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APPLICATION OF LASERS IN DECAPSULATION PROCESSES

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Abstract: *Microchip decapsulation has risen in prominence over the years in the fault analysis branch due to the increase of microelectronic component complexity. As such, a corresponding need for faster and higher quality decapsulation processes emerged. While chemical etching and CNC milling remain as the most widespread processes in professional and enthusiast decapsulation works, the application of lasers in such tasks is rapidly evolving to become an industry-leading approach to the intricacies of microelectronics fault analyses. This paper presents the fundamentals of decapsulation and explores the potential benefits of laser decapsulation techniques in the field of microchip reuse and bug analysis.*

Key words: *Laser, microchips, decapsulation, benefits, overview*

1. INTRODUCTION

It's no exaggeration to say that today's world is entirely dependent on silicon – and by association – the microchips which are made from it. Handheld calculators, computers, cars and phones are all things which are impossible to separate from everyday life. In 1954, the world took a big leap forward with the advent of the first all-transistor calculator. With processing power increasing and miniaturization – the circuits which lie upon the surface of a microchip's heart have been made denser.

A question then arises: with so many microchips around, how do we make sure they're functioning properly? While our manufacturing quality has advanced to such a degree that there hardly exists a high chance of widespread microchip failure, there must exist a way to check for defects when a software error or a hardware malfunction occurs. And that's exactly the job the fault analysts undertake, and they do so with several different approaches.

2. DECAPSULATION METHODS

A microchip is a small and compact circuit encased with an epoxy shell designed to protect the silicon core and wires connecting to the lead frame legs connecting which attach to a motherboard.

Decapsulation is a deprocessing technique that implies the removal of the mentioned epoxy capsule in order to access the software – the code which is stored on the silicon core – or hardware – silicon itself and the wires. A picture of the general packaging is shown in fig.1.

While the fig. 1 shows only one of many types of microchip packaging variations, all of them follow the same basic layout.

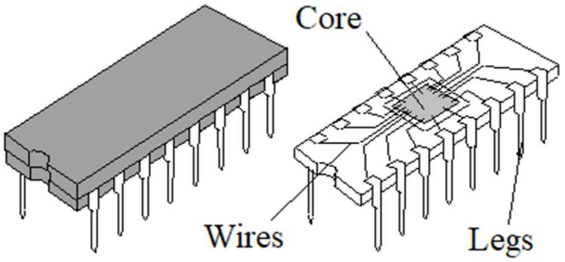

Fig. 1. Simplified illustration of microchip packaging [1]

Packaging zone that is exposed to processing can include differences in material properties and geometry making this process challenging. Monitoring of the process can be achieved by cameras [2], temperature measurement [3] or other controlling parameters [4] and techniques can be carried out. A review of the literature found that there are not so many available research results on the success of the process and applied techniques of decapsulation, but considering the limited resources of raw materials used in the production of microchips, as well as the large number of produced microchips, there is a justified need for the selection and development of the most suitable processing method. There exist several decapsulation method types other than laser decapsulation. The oldest one being something called chemical etching, wherein an acid is used to dissolve the surrounding protective capsule surrounding the silicon core. While it may be the simplest of all methods, it remains competitive due to several factors that'll be outlined later.

Machining is the second method type of decapsulation. This includes CNC milling and lapping. The milling process is commonly utilized for large-scale industrial microchips for various tools, machines and controllers, while the lapping has found some success in the desktop computer CPU market, where enthusiasts seek better thermal performances from their processors.

The final type is plasma etching – and probably the most exotic way to remove protective material from a microchip. It's a construction made from six elements – a vacuum tube with a gas chamber, an external microwave emitter which ionizes the gas, a faraday cage to protect the microchip, and of course the platform upon which the microchip sits, including a drain valve which removed etched material and aids the ion stream. Microwave Induced Plasma is an special technique to reduce the risk of any damage of the device to be treated. This system enables much higher etching rate than RF plasma systems causing the device to heat up.

Some authors involve pre-work decapsulation techniques. Dobriyal at all [4] performed chemical decapsulation tests with micro abrasion as prework to understand the die details such as location, wire bonds etc.

