оптоелектроніки. *О.Ю.Філатов, В.І.Сідорко, С.В.Ковальов, Ю.Д.Філатов, А.Г.Вєтров.*

В результаті дослідження полірування монокристалічних матеріалів показано, що продуктивність зняття матеріалу, що обробляється залежить від коефіцієнта об'ємного зносу та довжини шляху тертя елемента оброблюваної поверхні вздовж поверхні полірувальника. Встановлено, що полірування плоских поверхонь оптоелектронних елементів з монокристалів карбіду кремнію доцільно здійснювати з використанням полірувальної суспензії порошків на основі MAX-фази Ti_3AlC_2 та колоїдних систем наночастинок, монокристалів сапфіру — за допомогою суспензії з алмазних мікропорошків, порошків кубічного нітриду бору та MAX-фази Ti_3AlC_2. Нанополірування поверхонь елементів монокристалів сапфіру слід здійснювати при використанні колоїдної системи наночастинок. Показано, що продуктивність полірування монокристалів карбіду кремнію та сапфіру обернено пропорційна енергії переносу, максимальне значення якої відповідає мінімальній шорсткості.

1. Introduction

In present-day manufacture of optical and optoelectronic components made of sapphire, single crystal silicon carbide, nitrides of aluminium and gallium the diamond abrasive machining techniques are used. Fine and ultrafine diamond grinding operations for these workpiece are performed using functionally orientated diamond tools of dedicated specifications and working layer design. The final machining operation-polishing is carried out in a single or several stages depending on requirements for the machined surface. The polishing of optical components shall meet the requirements for form accuracy $N = 3–5$ interference rings and for quality of processed surfaces ($S–d$) 60–40 to 20–10 (U.S Military Surface Quality Specification, MIL-PRF-13830B).

The substrate surfaces, prepared under application of the epitaxial layer (epi-ready) must satisfy the requirements for accuracy of the crystal plane orientation (±0.2–0.5°), for dislocation density ($(1–4) \cdot 10^3$ cm^{-2}), for density of micropipes (less than 30 cm^{-2}), for structural perfection (FWHM — half-width of the rocking line — 30–50 arc. sec), and "optical" requirements for flatness (less than 10 μ to 3 inches diameter) and the surface roughness ($Ra = 0.3–1.0$ nm).

The roughness of finished surface is the most important indicator of the precision surface polishing process of the optoelectronic elements made from non-metallic materials (glass, quartz, sapphire, silicon carbide, AlN, GaN, GaAs and others) [1–9] and it characterizes the quality of treated surfaces. An improvement in the machining quality for precision surfaces of optoelectronic components made of single crystal materials can be achieved only through use of the novel types of tools and polishing suspensions and nanoparticle colloidal systems. Optimization of the characteristics of such systems is a task of the great importance.

Efficiency of the diamond abrasive machining of precision surfaces of the optical and optoelectronic components is conventionally determined by using the model of workpiece material removal in the polishing, which is based on the cluster model of wear of solid surfaces in friction [1,2], and the statistical model of slime particles formation and removal from the workpiece surface [10].

Size of these particles, their concentration in the tool-workpiece contact zone and pattern of their interaction with the tool wear particles and the surfaces in contact have influence on the polishing efficiency and tool wear rate in all machining operations as well as on the condition of the workpiece surfaces.

The objective of the present study is to clarify influence of the processed material and polishing slurry or colloidal system on performance of the polishing process and on the finished surfaces roughness.

2. Methodology and results

Based on the cluster model of wear [1,2, 11], the process of material removal while polishing can be considered as accumulation of energy within critical volume — cluster, i.e. as transitions of the cluster in a discrete equidistant energy spectrum. Taking into account the multiple-frequency mode of interaction between the workpiece and tool surfaces, where natural vibrations of fragments occur at frequencies ω_{01l} and ω_{02k} (l, k are the ordinal numbers of the frequencies), we can find the number of excited fragments $\xi_{ik} = \dfrac{\omega_{01l}^4}{(\omega_{01l}^2 - \omega_{02k}^2)^2}$, the characteristic frequencies $\omega_{lk} = \dfrac{3\omega_{01l}\omega_{02k}}{2(\omega_{01l} + \omega_{02k})}$, the number of molecular fragments per cluster $\xi = \left[\sum_{ik} \xi ik\right]$, and the cluster energy $E_{cl} = \sum_{ik} \left[\omega_{01l} \hbar \xi_{ik}\right]$ (where $\hbar = 1.054 \cdot 10^{-34}$ J·s is the Planck constant). Material removal from the workpiece surface occurs in the form of slime particles only when the cluster energy E_{cl} exceeds the bond energy E_b. The slime particle size distribution is described by the Poisson distribution $P(i,\nu) = \dfrac{e^{-\nu}\nu^i}{i}$ with a parameter $\nu = E_b/E_{cl}$ [11]. Dielectric constants of the workpiece material (ε_l) and tool material (ε_k) are determined at characteristic frequencies ω_{lk}, while the Lifshitz constant $A_L = \hbar\omega_{123}$ is calculated by formula

