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SUPPORT FOR SMALL CUTTING WIDTH OF WATERJET TREATING OF THE SIC-MICRARRAYS

In the work cutting of SiO-microarray to separate elements with high pressure jets of particulate abrasive has proved possible to use small-diameter jet for precise cuts of microchips as hard and brittle materials. Using a functional approach has reduced the width of the damage to the plating. The original way of using waterjet cutting slit masks is offered. The use of such masks significantly improves the quality and accuracy of the cut edges of the chip.

Keywords: *SiC-microarrays, hydro abrasive jetting, cutting quality.*

Introduction. Cutting microarrays mechanically with using finely dispersed tool containing diamonds is a technology that allows to perform straight cuts in compliance with a number of technical requirements for the quality of the surface layer, the absence of significant residual microstresses, any force-thermal damages. Sometimes, for plates cutting or small-width grooves performing a electrospark method is also using, which in the implementation of water environment satisfactory quality of edge with a relatively small output is gives.

Recently the spread began to take other methods of chips cutting, the most promising is considered a laser-jet method based on simultaneous action on a processed surface as heat and jet streams [1]. The combinations of these streams has such an impact on a processed surface, which due to strong heat sink gradient thermally high field on only a small area of the surface is localized, which provided fleeting fluid flow. This avoids problems with the cracking chips and with the changing of their physical and mechanical.

However, in some cases, the metalized pellicle inflicting on a plate surface is considerably limits the possibility of using laser-jet method. According to [2, 3] the presence of metalized pellicle can cause a redistribution of the temperature in the processing zone, which in turn will cause to its detachment from the surface. In addition, the SiC-plates cutting is also complicated by high strength and brittleness of the material resulting in a significant number of workpieces transformed into an incorrigible reject.

The Kremenchuk Mykhailo Ostrohradskyi National University attempts to perform cutting chips into individual elements using ultrahigh pressure liquid jet. Ability to use for processing hard materials (including silicon carbide) the fleeting fluid jet flowing from the nozzle and mixes with finely dispersed abrasive was studied in performance a number of works in particular [4].

However, unlike the processing of macrosolids larger than 10-25 mm with providing executable size at 3-12 mm in IT8-9 , getting microcuts on plates of 2-3 mm and a thickness of 0.1 – 0.2 mm ensuring accuracy implementation of sizes at ±IT9/2 is fundamentally different problem. It is related to the orientation and fixture of the workpiece, ensuring its keeping safe in the flow at the time of cutting, and the necessity create such a load at which at the maximum achievable jet compactness on the processed material will not have critical microstresses that can destroy the chip or separate inflicted pellicle.

Figure1 – The tested chip, mounted on subsidiary table

Research objective.

It is waterjet cutting process used to obtain precise cuts on the metalized microarrays of carbide materials, which can be implemented in a small-scale production.

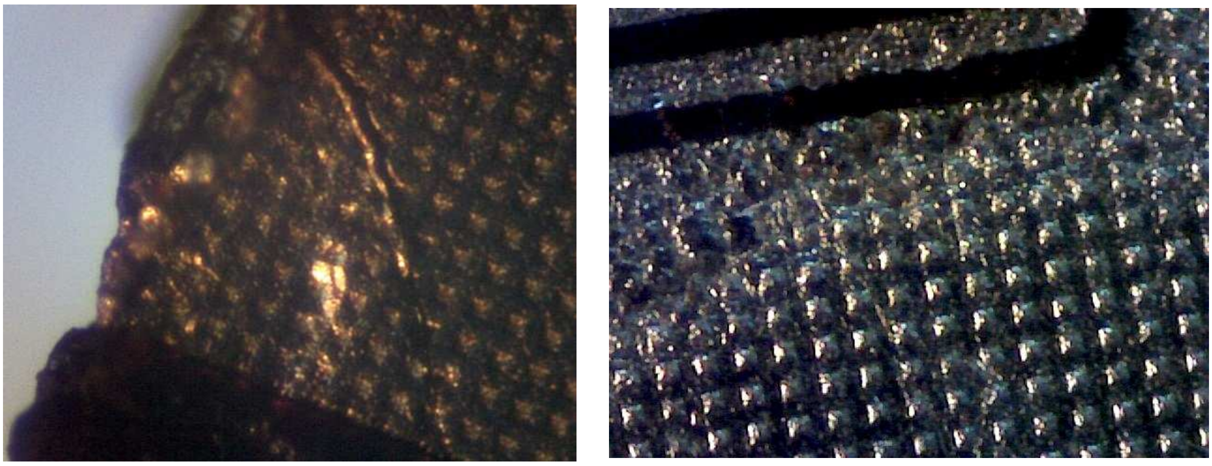
Basic maintenance and result of research.

