Abstract: Paper deals with the problem of considerate electronic component package opening for failure analysis purposes. That opening makes the system on chip accessible for detailed optical inspection as well as for electrical tests accompanied with surface events observation. The notion for such kind of package selective opening is called decapsulation, and the paper mentions the main techniques of that. The laser decapsulation technique is described in relation to experiments aimed at the proper process programming supported with analogue signature analysis. Illustrating pictures accompany the experiments of process development.

Key-Words: failure analysis, decapsulation, fibre laser, I-V characteristic, comparison, pin print

1 Introduction
The electronic components and circuits diagnostics is facing a wide variety of component types and different manufacturing technologies. That is why also diagnostics needs different approaches and any suitable technique being able to trace efficiently the failure possible causes.

Nevertheless, there is quite a big difference in diagnostic possibilities between electronic component designers/manufacturers and component users who are building them in electronic modules or systems. This article is written from the component user position view and his facility to perform the component failure analysis on the grounds of design modification supplier change when the serious quality flaw is revealed.

The electronic circuit failure analysis takes many cause aspects into account. Each aspect represents a particular challenge for an efficient diagnostic technique compatible with that particular component design principle and/or technology. The electronic component failure analysis whether separately or in the frames of a module, there exist a lot of test techniques and corresponding test devices.

As electronic component users, we can choose a full parametric test according to the data sheet, or we can somehow simplify that task and we can use analogue signature analysis approach comparing the I-V characteristics of chosen pin pairs with a model component [1]. Apart from electrical parameters, we should perform a suitable form of design and technology analysis [2].

The failure analysis during the electronic module assembling process is mostly aimed at the manufacturing process failure causes like component interconnection quality criteria represented with shorts, opens, higher than limit connection resistance or leakage occurrence. The final stage test is mostly aimed at electronic module functionality.

More detailed failure causes tracing procedures come to the necessity to analyse the particular component itself. That means to utilize either a variant of parametric test or to utilize some special analytical procedures like X-ray technique or component package selective opening to gain inspectional access to the system on chip (SOC). Such process of package selective opening is called commonly “decapsulation”, “decap” or “delid” nowadays.

The X-ray technique can visualize the component internal structure including chip, chip supporting base, interconnection between SOC and the outside leads, and other X-ray contrast anomalies as the case may be. The only necessary condition is that the package material is translucent for X-rays and the component internal objects are contrastive enough.

Unlike the X-ray technique which is taken as non-destructive in this aspect, the decapsulation process is a destructive one because any component
after decapsulation is impossible to use in any standard application. However, it does not mean that such component is not functioning any more. The decapsulation process can preserve the component functionality for further functional and parametric testing.

The substantial condition for the component functionality preservation during decapsulation is to use the decapsulation technology or some of their combinations compatible with the component vital materials. Very sensitive structures are bonding wires and SOC. Bonding wires are predominantly from gold, aluminium and copper. The chip material can be silicon, silica and other semiconductor, insulating and conducting materials used as a bulk chip and thin layers on the surface [3].

2 Decapsulation Technologies

Delid or decapsulation means package material removal confined prevailingly to the area above the SOC with some extent to reveal also that segment of bonding wires adjacent to the SOC. There is no rule how much material should be removed because it is exclusively dependent on the goal of particular analysis.

The decapsulation technology alternative is mainly related to the goal of analysis, and to the package material. Metal and ceramic packages can be opened mechanically by cutting or splitting. On the other hand, the plastic packages represent a tricky problem for decapsulation technology. These materials are based on epoxy resin filled with different sorts of insulating filling material like alumina or boron nitride [3]. SOC, lead frame and bonding wires encapsulated in the plastic package are tightly but not hermetically surrounded with package material mostly without any cavity above the SOC. Selective decapsulation goal in this cases is to get rid of material hiding SOC and as well as bonding wires if necessary for contact quality inspection, for instance with an optical microscopy.

There are about four decapsulation technologies in common use currently some of which are to be combined with others to reveal SOC surface completely for optical or SEM inspection. There is possible to remove certain part of package with a milling process what could be a very precise and sophisticated process with the help of a special milling device, or it could be just a simple partial removal of the package material performed with a hand milling tool before etching the rest with concentrated fuming nitric acid, for instance. Such milling process needs to be stopped early not to damage bonding wires or even SOC.

The chemical etching, so called wet process, is already a highly-developed decapsulation technology supported with a wide range of automatic equipment with the acid mixing options for specific etching approach to the variety of bonding wire materials not to be damaged. As was already mentioned above, the bonding wires materials are most frequently gold, aluminium or copper. The whole process is performed with concentrated fuming nitric and/or sulphuric acids. That component exposed to the etching process is protected with a gasket which has the opening shaped according to the decapsulation contour. The wet etching process can ensure the complete material removal from the SOC surface and from bonding wires with component functionality for further electrical inspection preservation.

The dry etching with plasma and controlled laser beam material removal are comparatively newer technologies for component package decapsulation. Equipment realising the dry etching with plasma is relatively most expensive, but it offers most flexible solution for decapsulation and for analytical purposes because it is possible to perform not only the complete decapsulation but also the SOC sequential delayering for a more detailed structural and material condition analysis.