$$\omega_{123} = \int_{\omega_1}^{\omega_2} \frac{[\varepsilon_1(\omega_{lk}) - \varepsilon_3][\varepsilon_2(\omega_{lk}) - \varepsilon_3]}{[\varepsilon_1(\omega_{lk}) + \varepsilon_3][\varepsilon_2(\omega_{lk}) + \varepsilon_3]}\, d\Omega,$$

(Ω *in* $[\omega_1;\omega_2]$, ω_1 and ω_2 are the minimum and maximum frequencies).

The surface area of i-th slime particle is defined as $S_i = S_0(i + 1)$ ($i = \overline{1,N}$, N —

number of samples, S_0 — surface area of the cluster, which depends on the structure of the material being processed and the number of molecular fragments ξ).

The surface area of the cluster depends on crystallographic plane orientation of the single crystal (lattice constants a and c), which is polished. Considering the crystals of hexagonal structure, we can determine how the clusters are formed from separate molecular fragments, which, coming off the processed surface are converted into slime particles.

When polishing the plane C [0001] the number of molecular fragments is defined by corresponding distances $1.5a$; $a\sqrt{3}$ and $c/6$, the number of molecular fragments $\xi = k_1k_2k_3$, and minimum surface area of the particles $S_0 = 3\sqrt{3}a^2k_1k_2 + (1/2)ack_1k_3 + (2/\sqrt{3})ack_2k_3$. When polishing the plane A [11$\bar{2}$0] the number of molecular fragments is defined by interplanar spacing $a\sqrt{3}$, $a/2$ and $c/6$, minimum surface area of the particles — $S_0 = \sqrt{3}a^2k_1k_2 + (1/\sqrt{3})ack_1k_3 + (1/6)ack_2k_3$.

The flat surfaces of silicon carbide elements (plane C) and sapphire (plane A) were polished on the grinding and polishing machine with polisher speed of 90 rev/min, pressure of pressing items to lapping — 0.003–0.005 MPa, displacement stroke of 30 mm, 50 mm stroke length and an average temperature in the contact zone — 300 K.

Single crystal silicon carbide (polytype 6H–SiC, a density of 3.21 g/cm^3, with thermal conductivity of 490 W/(m·K), the static dielectric constant — 6.5, the lattice constants $a = 0.3073$ nm and $c = 1.511$ nm [12]) was characterized by intrinsic frequency of the molecular fragments SiC: $\omega_{01} = 15.0 \cdot 10^{13}$ s^{-1} (794 cm^{-1}) and $18.9 \cdot 10^{13}$ s^{-1} (1000 cm^{-1}) [11, 13].

Single crystal sapphire (density 3.98 g/cm^3, thermal conductivity of 30.3 W/(m·K), the static dielectric constant — 9.3, the lattice constants of $a = 0.4758$ nm, $c = 1.2991$ nm) was characterized by intrinsic frequency of the molecular fragments Al_2O_3: $\omega_{01} = 10.8 \cdot 10^{13}$ s^{-1} (573 cm^{-1}), $12.1 \cdot 10^{13}$ s^{-1} (642 cm^{-1}) and $14.1 \cdot 10^{13}$ s^{-1} (748 cm^{-1}) [14–16].