For experimental researches were selected 10 chips with metalized pellicle inflicted on both sides. Chip material - silicon carbide (SiC), crystal size 2.8x2.8 mm, plate thickness 110 microns. Able to supply on the crystal placed four separate structures (Figure 1), which in the processing must be separated from the original structure. For the normal functioning of the chip to the product put forward a number of requirements, among which the main ones are the following: separate structures after separation must not contain cracks following in depth of plate at a distance of more than 0.02 mm; on the surface shouldn't be chippings that exceed 0.015 mm; metallization on the lower and top surfaces (obtained by spraying) shouldn't exfoliate and buckle up; allowable detachment at the lower edge of the crystal is not more than 0.05 mm from the edge; after cutting the surface of the crystals should not have dirt, oxide films or oxidized layer metallization; chip can be heated to a temperature no higher than 300 0C. Special requirements to roughness of the ends are not nominated.

Processed plate enshrined to the subsidiary table, because the size of chips does not allow the use of traditional means of orientation and fastening.

Before the work microscopic examination of the surface of the workpiece and quality of inflicting metallization are performed. Was found that the workpiece has some defects both on the separation structure edge and on the surface. It is hampered the work, because any defect could cause cracks and crystal cracking. Later, during the research with this phenomenon had repeatedly.

Attempts to use only liquid jet had no effect: The jet with flowing out pressure above 250 MPa significantly damaged metallization (Figure 2,b) in view of the demands put forward was unacceptable. Moreover the damage was spreading over a distance of 0.15 mm for the impact time of 3–4 s. Thus the need of implementation of the cut by abrasive liquid flow was evident.



a) b)

Figure 2 – Cracking of the workpiece (a) in an attempt to get a groove in the center of the chip and damaged metallization (b)

The workpiece can't be mounted cantilever because there is the possible compications associated with an absence of conditions for the free flow of waste liquid. Since in this case inleaked flow that creates pressure,

$$P_z = 162\left(\frac{p}{100}\right)^{-1,27} d_c^{\,2,05} h^{1.1} \left(\frac{\sigma_p}{100}\right)^{-1,27} s^{0,93},$$

where p – pressure in the hydraulic system, MPa; d_c – diameter at the cut profile of the jet of the forming nozzle, mm; h – thickness of the processing material, mm; σ_p – tensile strength, MPa, can cause it brittle destruction. Therefore was accepted an attempt to make abrasive jet cutting, which profiles were calculated on the assumption that is using of finely dispersed garnet abrasive with fraction of 50-100 microns, and working feed is installed such that the jet penetration of the processed material exceeds its thickness of 2 ... 3 times. By this was expected to create conditions for the groove forming in the retaining table for fluid flow at maximum saving of interaction pattern power. To determine the right processing modes used the equation

$$S = \frac{Q_m}{m} W_{is} \int_0^t \int_{x_i}^{x_{i+1}(t)} \frac{1}{2\pi\sigma_x\sigma_y} e^{-\frac{(x-a_x)^2}{2\sigma_x^2} - \frac{(y-a_y)^2}{2\sigma_y^2}} dxdt,$$

where , $W_{is} = W_1 + W_2 = \frac{\pi\delta_n^2(3R-\delta_n)}{3} + \frac{\delta_n(6a+8b)}{15}\delta_a,$

moreover $\delta_n = \frac{mv_n^2 Ra}{2k_n z_n HB}; \quad \delta_a = \frac{mv_a^2 z_n}{2k_a\sigma_b Ra} - \frac{k_a T_p^2 \sigma_b Ra}{2mz_n},$

Were m – mass of abrasive particles; v_n , v_a – normal and tangential components of the particle impact speed with the processing surface; Ra, HB,σ_b – roughness parameter, hardness parameter and durability parameter; z_n – grit of abrasive particles; T_p – constant which takes into account the inertia of the microcutting process; k_n, k_a – constant coefficients.