One of the important factors for the selection of modern technologies and thus the method of decapsulation is the controllability of the procedure and the resulting accuracy in application [5].

In the following paragraphs, mentioned methods will be presented more detailed, as well as an outline of their advantages and shortcomings.

3. DECAPSULATION BY CHEMICAL ETCHING PROCESS

The silicon core and wires are exposed by dissolving away the epoxy which makes up the structure of the capsule. There are many types of acids used, but the most common ones are yellow or red nitric acids (fig.2).

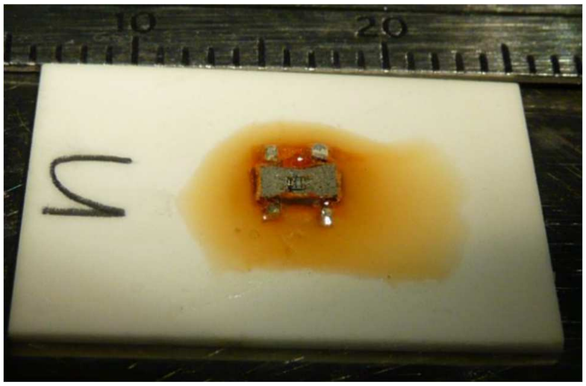

Fig. 2. Types of nitric acids dissolving away the epoxy capsule [6]

Yellow nitric acid (fig.2) is primarily used to remove the epoxy only until the wires are exposed, while for the rest of the decapsulation process the red nitric acid is applied. This way the process is highly selective. In fact, it's one of two only processes that can completely decapsulate a microchip, alongside plasma etching.

Low concentrations of red nitric acid are required to stop the corrosion of aluminum wires and lead frame legs, but it should only ever be used on a hotbed platform, since it evaporates at roughly 70°C. If the wires are made from copper, the hotbed is a requirement since the corrosion rapidly starts working through them.

While the process is highly selective and takes merely minutes to complete, it must be kept in mind that acid choice and their concentrations may vary with capsule material, packaging and location, if the microchip is unable to be isolated.

As such, other factors to pay attention to are: air moisture, which can worsen the corrosion, varied rates of etching according to said material

– which can, at worst, cause pitting and therefore reach the silicon faster, resulting in its destruction. Spillage is a concern if the microchip wasn't removed from its parent motherboard, and can without proper care damage surrounding components.

In addition, if the failure of said microchip caused the appearance of burnt or carbonized plastic, this method is unable to be used.

4. DECAPSULATION BY MECHANICAL PROCESSES

4.1. Lapping

Decapsulation via lapping is a fast way to remove excess material of the capsule, and is done across the entire surface of the chip. 400 to 600 grain paper is used to lap down to the depth of the wires. Lapping is unable to reveal the silicon, and as such is used in combination with other methods, such as chemical etching and plasma etching.

Fig. 3. Flat lapping of a copper heatsinks [7]

4.2. CNC milling

Similar to lapping, this isn't a process which can expose the circuitry on the silicon core, and most commonly chemical etching is used to finish the decapsulation. To increase the volume of removed material, microscopic and interferometric monitoring have become popular, as well as x-ray imaging during the milling period.

Both methods are limited by the size of the microchip itself, since it's difficult to find suitable clamps to fix the workpiece during decapsulation. For the case of lapping, manual labor can be used, however that's inefficient. Additionally, milling is also dependent on the size of the tool used. While small radius tools exist, they're unable to reveal the wires. Application of the milling process is also highly sensitive on dynamic performance of the milling machine specially with 4+ controlled axis with at least one rotary axis [9].

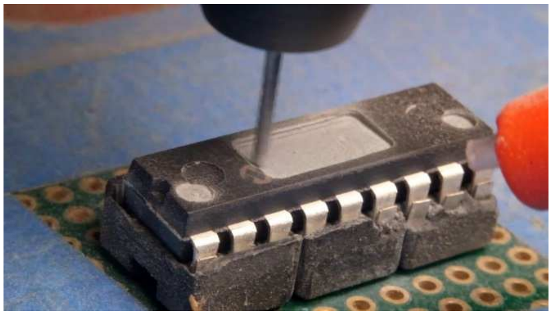

Fig. 4. CNC milling of the capsule [8]

5. DECAPSULATION BY THERMAL PROCESSES

5.1. Plasma etching

This process uses excited O2 and CF4 gases as sources of ions. Using different kinds of excitable gases, the processes will inherit different features, primarily the ability for selective material removal. The resulting plasma is directed through a vacuum chamber protected by a faraday cage which stops unwanted microwaves from damaging the rest of the setup.