The polishing of silicon carbide and sapphire was studied using specially prepared suspensions of diamond micropowder SDM 2/1 (1), cubic boron nitride powders KM 0,5/0 (2) and MAX-phase powders Ti_3AlC_2 0,5/0 (3) [11, 13, 17–18]. Also colloidal system (CS) of nanoparticles from proposed chemical compounds (4) and conventional colloidal silica (5) [19–24] based on distilled water without addition of acids, alkalis and surfactants were used. Intrinsic frequency (ω_{02}, cm^{-1}) of the molecular fragments of diamond polishing powders are 1135 and 1332, of cubic boron nitride — 1056, 1100 and 1304 and of MAX-phase powders Ti_3AlC_2 — 260, 420, 605, 1320 and 1590 [17]. The static dielectric constant of the diamond polishing powders is 5.7, of cBN — 2.5 and of Ti_3AlC_2 — 3.5 [13].

3. Results and discussion

Removal performance Q of the processed material when polishing the single crystal silicon carbide and sapphire was determined as the product of volumetric wear ratio η and friction path length L_f of the processed surface element on the surface of the lapping: $Q = \eta L_f$. It was dependent on size of d_i slime particles and their concentrations on the surface pressure rating pressing parts for lapping, their rate of relative displacement of the contact area, coefficient of thermal conductivity of the processed material and temperature in the contact zone [11].

Results of the calculations parameters of the generalized model of formation and removal of slime particles and removal of the processed material, as well as experimental data on the removal performance of silicon carbide and sapphire which were determined gravimetrically in mg/min (μm/h) are shown in Table 1.

The data analysis results in Table 1 show that the single crystal material polishing performance depends on the transfer energy which characterizes the energy costs of disposing mass unit of the processed material from the processed surface [10, 11, 13]. Dependences of the processed material removal rate Q (m^3/s) on the transfer energy W (J/kg) for polishing the silicon carbide (1) and sapphire (2) with different polishing compositions are shown in Fig. 1.

In logarithmic coordinates these dependences are depicted in the form of parallel lines and are described by linear function $\ln Q = -k_{12}\ln W + b_{12}$ (where $k_1 = 0.97 \approx 1$, $b_1 = 0.04$; $k_2 = 0.98 \approx 1$, $b_2 = -1.81$ — the coefficients determined by the least squares method, the approximation error — less than 0.5 %). This means that productivity of polishing the single crystal silicon carbide and sapphire is inversely proportional

Table 1. Performance of polishing the single crystal silicon carbide and sapphire

The parameters of interaction with SiC polishing composition	Polishing composition			
	SDM (1)	cBN (2)	Colloidal systems (4)	Ti_3AlC_2 (3)
The most probable size of the slime particle a_v, nm	2.4	2.7	2.6	2.4
Transfer energy W, J/kg	$0.6 \cdot 10^{12}$	$1.6 \cdot 10^{12}$	$1.3 \cdot 10^{13}$	$2.7 \cdot 10^{13}$
Density of transfer energy σ, MJ/m^2	1.5	4.7	45.0	73.0
Performance of polishing Q				
calculation, m^3/s	$4.7 \cdot 10^{-12}$	$1.5 \cdot 10^{-12}$	$2.0 \cdot 10^{-13}$	$1.0 \cdot 10^{-13}$
experiment, m^3/s	$4.4 \cdot 10^{-12}$	$1.4 \cdot 10^{-12}$	$2.2 \cdot 10^{-13}$	$9.3 \cdot 10^{-14}$
μ/h	15.5	5.5	0.8	0.3
Calculation error, %	7	7	10	5
Parameters of interaction sapphire with polishing compositions	Polishing composition			
	Ti_3AlC_2 (3)	cBN (2)	SDM (1)	Colloidal systems (4)	Colloidal systems (5)
The most probable size of the slime particle a_v, nm	2.7	2.9	2.5	2.0	2.0
Transfer energy W, J/kg	$5.2 \cdot 10^{11}$	$5.8 \cdot 10^{11}$	$6.5 \cdot 10^{11}$	$2.9 \cdot 10^{12}$	$3.6 \cdot 10^{12}$
Density of transfer energy σ, MJ/m^2	2.0	2.4	2.4	7.4	9.2
Performance of polishing Q					
calculation, m^3/s	$6.0 \cdot 10^{-13}$	$5.4 \cdot 10^{-13}$	$4.8 \cdot 10^{-13}$	$1.1 \cdot 10^{-13}$	$0.9 \cdot 10^{-13}$
experiment, m^3/s	$5.6 \cdot 10^{-13}$	$5.6 \cdot 10^{-13}$	$4.5 \cdot 10^{-13}$	$1.3 \cdot 10^{-13}$	$0.8 \cdot 10^{-13}$
μ/h	1.4	1.4	1.0	0.3	0.2
Calculation error, %	7	4	7	17	12

to the transfer energy and can be described by approximate dependence $Q = \alpha_{12}/W$ ($\alpha_1 = \exp(b_1) = 1.04$ — for silicon carbide; and $\alpha_2 = \exp(b_2) = 0.16$ — for sapphire).