Were established following modes of processing: liquid pressure p=200 МПа, it makes possible to determine the velocity of abrasive particles $v = \dfrac{2pf_c}{f_c\sqrt{2p/p} + M_a}$ for nozzle of 0.12 mm and gauge tube of 1.1 mm is 270 m/s. Gauge tube was chosen from the available ones, although it did not comply with the width of the groove – 0,25-0,4 mm. Of course, the use of smaller diameter tubes would get better grooves and openings, as well as provide a smaller area damaged adjacent to the surface processing zone.

The processing performed by setting contouring feed rate of 500 mm/s. This one tried to process the plate from the center toward the edge, and the other - with the introduction of the jet outside the crystal. Unfortunately, processing from the center has led to permanent damage of the chip with occurrence of cracks that led to chipping, truck cracks branching and to the formation of microcracks grid. Processing with gradual supply of jet to the processed workpiece had more success because surface defects has been avoided. Instead, the groove width of 1.1 mm is almost completely spoiled one part of the workpiece (which is permissible to the technical requirements) leaving the rest part of the chip in a satisfactory state (Figure 2,a). The value of edge roughness measured by electronic means estimated at 1.6 microns in the parameter Ra.

The data showed that the processing pattern is not rational and requires correction. It was found that waterjet cutting can be used for the microarrays cutting into individual structure provided that the groove width will be increase. At the same time receiving grooves over 0.3 ... 0.5 mm is hardly acceptable from the perspective of the technology. Invokes the complexity of the orientation and retention workpieces at work table, that for implementation of serial process requires the use of additional tools. Resulting edge roughness is satisfactory and has no significant chipping of the surface, has a homogeneous structure and has no defects as stress concentrators which is essential to ensure the stability of physical and mechanical properties. At the same time there is a likelihood of chip cracking that requires beginning of processing outside inleaked jet. When calculating the rate of the working feed should provide a deeper groove cutting, but on the other hand, reducing the rate of the working feed leads to growth damaged area on the lower edge of the chip and on the top edge of the chip (where applied metalized layer). The essential problem is to minimize the damage zone of metallization on the top and lower edges of the processing workpiece. It was pointed out to our previously results and the conclusions: quality and reliable cut can be obtained only if the wasted liquid is free to flow, and at such placement of the processing workpiece, which is cutting by particles that move relative to the processing surface at small angles of attack.

Of the above conditions led to the logical conclusion of the need to use special slotted masks. This allowed us to offer an original way to cutting these workpieces. The method of waterjet cutting of microarrays is realized using inkjet system. It consists of attached on the high pressure tube 1 (Figure 3) mixing chamber 2 which on the one hand coupled with the jet nozzle 3 (usually with diameter d_c=0.1…0,3 mm) and on the other hand contacted with the calibration tube 4. Gauge tube mounted coaxially with nozzle 2 so that between the end face of the tube and nozzle cut 2 loose ejecting abrasive particles that follow by supply channel 5. Getting into the gauge tube, abrasive particles being accelerated by the redistribution of the kinetic energy of the jet that coming out of the nozzle 2. Processing sheet workpiece 6 is installed on the support plates 7 that enshrined motionlessly on the work table of machine 8 in the distance Δ_1 from each other. The top of the workpiece pressed through the compensating spacer 9 by mask 10. The mask is protective plate (plates) with a cleft opening in width Δ_2 and at least one free end face. At the same time the cleft of the mask 10 is located coaxially to the end faces of support plates 7 so that cleft Δ_1 is over cleft Δ_2. And the mask connected with intermediate supports 11, one of which is simultaneously contacting with end face of the workpiece 6, providing precision setting of the mask. The axis of the jet stream 12 is located in the plane of the mask cleft axis 10, parallel to the end faces of support plates 7 and at an angle to the perpendicular of the processing plane.

The method have implemented in such a way. Workpiece 6 install on the support plates 7 so as to touch the end face of one intermediate support 11. Herewith another intermediate support is at a distance δ from the opposite end face of the workpiece 6. On top of the workpiece through compensating spacer 9 overlay mask 10 and press against the intermediate supports 11. Then the workpiece that has been preparing to processing is placing at the point of jet inleaking at some distance from the zone of hydraulic influence thereby eliminating instabilities of the cutting process at the initial jet acceleration. When liquid applied, it begins moving by tube 1 and flowing through the nozzle 3, at the same time avoiding the mixing chamber 2 and cause ejecting of the abrasive particles by supply channel 5. The resulting jet-abrasive flow goes by gauge tube 4 and further inleaking on the mask 10. Herewith its part does not perform useful work and screened from the surface of the workpiece 6 by mask 10 (Fig. 2), and the necessary width provides by a working cleft Δ_2 of mask 10. Moving of the jet with a working feed s_p allows to transfer hydraulic influence on the desired length, usually L=B+1,2D_k, and inclination of the jet provides sliding effect of abrasive grains and free flow of waste stream.

To check and to prove the proposed method the fairly simple devise (Figure 4) with cemented carbide (WC type) plates were assembled, into which established the processing microarray and enshrined on the desktop of the machine LSK-400-5. Working cleft performed to the size of Δ_1=Δ_2=0,3 mm; herewith used the special thickness gauges. As an abrasive was used electrocorundum with fraction of 20/50 mm, which filed with a expenditure of 0.5 kg/min from additional hopper that mounted on the working organ (this was possible because the processing time didn't exceed 2–5 s).

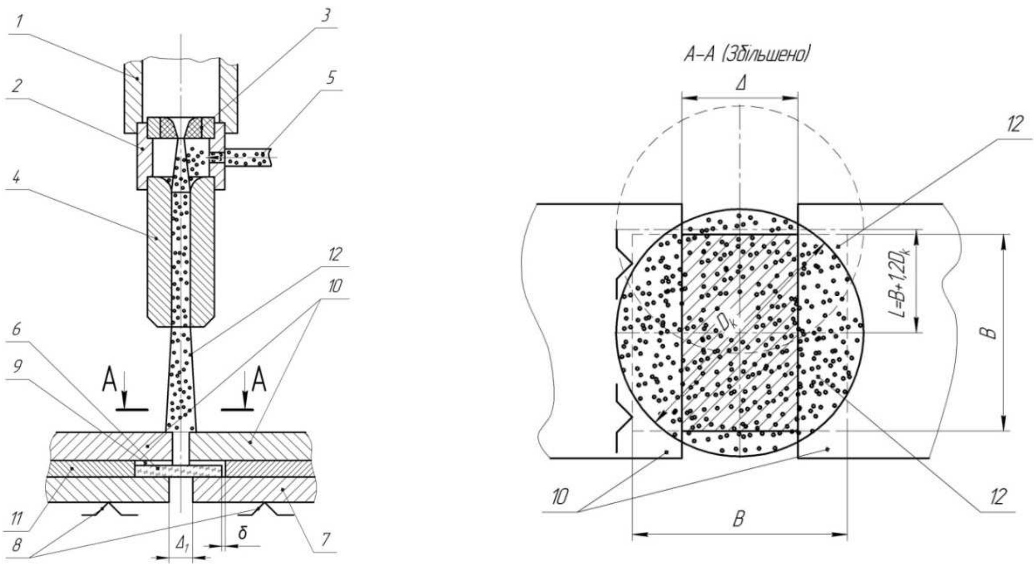


Figure 3 – Scheme of the device for conducting processing of chip with cleft mask

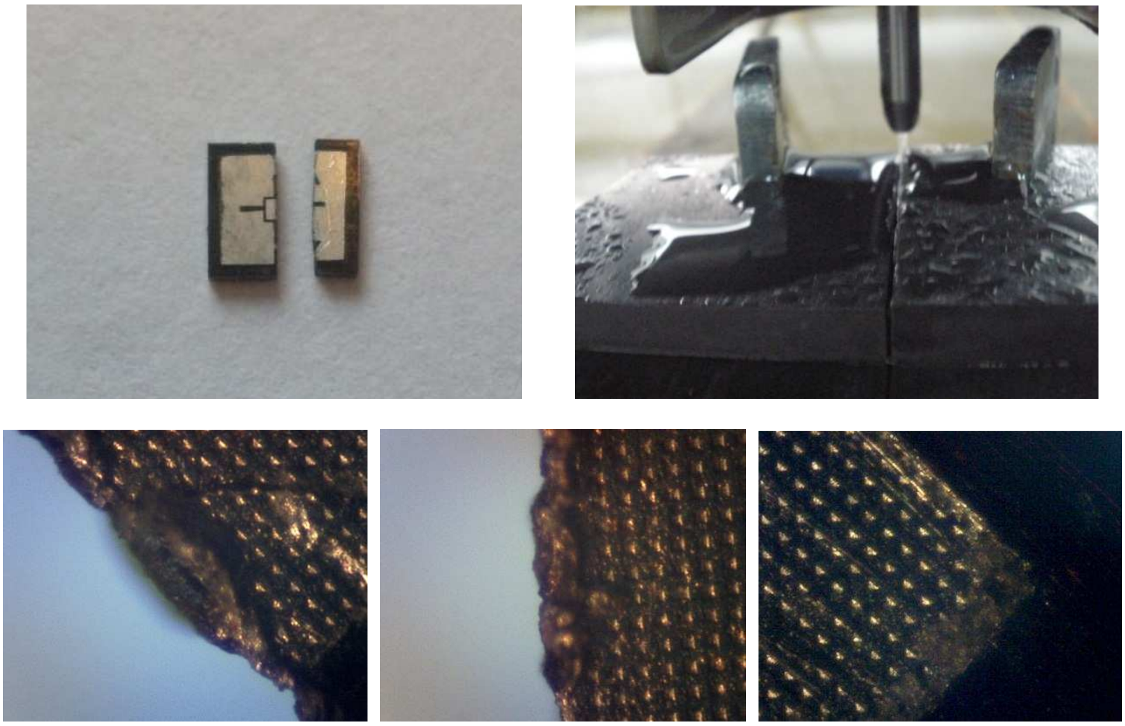


Figure 4 – Workpiece mounted in the device layout and alignment of technological equipment on the desktop of machine

Working feed was chosen on the basis of equation $S_q = \left(\dfrac{N_t p_b^{1,593} d_c^{1,374} M_a^{0,343}}{CQh} \right)^{1,15}$ with the requirements of the desired edge quality, where N_t – manufacturability processing of the material; C – constant; Q – quality index which is inherent to a particular type of processing; p – rated pressure, MPa; h – thickness of the processing material, mm; σ_p – tensile strength of the material, MPa; d_a– diameter of the abrasive grains, microns; M_a – mass concentration of grains, %. The complexity and additional refinement of the coefficients were caused by the fact that the process was short-term and therefore unstable. After a few test passes was installed s_q=500 mm/min.

The results in Figure 5 are shown. So, it was found that the chip was cuted according to the mask, which was installed above the surface of processing, herewith the level of roughness that obtained on the edge did not exceed 6.3 mm in the parameter *Ra*. The width of cut did not exceed a given size, but some waviness of the surface was determined by the corresponding deviation from parallelism of plates used as a mask. Was also implemented a series of experiments directed at identifying of the functional conditionality of surface roughness by fraction used abrasive.

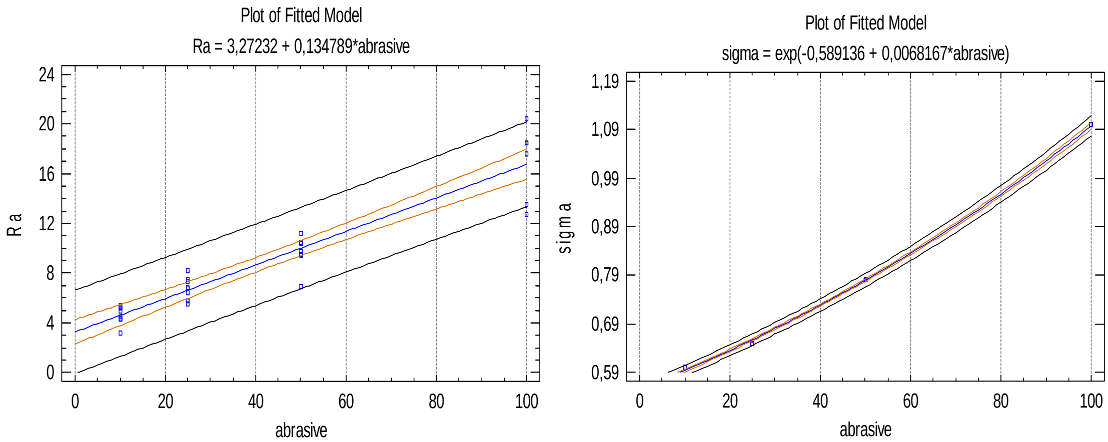


Figure 5 – Dissected microchip and the received edge on the end face of the cut (x50). The size of the plate before processing 2,8x2, 5 mm, width of cut – 0.3 mm