Laser decapsulation technology is often referred to as a process which needs the final wet or dry etching to reveal SOC safely. On the other hand, some manufacturers are presenting their laser equipment as being able to manage the whole decapsulation process preserving component functionality. Such statements and our own experience are encouraging our effort in decapsulation experiments with a fibre laser we have in our diagnostic laboratory [6]. We don’t doubt those very advanced and sophisticated equipment abilities to do the job well according to those statements. Nevertheless, our effort is aimed at more modest means affordable for wider range of users to monitor the product quality.

3 Laser Decapsulation Expectations

Fiber laser systems are being intensively developed recently, and they are gaining popularity because of their application possibilities [5]. We are using a laser decapsulation device based on a fiber laser system in our laboratory. It has been procured to assist in failure analysis projects for SOC optical inspection, function analysis and power dissipation monitoring.

When preparing the fiber laser decapsulation process, we can rely on many variables.
These variables are represented with particular value ranges which may influence the quantity of material removal and how much energy SOC and bonding wires will be exposed to. Some variables like power portion, for instance, have a direct influence on energy transfer while some others like beam trace speed have an indirect influence. Fig. 1 to Fig. 5 is illustrating a few steps in the fiber laser beam executed decapsulation process. These pictures have been recorded with the laser equipment inbuilt camera. Fig. 1 represents the programmed outline of package section above SOC which should be removed during decapsulation process.

Fig.1 Programmed opening outline.

Fig.2 First material layer has been removed.

Fig.3 Two material layers have been removed.

The laser beam can frame the processed opening.

Fig.4 Three material layers have been removed.

Fig.5 Component before final decapsulation step.

Following figures, Fig.6 to Fig.9, are digital microscope images of that experimental component after decapsulation. The digital microscope had magnification range from 10 to 70 and an inbuilt polarization filter.

Fig.6 Global view of component in direct light.

Samples were illuminated with a direct LED light (see Fig.6 and Fig.8), and with an oblique LED light (see Fig.7 and Fig.9). That first decapsulation process optical inspection was just indicative. It showed generally the amount of material residues.
The application of a polarization microscope with magnification of 200 for final SOC surface inspection is illustrated with Fig.10. That value of magnification and the adjustable polarization filter are necessary to see the SOC structure details like marking, numbering and damages dimensions of which are in range of micrometers.

The laser decapsulation process has to be programmed in segments to allow for preventing SOC and bonding wires to be damaged. Each segment represents the set of process parameters with particular values corresponding to that process segment task. At the beginning, the task represents quick package material removal down to the safe level above the SOC. The slower and much more careful progress follows then. All that mentioned so far indicates that the decapsulation process programming is a delicate problem. It requires not only knowledge and experience, but also some feedback about the component being decapsulated.

4 ASA Assisted Decapsulation

Above mentioned need for a feedback about the laser decapsulation process influence on the component can be fulfilled with an applicable method for evaluation the component functionality. I-V characteristics comparison method known also as analogue signature analysis (ASA) is well possible to be used for component functionality monitoring in course of laser decapsulation process development [4].

As a reference model for I-V characteristics comparison shall serve each component for itself. There is a set of component I-V characteristics to be recorded with each component before laser decapsulation process starts. The initial set of component I-V characteristics is compared with I-V characteristics of the same component when it passes the corresponding decapsulation segment in course of decapsulation process development and parameter values experimental adjustment.

Laser decapsulation process can cause remarkable changes in course of experimental process development. It, of course, could destroy SOC and bonding wires in an extreme case.
That could happen if parameter values are not set properly. Nevertheless, the component functionality could be badly influence even without damaging SOC and bonding wires. The package material burn residues deposited between bonding wires have lower than insulating resistance so that the leakage current can flow between neighboring leads. The resistance I-V characteristic can dominate over original diode junction characteristic, for instance, and the result is a resistor I-V characteristic. All such events are reflected in the I-V characteristics.

The following pictures (Fig.11 to Fig.15) are illustrating changes in I-V characteristics according to extent the SOC and bonding wires environment had been influenced. Those illustrations cover some extent an insensitive process parameter value can damage or influence the component to.

![Fig.11 Dual pin print of a functional pin pair.](image1)

![Fig.12 Dual pin print of an influenced pin pair.](image2)

![Fig.13 Single pin print of a functional pin pair.](image3)

![Fig.14 Pin print modification caused by process.](image4)

![Fig.15 Open circuit – damage caused by process.](image5)
Pin print in Fig.16 exhibits the prevailing resistance character of burnt residues between bonding wires belonging to that pin pair. The resistance is higher in this case. Pin print in Fig.17 shows a similar situation, only the resistance between pins in that pair is much lower so that a higher current flows via the pin pair during I-V characteristic recording.

5 Conclusion
The experience we have collected from our experiments with fiber laser decapsulation device and with I-V characteristics comparison as a feedback for process development so far encourages us to continue in chosen direction. All process adjustable parameters are still intensively studied and their participation on clean and safe decapsulation is further evaluated.

ACKNOWLEDGMENT
The work has been supported by the Ministry of Education, Youth and Sports of the Czech Republic under the Research Plan No. MSM 7088352102 and by the European Regional Development Fund under the project CEBIA-Tech No. CZ.1.05/2.1.00/03. This support was very gratefully accepted.

References: