IMPROVING THE SLICING PROCESS CHARACTERISTIC PARAMETERS

Tiberiu DOBRESCU[1,*], Nicoleta Elisabeta PASCU[2], Aurel Florin ARION[3]

1) Assoc. Prof., PhD, Machine and Manufacturing Systems Dpt., University "Politehnica" of Bucharest, Romania
2) Lecturer, PhD, Engineering Graphics and Industrial Design Dpt., University "Politehnica" of Bucharest, Romania
3) Assistant Prof., Engineering Graphics and Industrial Design Dpt., University "Politehnica" of Bucharest, Romania

Abstract: *Although improvements in wafering techniques have produced great saving in device manufacture, further advances in both wafer productivity and quality can be achieved by a systems approach to the slicing operation. An ID blade is a bonded abrasive grinding wheel whitch cuts a deep, narrow slot in the material. In the case of cutting silicon wafers, the major objective are to make a perfectly stright cut, to remove material fast, and to minimize subsurface wafer damage. With impetus from the semiconductor industry, the I.D. diamond saw blade was developed to reduce kerf losses when slicing these expensive material. This paper presents experimental results obtained to optimize the characteristic parameters of the slicing process of hard and brittle materials (silicon, germanium, ceramic a.s.o.) used in the electronics industry. Experimental data are used to optimize the slicing process of brittle materials (silicon, germanium, ceramic, a.s.o.) to obtain some wafers of high shape and dimensional accuracy such as the resulting wafers require a shorter processing time through the super- finishing process.*

Key words: *slicing, I.D. cutting, I.D. diamond wheels, silicon wafer, productivity, quality.*

1. INTRODUCTION

One of the most spectacular improvements came in the early 1960's when slicing saws were converted from O.D. (Outer Diameter) to I.D. (Inner Diameter) cutting. In 1962, R.G. Heinrich of Hamco Machine & Electronic Company patented a vertical spindle I.D. slicing machine with programmed feed and rotating workpiece capability. It was one of the earliest saws for production use which was designed totally around the I.D. blade concept. Subsequently, other manufactures introduced I.D. slicing equipment to the marketplace. Names such as K&O Lee, Mayer & Berger, Capco, Crouzet, Silicon Technology Corporation and TSK appeared.

Over the years, I.D. equipment and technology have progressed steadily. As a result kerf losses were as much as 2 to 3 times wafer thickness. Further improvements, such as stainless steel diamond, wheel cores and faster cutting rates have produced significant saving for the materials processor and the device manufacturer. Today, automatic machines for high productivity are available with workpiece capacity of up to 400 mm diameter. These past improvements focused primarily upon the slicing machine and the cutting wheel. It should be apparent; however, that there are many other variables involved in slicing. These include mounting the wheel, mounting the crystal for cutting, the choice and handling of coolant, and operator technique and competence. Close control of all these variables can provide even further improvements and saving in the wafering operation. This calls for a systems approach, and an understanding of the dual disciplines of materials and equipment engineering. Slicing is one of the most critical operations in the processing of semiconductor materials.

Damage occurring during this early stage of processing can carry over to produce defective finished devices. Wafer tolerances are tight, and failure to meet them means either extra processing steps or rejected wafers. In addition, because any slicing wheel must have finite dimensions, losses due to kerf are inherently high as a percentage of the total material involved. Adding high rejection rates to high kerf losses can produce intolerably high material costs.

2. PRODUCTIVITY AND QUALITY

Slicing problems are being further complicated today by the production of larger and longer crystals. Although larger, longer crystals mean greater productivity to the processor, they create problems in that much existing slicing equipment is not designed to handle such large work pieces. Larger diameters also mean greater waste when rejects occur. Further-more, with new semiconductor materials, some of which cost 20 to 30 times more that silicon and germanium, excessive kerf losses and high reject rates are extremely expensive. Wafer quality is defined in terms of geometry and surface finish. Dimensional tolerances include thickness, parallelism, taper and bow. Surfaces are specified in terms of surface finish and surface damage. The ability to produce in-tolerances slices repeatable is the primary goal of any slicing operation.

Presently acceptable industry standards for slices cut with I.D. wheels are shown in columns A and B of Table 1 [1].