Performance of the polishing silicon carbide and sapphire depends on transfer energy density $\sigma = W\rho V_s/S_s$ (J/m^2), which indicates the costs of mechanical energy on removal the volume V_s of slime particles from the processed surface with the area S_s. In logarithmic coordinates this dependence is a the linear function $\ln Q = k_{34}\ln\sigma + b_{34}$ (where $k_3 = -0.9$, $b_3 = -12.8$ — for silicon carbide; $k_4 = -1.3$, $b_4 = -9.5$ — for sapphire — the coefficients determined by the least squares method). From this follows that the productivity of polishing the single crystal silicon carbide and sapphire inversely is proportional to the energy consumed on the removal of slime particles from the processed surface, and it is given by $Q = \beta_{12}/\sigma$ ($\beta_1 = 7.2 \cdot 10^{-6}$ W·m — for silicon carbide; $\beta_2 = 1.1 \cdot 10^{-6}$ W·m — for sapphire). The performance of processed material removal for polishing silicon carbide and sapphire with different polishing slurries (1–3) and colloidal systems (4, 5) is characterized by approximate ratio $Q_1/Q_2 = \alpha_1/\alpha_2 = \beta_1/\beta_2 \approx 6.5$.

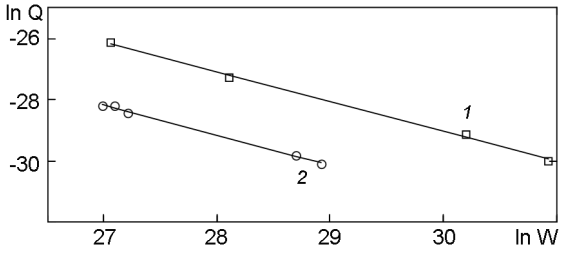

Fig. 1. Dependences of polishing performance of single crystal silicon carbide (*1*) and sapphire (*2*) on transfer energy: calculated (—) and experimental (□ — 1, ○ — 2) data.

Since the transfer energy W is dependent on the thermal conductivity coefficient of the processed material, it is generally used the generalized transfer energy $W_0 = [\lambda_{K8}/\lambda]W$, which characterizes the slime particles participation in the transfer of heat energy in the processing of silicon carbide or sapphire to the process of polishing

of the reference material — optical glass K8 with $\lambda_{K8} = 0.95$ W/(m·K) [11, 13]. It is shown that the polishing of the single crystal silicon carbide is advantageously carried out using slurry with MAX-phase powders Ti_3AlC_2 (3) and the colloidal nanoparticle system (4). Sapphire surface can be polished using slurry of the diamond micropowder (1), cubic boron nitride powders (2) and MAX-phase powders Ti_3AlC_2 and the nano-polishing or chemical-mechanical polishing of single crystal sapphire should be carried out by means of the colloidal nanoparticulate systems (4) or (5) as confirmed by many years of practical experience.

Comparison of the results calculation for performance of polishing plane surfaces of the single crystal silicon carbide and sapphire elements using suspension of the diamond micron powders, the cubic boron nitride powders and the MAX-phase Ti_3AlC_2, with the experimental data shows a good convergence (deviation between the calculated and experimental results reaches to 10 %, Table 1).

This confirms the legality of use of the generalized model of slime particles formation and removing and using the generalized transfer energy as a criterion for assessing the effectiveness of the polishing process.

Analysis of the slime particles formation and removal while finishing of non-metallic materials as a part of physical-statistical model [10] showed that size of the particles produced in the process of polishing, satisfy the inequality $d_i < R_{max}$.

On this basis, it can be assumed that removal of the processed material during polishing of non-metallic materials is the result of dispersion processes of the nanoparticles.

The sizes of these particles, their concentration in the contact zone and the type of interaction with wear particles of polishing powders, contacting surfaces of lapping and details determine the most probable size of the slime particles [2, 13] as well as the pattern of forming the finishing surface and plaque formation on the processed surface.

