Parameter control of laser beams
in function of the pattern of multilayer structures

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The development of electronic industry is strongly related to the permanently shrinking sizes, a challenge that in many instances cannot be coped with by means of the perfection of traditional technologies. The laser devices can be a useful means for their substitution, but as we do not know perfectly the processes that occur at the interaction of the laser with the material, we are unable to make the best of the laser technology. This contribution intends to highlight the features of this interaction, the impacts that the pattern applied on the substrate and the machining parameters have on the results of the machining process. We have set us the goal to exploit more efficiently the opportunities presented by the laser-based machining, by changing the laser beam parameters in function of pattern and material.

Introduction

The electronic industry is developing restlessly, though not necessarily at the space that had been predicted a few decades ago. Our need is constantly growing for smaller and smaller circuits and devices with even more reduced consumption, but with an ability to provide a greater range of services. As the sizes are getting smaller, the traditional manufacturing technologies are nearing by slow degrees the limits of their capabilities. Clearly, the manufacturers tend to reduce even further the strip width and to increase the number of the integrated functions. In this way, the IC sizes can just become smaller, entailing however the necessity of providing for them more connection points, i.e. bond-outs toward their environment. The high number of the leads, which can be as high as several hundreds, is impeding the easy handling of the integrated circuits by means of traditional packaging, because these would take up a much greater space on the surface being so small anyhow. Thus we are constrained to ignore the ease of handling, and to select the smallest possible packaging for the integrated circuits. In this way we are reaching the concept of the present CSP (Chip Scale Package): μBGA, flip-chip, TAB.

The rejection of „huge" packages can smooth things down for IC manufacturers, but the circuit substrate industry must face completely new challenges. The wires of the CSP IC are connected either to leads of line width down to 25 μm or to pads of 50 μm diameter. Therefore the substrate manufacturers are bound to refine their technologies to the order of magnitude of the hair diameter. But the traditional solutions used for this purpose are either unviable or not cost effective.

One of the alternatives for the solutions, which have been based for tens of years on the same principle and which have already achieved their limits of capacity, could be the laser technology. In the following we will outline the widespread use of the technology in our era, the advantages and perspectives it can provide and the compromises we are constrained to, while concentrating on one of the best-known material of the flexible circuit substrates, i.e. the polyimide.

The laser beam as tool

The individual features of the laser beam are well known: the beam is coherent, parallel and fundamentally monochromatic. The ideal laser beam can be focused extremely well, thus being able to produce energy densities of several MJ/mm^2 on the machined material. This feature permits to generate explosion-like processes on the surface, and makes it possible to remove material in small doses, in a tolerant way for the ambient environment. The focused laser beam as a machining tool (with diameter just down to 5 to 10 μm) can be moved along optically at a relatively perfect precision, without any defined feeding direction and, of course, any tear-down [2].

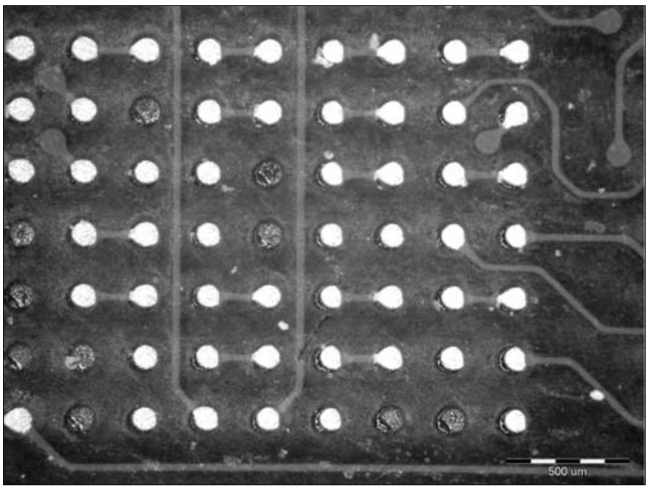
Drilling of through-holes or blind holes (vias) on circuit substrates by laser machining is incontestably more advantageous than mechanical drilling, irrespective of the larger diameter holes. In these applications, the history of laser machining began several decades before, so that micro-via machining lasers can be found in any substrate manufacturing line that fulfils the most recent needs. Due to the controllable, pulse operation mode of micro machining lasers, the laser beam can drill vias of preset depth in multi-layer structures as well, even in the case where the beam has to penetrate materials of clearly different physical features (copper, synthetic resin). This is achieved at a production capacity of several hundreds of vias per second [5].

When creating conveniently fine patterns during the production of circuit substrates, the laser technology is by far less commonly used than in the case of drilling. While drilling in a one-step technology could be replaced straight-out by laser machining, the multi-step pattern machining needs a definitive answer to the question whether and which steps could be qualified as viable by lasers. The arguments for the lasers are the extremely fine granularity to be achieved on the circuit substrates (line widths going incidentally down to the range under 1 mil), the substitution of up to 5 technological steps (photoresist application, exposition, development, etching, resist removal) by a single laser machining phase, the flexibility and the re-adaptation facility during the machining process [2]. The arguments against it are however the lower production capacity and the neighbourhood exposed to heat effects both in lateral direction and in the lower layers not affected directly. The patterned multi-layer structures have the ability to transform also thermally the subject of the micro machining into an inhomogeneous medium, so that the power input represented by the laser pulses – which can be fed also individually – can have from time to time different effects.

The interaction between the laser beam and the material is an exceptionally complex process. The users of the laser machining equipment, not obliged to have an insight into these processes, possess the skill of fitting the machine, pre-tuned roughly in a convenient manner, by means of a few settable parameters into the manufacturing line. The only question is, however, whether such appliances with a dedicated function are fully exploiting all the possibilities that the lasers could present. As a matter of fact, they do not change the machining parameters in function of the patterns of the inner layers, which thermally are just in connection. Production engineers, while setting present laser appliances by a "cut-and-try" method, are inclined to score this technique rapidly as unapt for certain complex jobs.

Fig. 1. shows an example of our investigations.

Fig. 1.
Laser-drilled 100 µm holes in the soldering-prevention layer – The non-leaded soldering pads were damaged in the presence of the same machining parameters



Here the effect of thermal conductance comes directly to light. A more sophisticated dilemma is when the patterned copper layer is not directly connected to the machined layer, but thermally it effectively influences the results.

If we knew both the interaction process between laser and the machined material and the influence which certain accompanying phenomena of the processes are exerting on this (thermal, optical, acoustic, etc.), we could have a model at hand, based on which we would be able to prepare the lasers used in the mass production for the solution of more specific and more complex problems, while keeping the flexibility. So the laser-based machining could be an alternative for the traditional technologies being at the limit of their performance.

Parameters of the laser-based machining

The abundance of the direct machining parameters is by itself representative of the complexity of the process. A possible grouping of the main parameters is shown in the following:

1. *Parameters characteristic for a Q-switched laser source:*
   - wavelength,
   - pulse width, time-dependent distribution of the energy,
   - per-pulse energy, average power,
   - pulse repetition frequency,
   - beam quality (energy distribution over the beam cross-section),
2. *Parameters describing the characteristics of the optical system:*
   - beam sweeping speed,
   - diameter of the focal plot,
   - focal range.
3. *Parameters defining the machining geometry:*
   - pattern,
   - grid spacing,
   - number of the machining steps.
4. *Environmental parameters:*
   - composed thermal conductance of the inhomogeneous, multi-layer structures,
   - characteristics of the atmosphere (gas type, gas flowing speed) [3].

Due to the characteristics of the material to be machined and of the technical realities, the possible values of the majority of the above parameters will be constrained – fortunately – soon to a manageable interval. The laser type defines the wavelength. In the electronic technology, the 355 nm wavelength is prevalently used, which is produced of the Nd:YAG laser beam by frequency tripling. This prevalence is not by accident: the beam at the border of the visible and the UV range is absorbed well in almost every material used in the rigid and/or flexible NYHL technology. (Therefore, we obviously cannot refer to the processes that automatically dominate the selective material removal, so it is necessary to maintain the controllability as much as possible during the machining process.) Similarly, both the width and the power to time function of the laser pulses emanate from the viability of the laser. As a well-proven fact, the machining "purity" is, in the sense of thermal load, strongly dependent on the duration of the interaction. The shorter the interval is in which we communicate energy to the surface, the more intensively we can cause the exposed part to ablate, as the heat has reduced time to propagate from the area directly affected [1].

We have greater chance to choose from all the multitude of the machining parameters those, which we are able to change at a rate that is comparable to the machining speed in function of the pattern. We cannot modify abruptly the energy and/or frequency behaviour of the laser beam without the change of the beam quality. (There are certain lasers that provide the possibility to compensate the thermal lens created in the laser crystal, but this may require several seconds.) The sweeping speed, the machining geometry, however, can be changed at any time. But before proceeding to examine the way in which it influences the machining results, we present the effects of thermal conductance in the case of copper-polyimide substrates.

The effects of thermal conductance

As referred to earlier, there is a need to fit the machining behaviour to the pattern in order to utilize completely the features of laser-based machining. The diversified pattern created on the substrate, in its several layers, may result in an extensive diversification of the thermal behaviour next to the surface. While the UV lasers have an obviously smaller thermal effect than their counterparts of greater wavelengths [4], this effect has all the same an important role when compared with the 355 nm wavelength of the frequency-tripled Nd:YAG laser. This statement is well underscored by the fact that the thermal conductance of a copper layer not directly affected influences the machining outcome in a detectable measure.

The patterns shown in *Fig. 2/a. and 2/b.,* at completely the same settings (frequency: 100 kHz, beam deflection speed: 300 mm/s, grid spacing: 10 μm, pulse energy: 3,7 μJ), have been produced at a 15x exposure. At places where no copper has been present on the substrate, almost all the polyimide volume could be removed. The copper foil, with a thermal conductance by order of magnitudes better than that of the polyimide substrate, has been capable of carrying away a part of the heat produced, thus a 10 μm thick polyimide layer could be formed on its surface.

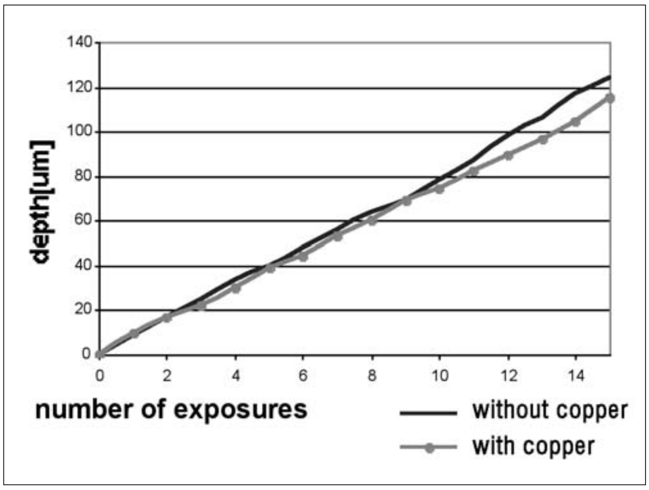


Diagram 1.
Depth as a function of the number of exposures

As it can be seen in *Diagram 1.,* each exposure step removes a ca. 8 μm thick polyimide layer. While maintaining the same settings, the copper foil bonded to the substrate did not produce any remarkable difference till the eleventh exposure. From this point on, the thickness, i.e. the heat insulation ability of the copper layer has also been reducing, so the copper could lead away certain part of the heat produced. Cleary, the ablation of the material of lower temperature requires higher energy, so that the same amount of energy permits to remove less material.

Thus it can be stated that the differences of the heat conductance caused by the patterns of the lower substrate layer have a noticeable effect on the quantities of the material removed. But modifying the laser parameters during the machining process can counter-

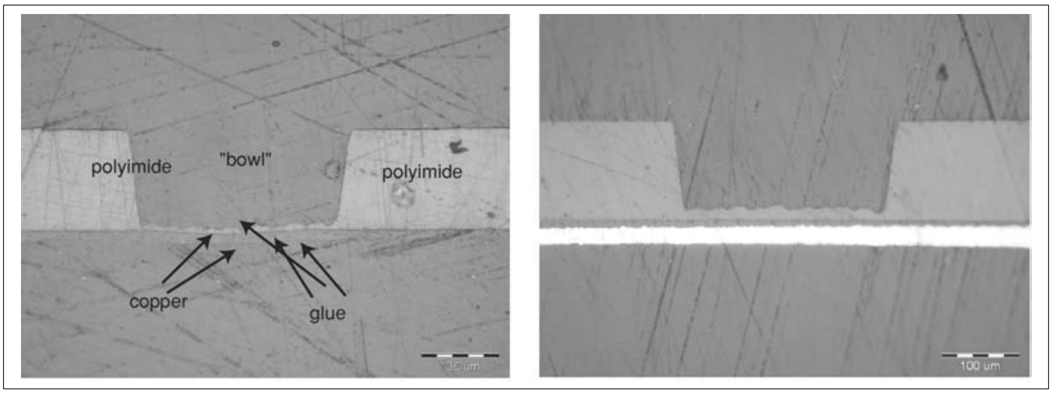


Fig. 2/a and 2/b.

Opening a window in the polyimide foil – the state after 15 exposures.

When the copper layer is present (Fig. 2/b), approximately 10 μm less material is removed.

balance this effect. In our experiments we investigated as well how the polyimide substrate responds to the changes of certain parameters. This will be shown in the following.

Effects of the pulse energy

It can be seen in *Diagram 2.* how the changes of the pulse energy, ceteris paribus, influences the depth of the "bowl" created. There is a linear correspondence between the amount of polyimide removed and the energy within a narrow range, where the depth of the grooves can be controlled easily by changing the energy. Above a specific level (25 μJ in this case), however, the increase of the pulse energy has little weight on the amount of material removed.

Because in the case of most appliances it can take several seconds to change the pulse energy, it is expedient to carry out this modification between the machining phases. We will compensate the pattern unhomogeneity by means of an other parameter, which can be changed more rapidly.

Diagram 2.
Depth as a function of the pulse energy

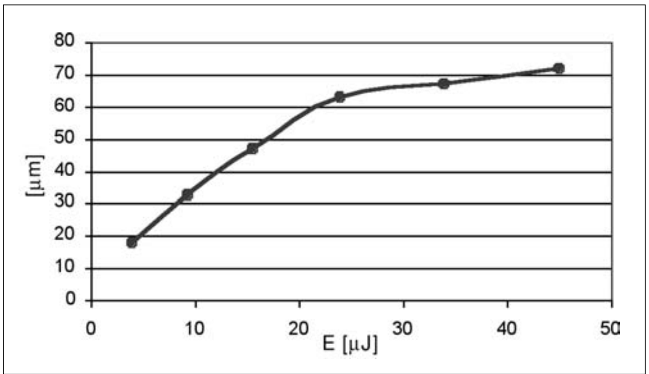
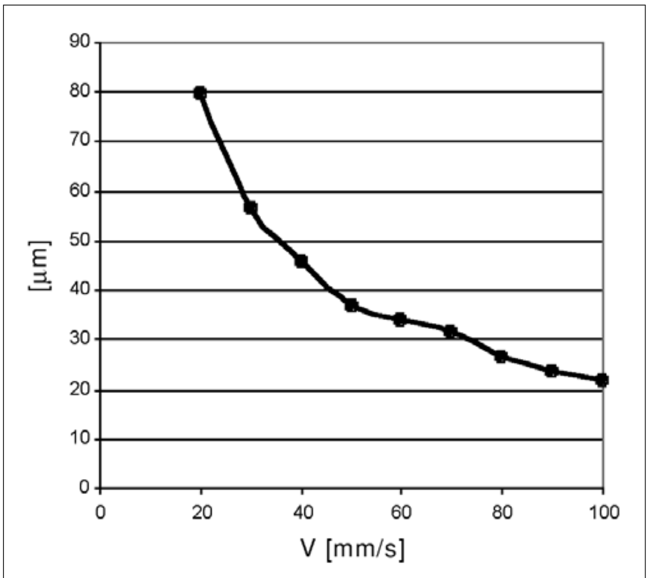


Diagram 3.
Depth as a function of the beam deflection speed



Sweeping speed

The widely used galvanometric beam deflection systems permit to produce jump changes in the sweeping speed. The speed increase produces a logarithmic reduction in the amount of the material removed, thus relatively small speed changes can compensate the high thermal conductance differences caused by the pattern. But at a given pulse repetition frequency, the beam deflection speed cannot be increased above all limits, because in this case the overlaps between the "prints" of the successive shots would diminish in such a measure that this could lead to ragging of the grooves produced.