* Corresponding author: Splaiul Independentei, 313, sector 6, Bucharest, Romania, 060032
Tel.: +40214029420;
E-mail addresses: *tibidobrescu@yahoo.com* (T. Dobrescu),

Table 1

Semiconductor Wafer Tolerances (total variation 4%)

Parameter	**Present Standards [mm]**		**System Standards [mm]**	
	A<76.2 mm diameter	B>76.2 mm diameter	C<76.2 mm diameter	D>76.2 mm diameter
Thickness (five readings)	0.0127	0.0127	0.0076	0.0076
Thickness variation, slice-to-slice	0.0127	0.0127	0.0076	0.0076
Bow, warp	0.0127	0.0203	0.0101	0.0152
Parallelism	0.0127	0.0203	0.0076	0.0127
Taper	0.0127	0.0203	0.0076	0.0127
Surface damage	No saw marks or burnishes		No visible marks	

Although this specification may suffice, there is no doubt that semiconductor processors would like to improve on them in order to reduce material and processing costs and increase yields.

Using the systems approach, the more exacting tolerances and specifications shown in columns C and D of Table 1 are being met today.

The slicing machine is the heart of the system [4, 5].

The basic requirements of any machine designed to repeatable produce work to such close tolerances on a production basis include: internal tolerances two or three times closer than those of the work being produced; minimum wear of moving parts; minimal acceptable level of vibration; precise adjustment and set-up.

In addition to these basic requirements, any machine tool should be relatively easy to operate and maintain.

Automation with an I.D. cutting machine presents a problem because the work must be fed through the centre of the wheel, making recovery of finished work difficult.

Wafers cannot be simply caught and removed on the opposite side of the blade as with a cut-off wheel because this area is totally enclosed by the wheel head and the spindle hub.

Wafers must be removed from the same side that they entered the machine, through the hole in the saw. In the past, this has prevented practical solution of the automation problem.

3. TYPES OF MACHINES

Although there are functional differences between various proprietary machines in use today for slicing semiconductor crystals, they can be generally classified in two ways: first, by the method of mounting the crystal and secondly, by the manner in which the cutting action is achieved. There are two basic methods for mounting the crystal: the ingot box system and the machine tool rigid mount.

The ingot box system is preferable because it permits mounting longer length crystals without a second set-up and allows the crystals to be oriented on the machine.

On the other hand, the conventional machine tool mount can handle crystal lengths of only 76.2 mm with a single set-up and the crystal must be oriented off the machine.

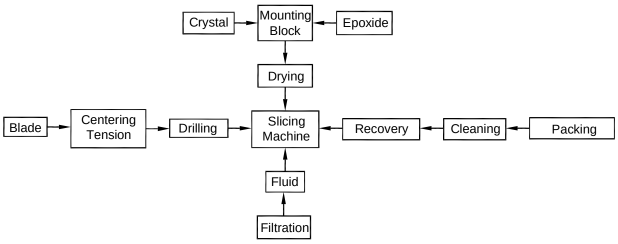

Fig. 1. Block diagram of the slicing system.

Using an accessible system (Fig. 1), we can obtain specific exact tolerances in columns C and D.

Figure 1 shows the block diagram of the slicing system. Experimental tests are based on slicing process with annular disc using a slicing machine with vertical disc and rotational motion of the disc support device (STC ID produced by Silicon Technology Corporation in the U.S.)

The kinematics of slicing process used for experimental tests is exemplified in Fig. 2. Obviously, by minimizing the number of set-up the ingot box mount reduces downtime and the probability of operator error and permits one operator to run more machines. The ability to slice longer crystals also leads to minimizing waste.

The second method of classifying wafer slicing machines is by the manner in which the cutting action is achieved. Three types of I.D. cutting machines can be categorized as follows: work fed into fixed horizontal wheel; work fed into fixed vertical wheel and pivoting vertical wheel fed into fixed workpiece.

In Fig. 2 we used the following notations:

1 – diamond cutting disc;

2 – work piece;

3 – blade;

v_a – feed rate [mm/min];

n_d – disk speed [rev/min].

Before slicing operation we follow the next steps:

- mechanic processes performed outside the ingot with abrasive tools to achieve cylindrical shapes at controlled strict dimensional parameters;
- secant cuts which have the role to help further crystallographic orientation of the ingot (a primary milling greater which has the role to facilitate wafers orientation on the automatic systems of positioning and fixing during the manufacturing process of circuits and secondary milling that serve to identify quick visual crystallographic orientation and type of conductivity of semiconductor materials);
- after the achievement of these preparatory operations the slicing of the monocrystalline ingot can be made in wafers.

Table 2 presents the main parameters of the silicon wafer after slicing operation. These values are recommended by the manufacturer.