Based on the results of study of the mechanism of surface roughness formation on the processed surfaces [13] a method of computer modelling of the microprofile was developed, which provides a good convergence of the results of calculation of the height of nano-roughness with the experimental data. The nano-roughness height of polished surface is proportional to the surface density of the slime particles (square of the modulus of the cluster state $|\psi|^2$, m^{-1}) in accordance with formula $z(x) = k|\psi|^2$ [13], and the coefficient of proportionality is defined as $(d_i/2)^2$. To calculate the surface roughness of the polished surface when the line of protrusions and depressions practically coincide with the centre line of the profilograms, the proportionality coefficient in the formula for calculating nano-profile $z(x)$ is defined as d_i^2.

The function that determines the height of the nano-surface irregularities in the process of polishing, along the baseline is given by

$$z(x) = d(k_0)\Phi_{k_0}^2\left(\frac{z}{d(k_0)}\right) + \sum_{i}^{G-1} C_{k_i}^2 d(k_i)\Phi_{k_i}\left(\frac{z - y_i}{d(k_i)}\right), \quad (1)$$

where C_{ki} — constants; y_i — displacement of the state functions of slime particles; $k_i = \overline{1,M}$ — indexes that define a random sequence of forming slime particles with d_i, M — the number of groups of slime particles; $\Phi_k(x) = [k!2^k\sqrt{\pi}]^{-1/2}e^{-x^2/2}$ $H_k(x)$ — parabolic cylinder functions, $H_k(x)$ — the Hermite polynomials.

To calculate nano-profile of the polished surface by formula (1) is necessary and sufficient to determine the sizes of the slime particles $d(k_i) = [S_0(k_i + 1)/\pi]^{1/2}$ and function of their size distribution (the Poisson distribution $P(i,\nu)$). The computer modelling method for the nano-surface profile elements of the single-crystal material during polishing based on the Monte Carlo method.

A sequence of numbers k_i is used as the input random variable, which is generated by a computer in accordance with the distribution $P(i,\nu)$. According to the formula (1) is determined by the height of the surface profile $Z(x)$ in area of $x \in [0, L]$, that was formed due to formation of the slime particles. According to the model profilograms obtained by computer simulation of the nano-profile polished surface, the roughness parameters determined: the arithmetic average roughness $Ra = \frac{1}{L}\int_0^L Z(x)dx$, the mean

Table 2. Parameters of the polished surface roughness of silicon carbide and sapphire

Roughness parameters of silicon carbide	Polishing composition			
	SDM (1)	cBN (2)	Ti_3AlC_2 (3)	Colloidal systems (4)
Ra, nm	5.4±0.1	5.6±0.2	5.1±0.2	4.6±0.1
Rq, nm	5.8±0.2	5.9±0.2	5.4±0.2	4.7±0.1
Rmax, nm	9.3±0.9	8.2±1.1	7.4±0.5	6.5±0.2
χ	1.7	1.5	1.5	1.4
k_a	2.3	2.1	2.1	1.7
k_q	2.4	2.2	2.2	1.8
k_m	3.9	3.0	3.1	2.5

Roughness parameters of sapphire	Polishing composition				
	SDM (1)	cBN (2)	Ti_3AlC_2 (3)	Colloidal systems (4)	Colloidal systems (5)
Ra, nm	6.3±0.3	6.5±0.2	6.4±0.2	2.8±0.2	2.7±0.1
Rq, nm	6.7±0.2	7.0±0.2	6.8±0.3	3.0±0.2	2.9±0.1
Rmax, nm	12.3±0.2	12.8+1.4	12.9±1.0	4.7±0.3	4.7±0.2
χ	1.9	2.0	2.0	1.6	1.7
k_a	2.5	2.3	2.3	1.4	1.4
k_q	2.7	2.4	2.5	1.5	1.4
k_m	4.9	4.4	4.7	2.3	2.3

square roughness $Rq = \sqrt{\frac{1}{L}\int_0^L [z(x)]^2 dx}$ and the maximum height of the profile *Rmax*. As a result of the computer simulation by averaging the height roughness by five model profilograms obtained values of *Ra*, *Rq*, *Rmax*, the ratio $\chi = Rmax/Ra$, and the relative roughness coefficients $k_a = Ra/a_v$, $k_q = Rq/a_v$ and $k_m = Rmax/a_v$, are normalized to the most probable size of slime particles (Table 2).

Analysis of these data shows that the roughness parameters *Ra*, *Rq*, *Rmax* decrease with increasing of the transfer energy (Fig. 2). The more energy is spent on the formation and removal from the processed surface of slime particles, there is smaller their size and height of nanoprofile of the polished surface. That is why the amount of transfer energy can be used as a criterion of the efficiency of polishing the single-crystal silicon carbide and sapphire. Table 2 shows the values of the coefficients of roughness k_a, k_q, k_m and χ, characterizing formation processes of the nanoprofile of processed surfaces elements of silicon carbide and sapphire while polishing with slurries (1)–(3) and colloidal systems (4)–(5).

In contrast to the processes of grinding the nonmetallic material $d_i > Rmax$, when the roughness coefficients k_a, k_q, $k_m < 1$ and $\chi > 1$, the polishing of single crystal silicon carbide and sapphire provides $d_i \le Rmax$ and these coefficients k_a, k_q, k_m, $\chi > 1$ are reduced while improving the quality of processing.

To compare the effectiveness of different polishes it is enough to find the minimum value of these coefficients. The minimum roughness coefficient values k_a, k_q, k_m, χ (Table 2) are characteristic for the surface roughness elements made of single crystal silicon carbide processed using a colloidal system (4), and sapphire, which polishing was performed using the colloidal systems (4)–(5). Comparing the values of these coefficients for the processes of grinding and polishing, we can conclude that the roughness coefficients k_m, k_q and k_a reduce by 1–2 orders of magnitude, which is indicative of the fundamental differences in the mechanisms of formation of micro- and nano-relief of the processed surfaces. Comparing the values of the roughness coefficients for the processing of silicon carbide

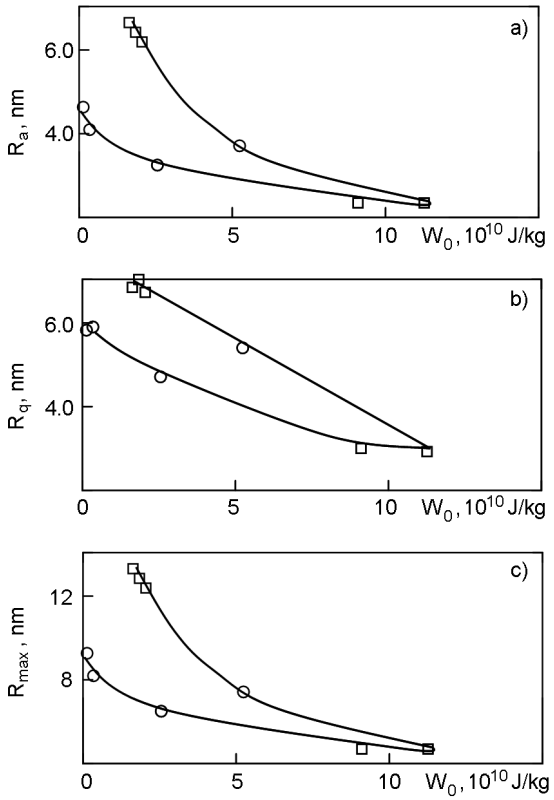

Fig. 2. Dependences of roughness of the polished surfaces *Ra*, *Rq* and *Rmax* on the generalized transfer energy (□ — silicon carbide, ○ — sapphire).

and sapphire using different polishing compositions, it can be argued that it is advisable to use the polishing powders, suspensions for polishing, and colloidal systems of nanoparticles for the nano-polishing.

4. Conclusions

As a result of theoretical and experimental studies of regularities of polishing surfaces of silicon carbide and sapphire it is found that the performance criteria appropriate to use are the processing transfer energy, which maximum value meets the minimum surface roughness, and roughness coefficients that determine the minimum permissible altitude parameters. It is also shown that for its polishing it is advisable to use a polishing slurry of diamond micron powders, powders of the cubic boron nitride and MAX-phase powders Ti_3AlC_2. And for nano-polishing it is effective to use the nano-powders of colloidal systems, including colloidal silica, which is commonly used worldwide in production of the optoelectronic components of single crystal materials. This confirms the possibility of using the generalized physical-statistical model of formation and removal of slime particles from the treated surface to the polishing processes of silicon carbide and sapphire.

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