Unlike CNC milling and laser decapsulation, while this process can be isolated to the face of the microchip, the removal is not uniform. Due to this property, additional protective films need to be applied onto the surfaces which do not require etching. Since this is also done within the confines of a vacuum chamber, the danger of overheating the chip shouldn't be disregarded, as this can destroy the circuitry of the silicon core.

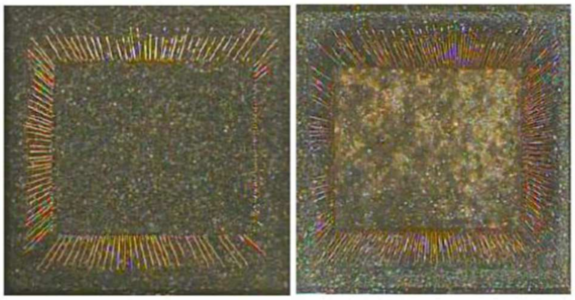

Fig. 5. Non-uniform decapsulation of plasma etching [6]

The speed of etching is depended on the parameters of microwave radiation. Older 300-watt systems require nearly two hours to decapsulate a single chip, while newer 500-watt systems need around 20 minutes for the same type of chip.

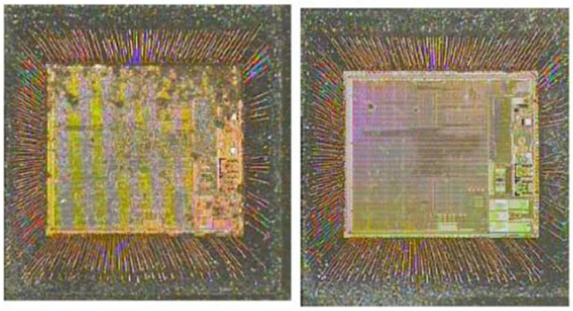

Fig. 6. The final result of plasma etching [6]

5.2. Laser ablation

Pulsed lasers which work on wavelengths between 1000~1100 nanometers can be used for microchip capsule material removal. Because of the completely digital nature of the workstation, the machining parameters can easily and precisely be defined.

The rate at which the capsule is removed varies with ablation rates determined by laser strength, however due to the flimsy and vulnerable nature of the microchip and its internals, the ablation rate is anywhere between 25 and 100 micrometers. At this pace, decapsulation is done within minutes.

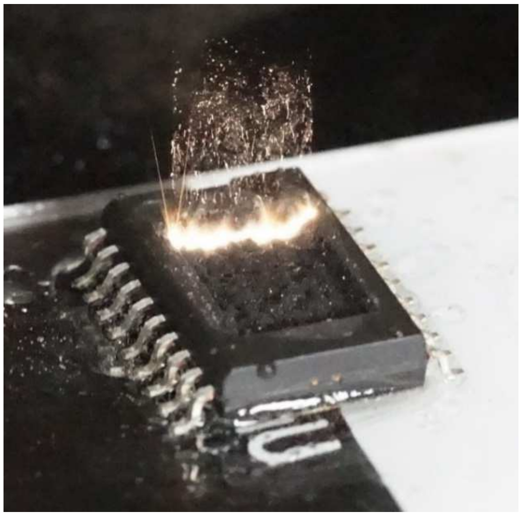

Fig. 7. Laser ablation [10]

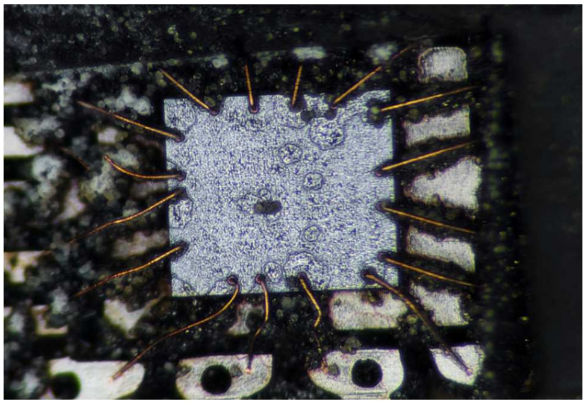

Fig. 8. Melted core after it was in direct contact with the laser [10]

The duration of the pulse is kept as short as possible since the removed material is a polymer. Unfortunately, the silicon core mustn't be exposed to the laser if the thickness of the remaining material is less than 100 micrometers, since there's a possibility of melting the core.

As far as selectivity is concerned, the wires remain completely untouched (as seen on figs. 8 and 9). Copper for instance, isn't at risk of damage since it reflects almost all the light emitted from the laser.

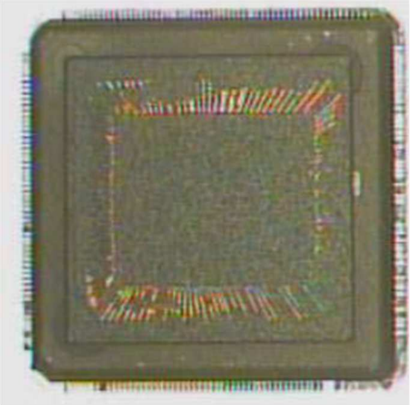

Fig. 9. Ablation limits achievements [6]

6. DECAPSULATION METHODS COMPARISON

Similar to other manufacturing processes, the decapsulation process can be achieved by different material removal techniques which are presented in this paper. Considering the high sensitivity of the components being processed, we tried to look at different aspects of the impact of the applied technology. It was identified the following important parameters for preserving the treated components: preparation of the processing, speed of processing, destructive influence, selectivity during processing, product contamination, economy of the process and future improvements and development of the process.

Assessing of applied method was made by analysis of available literature sources and data. Grades are defined by labels (+, o, -) with meaning better, mediate or weaker. All the findings relevant for decapsulation method selection are presented in table 1.

Table 1

Decapsulation methods comparison

	Chemical processes	**Mechanical processes**	**Thermal processes**	**Laser**
Process preparation	+	- -	o	+
Processing speed	o	++	o	+
Destructivity	+	- -	o	o
Selectivity	+	+	+	o
Product contamination	o	o	+	+
Processing costs	o	o	+	+
Developing possibility	+	-	o	+
Overall rating with rank	2	4	3	1

7. CONCLUSIONS

The decapsulation process involves the removal of material in the way that the contents of the capsule remain intact. The application of the laser in this process is achieved by removing the surface layers of the material by ablation.

In order to determine the effectiveness of laser ablation, a comparison was made of other commonly used procedures for decapsulating microchips. Main advantages and disadvantages are pointed out, namely during acid etching, milling with a CNC machine, lapping, plasma etching and finally laser ablation processes.

In this particular application, the laser is a very good choice, because it enables sufficiently high processing precision and a short procedure time, which is almost incomparable to the other listed procedures. In this context, the laser can almost completely replace CNC machines and the lapping process.

However, comparing the application of the laser with acid or plasma etching, the laser is not able to completely decapsulate the microchip, because it is not selective during continuous processing. By applying laser ablation, even if it is very uniform in processing, the destruction of the microchip core cannot be avoided if the beam comes into contact with the core.

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APLICAREA LASERELOR ÎN PROCESELE DE DECAPSULIZARE

Rezumat: Decapsularea microcipului a crescut în proeminență de-a lungul anilor în ramura analizei defecțiunilor datorită creșterii complexității componentelor microelectronice. Ca atare, a apărut o nevoie corespunzătoare pentru procese de decapsulare mai rapide și de calitate superioară. În timp ce gravarea chimică și frezarea CNC rămân cele mai răspândite procese în lucrările de decapsulare profesioniști și entuziaști, aplicarea laserelor în astfel de sarcini evoluează rapid pentru a deveni o abordare lider în industrie a complexității analizelor defecțiunilor microelectronice. Această lucrare prezintă elementele fundamentale ale decapsulării și explorează potențialele beneficii ale tehnicilor de decapsulare cu laser în domeniul reutilizării microcipurilor și analizei erorilor.

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