Table 2

Parameters of the wafers

Diameter Inches (mm)	**Thickness (mm)**	**Roughness *Ra* (µm)**	**Curvature (µm)**
2(51)	0.350	0.6	Max. 20
3(76.5)	0.580	0.6	Max. 20

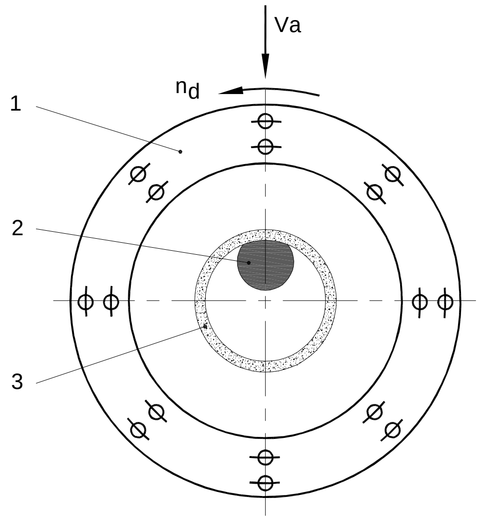

Fig. 2. The process of slicing I.D.

4. I.D. DIAMOND WHEELS

Stainless steel diamond wheel cores have all but replaced phosphor bronze today.

Its greater tensile strength and ability to withstand strain reduces the need for retensioning.

Core thickness ranges from 0.0508 mm to 0.127 mm [4, 5].

In general, the larger the diameter, the wheel is thicker.

Wheel geometry determines the maximum diameter of ingot it can cut.

Diamonds are plated to the wheel I.D. in a nickel matrix.

All other factors begin equal, the bond strength of the matrix determines the life of the blade.

Wheels must be mounted to run true.

To accomplish this, the wheel head must be dynamically balanced and clamping surfaces must be parallel, clean and smooth.

If the rings are out of round or if the wheel is not clamped uniformly over its entire clamping surface, the cutting edge will be oval rather than circular.

If the wheel is not centered, the high spot will wear faster than the rest of the cutting edge and wheel life will be shortened.

Once centered and clamped the wheel is tensioned either mechanically or hydraulically.

In theory, hydraulic tensioning is better than mechanical. It is easier, faster and simplifies retensioning on the machine.

Also, hydraulic pressure can be easily measured to give an indication of blade tension.

There are two methods of tensioning blades mechanically. The threaded mount is one.

In the other method individual bolts around the periphery of the tensioning ring are tightened after proper tension has been achieved by means of a tensioning plate.

Mechanical tensioning takes more time and effort than hydraulic tensioning but it is proved and positive.

A pneumatic impact tool, present to the proper torque, will save time in tensioning.

After tensioning, the blade is mounted on the machine and checked for concentricity. In operation, friction and heat may relieve stresses in the core material, causing tension to relax.

Therefore, retensioning on the machine is common practice.

Care exercised at this point pays off by minimizing problems during slicing. With respect to the shape of cutting edge, the most common type of blade is the continuous rim in which the plated surface is uninterrupted. Several variations have also been made in an effort to improve swart removal and cooling (Fig. 3).

These include the segmented or interrupted blades and scalloped blades in which the cutting surface is interrupted at regular intervals.

Another variation is the blade in which the cutting edge is bonded only it the edge or rim of the I.D. without support from the sides of the core.

The interrupted or segmented blade works reasonably well. But, as might be expected, it has a shorter life than one with a continuous rim because of the lower volume of diamond cutting particles.

Scalloped sides perform no useful function.

As can be seen, they do not really provide openings for either swart or coolant. Theoretically, the scalloped rim is the best of these cutting edge variations.

The valleys, usually about 0.076 mm deep, provide relief for coolant flow and swart removal without drastically reducing the volume of diamond particles available for cutting.

The key to cutting with such a thin blade is the ability to apply tension to the wheel along its outer periphery.

The metal core of the blade is stretched under pressure and held under tension.

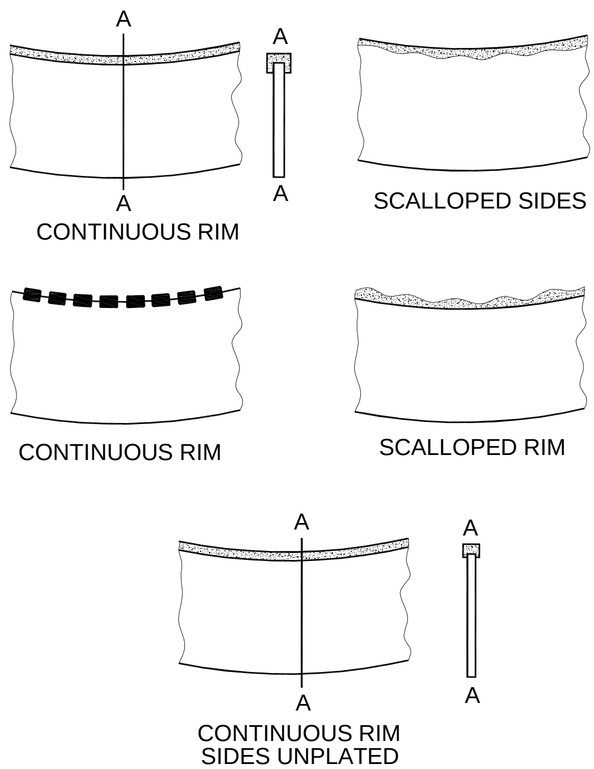

Fig. 3. Variations of the continuous rim I.D. blade.

This gives the blade the rigidity necessary to firmly support the cutting edge on its inner diameter without wobble or flutter.

There are a large number of variables in blade design, manufacture and use.

Obviously all of them must be closely controlled in order to provide the performance demanded by the semiconductor industry.

The thin metal core which supports the inner cutting edge must be capable of withstanding high tensile forces without tearing.

Its composition must be such that the resulting stress is distributed evenly across its entire structure.

The diamond particles must be firmly bonded to the I.D. in order to cut efficiently, but not so strongly that excessive fracturing occurs.

The diamonds themselves must be carefully selected for particle size, shape and strength.

Finally, the blade must be skillfully handled.

It must be properly mounted, tensioned, dressed and operated.

All of these factors contribute to the end result, the efficient and accurate slicing of semiconductor wafers to exacting tolerances with minimum kerf loss and product damage [2].

Although most I.D. cutting wheel is predressed, new wheels should be sharpened and broken in on the individual machine.

Periodic dressing is required during the life of the wheel.

Primarily, this is to remove mounting wax or epoxy, which builds up on the cutting edge [4, 5].

Stick dressing has three functions:

- it puts a radius on each edge of the I.D.;
- it trues the side of the blade;
- it opens up the bond to expose the diamond particles.

Usually a coarse 150 grit silicon carbide stick is used to apply the radius to the cutting edges of the blade.

A finer stick, 320 grit, trues the sides and opens the bond.

After dressing, the operator should examine the first slices cut for taper, head cracks and surface finish.

If taper is within tolerance and there are not heat cracks, the blade is properly dressed.

If this is not the case, the geometry of the taper or the location of the heat cracks will indicate how the blade has been improperly dressed [3].

5. PRESENTATION OF DATA

The first part of the experiment (E1) consists in the ingot slicing of 76.5 mm diameter with constant parameters of the slicing process (constant feed rate and constant wheel speed) to determine their effect on the wafers quality (curvature, thickness and roughness).

The second part of the experiment is separately performed by the previous tests and.

It was necessary to see if they get the same quality of the wafers at a time when varying the feed rate and the speed of rotation of the disc.

Tables 3 and 4 show the experimental test order.

Table 3

Parameters of the experiment

Experiment	Diameter wafers (mm)	Cooling fluid
E1	76.5	Aquasol 1000S
E2-E6	51	Aquasol 1000S

Table 4

Parameters of the experiment

Experiment	Disc rotation speed (rev/min)	Feed rate (mm/min)
E1	2100	20
E2	1700	10-20
E3	1900	10-20
E4	2100	10-20-30-40
E5	2300	10-20-30-40
E6	2500	10-20-30-40

To calculate the cutting force in slicing, the following formula is used:

$$F_{as} = \frac{P \cdot l_c \cdot n\left[N_{gc} \cdot W_{gc}\right]^{3/2}}{1000 \cdot V \cdot b \cdot V_W} \cdot k \,, \tag{1}$$

where:

F_{as} – cutting force;

P – power consumption;

l_c – contact length;

b – width of grinding wheel bulge;

N_{gc} – the number of abrasive grains per carat or per unit weight;

W_{gc} – abrasive grain weight corresponding unit volume of grinding wheel;

V_W – the feed rate of grinding wheel;

V – cutting speed [m/min];

k – the cutting angle factor:

$$k = 2/(\cos\varphi_1 + \cos\varphi_2). \tag{2}$$

6. PRESENTATION OF RESULTS

6.1. Set 1 of tests (A)

The experiment consists in ingots slicing of 51 mm in diameter, keeping the constant slicing process parameters, to determine the quality of wafers (thickness, curvature and roughness, table 5).

Cutting regime parameters:

n = 2 200 rev/min; V_w = 30 mm/min.

The test results are listed in Table 5.

For the first part of the test the measurements have been done at intervals of five minutes after turning on the machine.

Arising conclusions from the process analysis are these:

- a lower number of rejects is obtained;
- the voltage is constant;
- current intensity doesn't vary significantly, which implies a small variation of power consumption.

After processing the experimental results the following graphs have been plotted in Figs. 4, 5 and 6.

Table 5

Parameters of the wafers

Nr. Crt.		Thickness [μm]	Curvature [μm]	Roughness [μm]
I	1	257	10	0.69
	2	256	5	0.72
	3	255	20	0.71
	4	256	20	0.68
	5	258	10	0.70
	6	257	10	0.72
	7	256	5	0.61
II	1	257	20	0.68
	2	253	40	0.73
	3	259	40	0.74
	4	259	40	0.73
	5	258	20	0.73
	6	257	10	0.69
	7	266	5	0.68
III	1	238	20	0.73
	2	254	10	0.72
	3	252	10	0.72
	4	264	5	0.72
	5	259	20	0.79
	6	256	20	0.73
	7	257	20	0.79

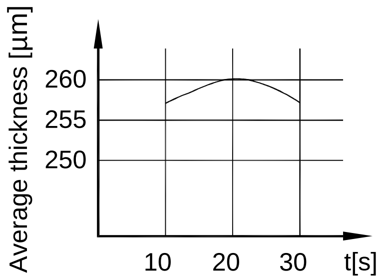

Fig. 4. Average thickness.

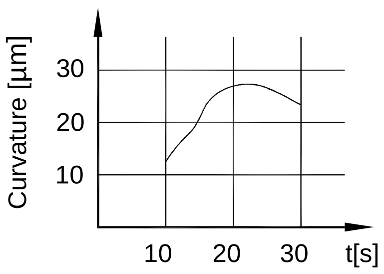

Fig. 5. Curvature.

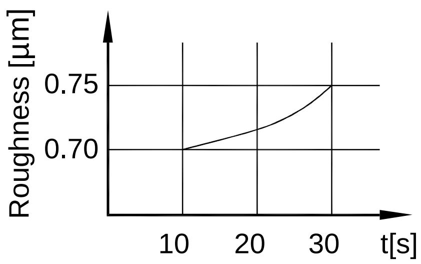

Fig. 6. Roughness.

6.2. Set 1 of tests (B)

The second part of these tests was separately performed for the previous tests, but also on a bar of 51 mm in diameter, but with different parameters of the slicing process (Table 6).

Values power consumption in slicing process is determined depending on the voltage and current intensity.

To determine the influence of the characteristic parameters of the slicing process on engine power output is sufficient to analyze behavior motor spindle.

Experimental test results are shown graphically, for each set of values of the speed advance in Figs. 7, 8, 9, 10, and 11.

It is observed that the power consumption increases slightly for each set of measurements, once with the increase in feed rate.

A greater increase of power occurs once with the increasing of grinding wheel speed.

Table 6

Parameters of slicing

Nr.	*n* [rev/min]	V_w [mm/min]	Thickness [μm]	Curvature [μm]	*I* [A]	*U* [V]
1	1 700	10	340	60-0	1-2.2	143
		20	343	60-0	1.4-1.7	143
		30	344	60-0	1.6-1.7	143
2	1 900	10	346	70	1.7-1.9	160
		20	484	0-20	1.6-1.8	160
		30	486	0-20	1.6-1.8	160
3	2 100	10	346	0-40	2.1-1.7	177
		20	344	0-50	2-2.1	177
		30	345	0-40	2-2.5	177
		40	487	40-0	2.1-2.5	177
4	2 300	10	328	0-40	2.2-2.3	193
		20	349	0-50	2.2-2.5	193
		30	367	30-0	2.3-2.7	193
		40	463	30-0	2.4-2.7	193
5	2 500	10	312	70-0	2.4-2.5	210
		20	435	0-30	2.5-2.8	210
		30	235	0-60	2.6-3.1	210
		40	311	0-50	2.6-3	210

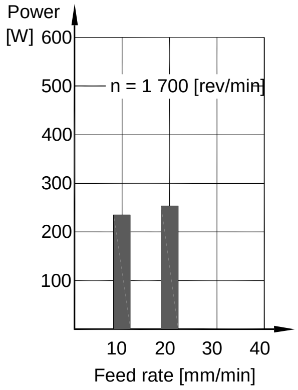

Fig. 7. n = 1 700 [rev/min].