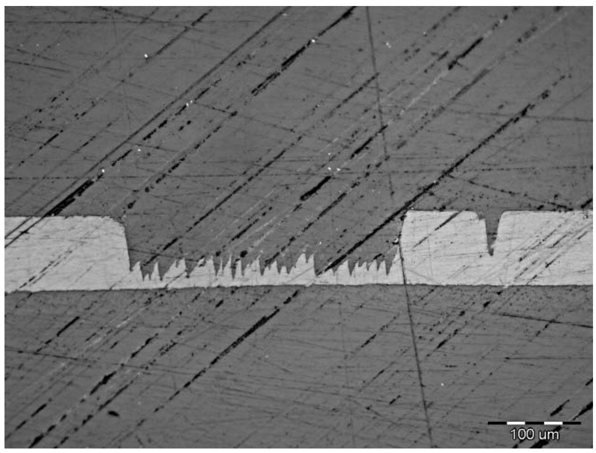
Grid spacing

When machining a given surface, the number of the adjacent grooves depends on the grid spacing. By reducing the grid spacing, the number of the lines and thus the machining time increases proportionally.

Along with the sweeping speed, the spacing of the grooves has proved to be the second definitive parameter, as it can be changed at any time, and it determines the energy fed into a unitary surface. On the other hand, the amounts of energy and its transmission interval have a direct effect on the quantity of the material ablated, i.e. on one of the most important factors of the phenomena we have investigated.

For mass production, it would be efficient to use large grids, which would permit to save time. We must, however, opt for sufficiently small groove spacing, because otherwise the surface of the material machined would be unreasonably uneven. *Fig. 3.* shows the cross section of a window manufactured at too large grid spacing. (The V shape shown on the right-hand side is the cross section of a laser-made groove.)

Fig. 3. Uneven surface due to the too large grid



Conclusion

The widespread use of CSP packages with a large number of bondouts calls for the introduction of laser-based technologies. In fact, these are not completely made suitable for the production of exact and reproducible results just down in the 10 micron range. We have seen that machining processes, as fine as this, results in the reaction of the ambience of the relevant volume on the material on the process itself.

Our experiments took place within the framework of two projects of the European Union, where we have been selecting and optimising the appropriate laser-based technologies for four sorts of rigid and flexible substrates, respectively.

Furthermore, our work aims at creating such a model, which could be a useful means for the material- and pattern-specific control of the laser beam parameters. For this purpose, we must define and simulate the dominant processes. Once this task performed, the model will be able to be built into the control program of an industrial laser-based machining station.

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News

Veraz Networks announced that MobilTel,
the largest GSM cellular operator in Bulgaria serving over two million customers, has deployed Veraz's high-compression I-Gate 4000 media gateways in its cellular network to carry domestic and international traffic. Initially, the media gateways will be used for a multi-point trunking application launched between three major cities in Bulgaria and an international point of presence (POP) in Frankfurt, with the opportunity to expand to more international POPs.

This is possible due to the advanced functionality of Veraz's media gateways to support voice, fax, modem and signaling transport while offering a unique migration option that protects existing investment and delivers a future proof, next-generation solution.

ITU has reached agreement on a new global standard
that specifies the application of the two main technologies used for encoding signals for DSL – Discrete MultiTone (DMT) technology and Quadrature Amplitude Modulation (QAM) – to VDSL (Very high-speed Digital Subscriber Line) technology. VDSL gives multi-megabit network access via ordinary telephone subscriber lines, allowing operators to offer a 'triple play' of services – multiple high-quality digital video streams, high-speed internet access and voice.

"Future evolution of the VDSL standard, promising even higher bit rates and longer distances, will be based on the DMT technology used for ADSL, thus establishing a single world-wide standard. This will allow the broadband telecom consumer to benefit from the economies of scale offered by global volumes as well as the technological innovation driven by competition." – said the Chairman of ITU-T Study Group 15.

VDSL can be deployed from central offices or from optical fibre-fed cabinets located near customer premises. Actual bit rates obtained will depend on the distance between the central office/cabinet and the customer premises and can be up to 50 Mbits downstream, but will typically be closer to 23 Mbits and 4 Mbits upstream.