Herewith found that the use of more small abrasive (fraction of 10/30 microns) gives better result - the level of roughness managed to partially reduce. However, in our opinion, a more effective result would be to optimization of the thickness of the mask plates. This conclusion follows from the analysis of the cutting zone. Because diamter gauge tube is much greater than the diameter of clefts mask, the most of the abrasive flow does not perform useful work. Vice versa at the time of inleaking on the obstacle (and the use of hard or ultrahard materials causes almost complete lack of cutting for a short time) the greater number of particles changes the direction of the movement and affects on the particles, that is moving in the stream opposite the entrance to the working cleft. Having the momentum, the particles change the direction of the movement and upon reaching the surface of the microchip can perform it damage to the outside area that limited by the mask. This phenomenon leads to the fact that the surface roughness is in the functional dependence of the kinetics of particles in the stream, which requires further researches in this direction.

Conclusions. Thus, we have proved the possibility of using small diameter jet stream to perform precise cuts of microchips with hard and brittle materials, such as SiO-chips with double-sided metalized applied. In this case damage of the structure are not observed. At the same time, analysis of the kinetics of two-phase stream when using high-strength mask will allow better use of the energy of the jet stream, will provide better cut quality and reproducibility of the process and also will reduce the cost of funds for making masks for processing.

Bibliographical list of references

1. About some results of exploration of water jet guided laser onto the solids'surface / A. Salenko, O. Fomovska, V. Dudyuk, O. Mana. // Unitex – 10: International scientific conference 19–20 November 2010, Gabrovo. — 2010. — P. 414–421.

2. TECH front Cutting Laser Guided by Waterjet. Damage-free wafer dicing using the water jet guided laser technology / Delphine Perrottet, Dr. Tuan Anh Mai and Dr. Bernold Richerzhagen, Synova SA, Ch. De la Dent-d'Oche, CH-1024 Ecublens, Switzerland. J. — 2005.

3. Gentle dicing of thin semiconductor materials by water-jet-guided laser // Yasushi Kozuki, DelphinePerrottet, Phil Durrant and BernoldRicherzhagen // Synova Japan, 2-949-12 Nanyo, Nagaokashi, Niigataken 940 – 1164 Japan // Synova SA, Ch. de la Dent-d'Oche, CH-1024 Ecublens, Switzerland // Proceedings of the 4th International Congress on Laser Advanced Materials Processing.

4. Salenko A. On the experience of the application of the functional approach to getting by waterjets deaf cuts in sintered superhard materials // A. Salenko, S.S. Strurinskyi // Cutting and tool for professionals. — Kharkov, 2011. — № 4. — P. 56–62.

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Саленко О.Ф., Дудюк В., Никитін В.А. Забезпечення малої ширини різання при обробці мікрочіпів гідроабразивним струменем

У роботі виконано розрізання SiO-мікрочипів на окремі елементи за допомогою струменя надвисокого тиску із дрібнодисперсним абразивом. Була доведена можливість використання струменю малого діаметра для виконання точних різів мікрочипів як з твердих так і крихких матеріалів. Використання функціонального підходу дозволило зменшити ширину пошкодження металізації. Запропоновано оригінальний спосіб гідро абразивного різання із застосуванням щілинних масок. Використання таких масок значно підвищує якість і точність крайок розрізаного чіпа.

Ключові слова: SiC-мікрочипи; гідроабразивне різання, якість різу.

Саленко О.Ф., Дудюк В., Никитин В.А. Обеспечение малой ширины резания при обработке микрочипов гидроабразивной струей

В работе выполнено разрезание SiO-микрочипов на отдельные элементы с помощью струи высокого давления с мелкодисперсным абразивом. Была доказана возможность использования струи малого диаметра для выполнения точных резов микрочипов как из твердых так и хрупких материалов. Использование функционального подхода позволило уменьшить ширину повреждения металлизации. Предложен оригинальный способ гидроабразивной резки с применением щелевых масок. Использование таких масок значительно повышает качество и точность кромок разрезанного чипа.

Ключевые слова: SIC-микрочипы, гидроабразивное резание, качество резания.