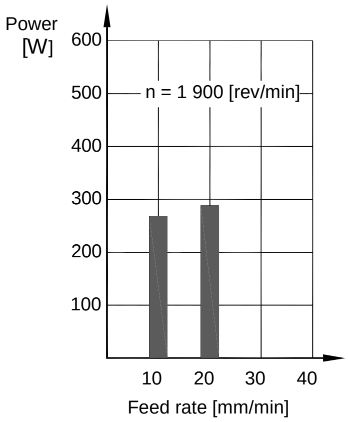

Fig. 8. n = 1 900 [rev/min].

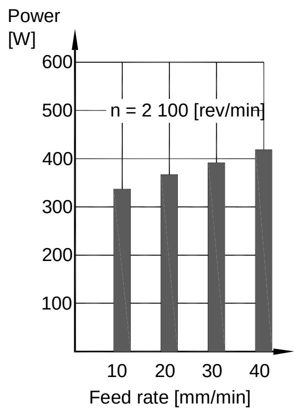

Fig. 9. n = 2 100 [rev/min].

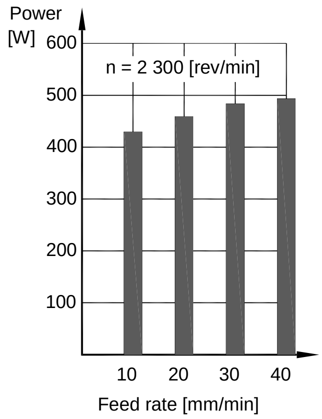

Fig. 10. n = 2 300 [rev/min].

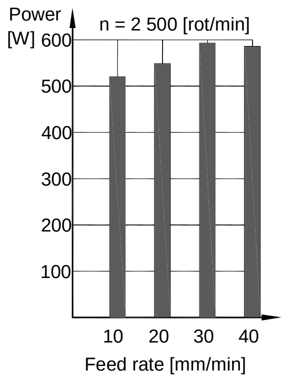

Fig. 11. n = 2 500 [rev/min].

7. CONCLUSIONS

Yet, even as increased crystal size and the introduction of new, more costly materials impose new processing problems, the semiconductor industry continues to seek increased wafer productivity and improvements in wafer quality.

Such improvements are possible only if one views the entire wafering operation as a single, integral system. Normally, slicing higher quality wafers means slow feed rates, resulting in low productivity.

However, the tolerance shown in Table 1 using the systems approach are being met on a production basis at equal or greater production rates than before.

If the present standards shown in Table 1 are acceptable, production rates can be greatly increased using the system approach.

The power consumption increases slightly for each set of measurements, once with the increase in feed rate; a greater increase of power occurs once with the increasing of speed grinding wheel

Thus, the systems approach can improve productivity or quality, and frequently will increase both.

Within a few short years, improvements in the design, manufacture and application of this important tool have contributed significantly to the increased productivity of the semiconductor industry.

Even more rapid advancement in the state of the art of I.D. slicing can be expected. These improvements will come as a result of efforts which recognize the fact that I.D. slicing is a total system in which the saw, the blade and the operator are co-equal components.

REFERENCES

[1] T. Dobrescu, *Cercetari privind optimizarea masinilor de superfinisat materiale fragile*, PhD Theses, University „Politehnica“ of Bucharest, Romania, 1998.

[2] T. Dobrescu, *A Study to Improve Wafer Produvtivity and Quality in Semiconductors Slicing*, Annals of DAAAM for 2007, Katalinic, B. (Ed.), Published by DAAAM International, Vienna, Austria, 2007, pp. 227–228 .

[3] T. Dobrescu, A. Dorin, N.E. Pascu, D. Ciobanu, *A Study of Abrasive Slicing Large Diameters Silicon Wafers*, Proceedings of the 4th International Conference “Optimization of the Robots and Manipulators”, Edit. Bren, pp. 263–267, Constanta, Romania, May 2009, Published by Romanian Academy of Sciences, Bucharest, Romania, 2009

[4] *** STC Wafering Systems, Bulletin No. 4400, 1995.

[5] *** STC I.D. Diamond Blades, Bulletin No. 2300, 1995.