



Published in the SUSS report 2019

AN OVERVIEW ABOUT THE EXCIMER LASER ABLATION OF DIFFERENT POLYMERS AND THEIR APPLICATION FOR WAFER AND PANEL LEVEL PACKAGING

Robert Gernhardt

Fraunhofer Institute for Reliability and Microintegration
IZM Berlin | Germany

**Markus Wöhrmann, Friedrich Müller,
Karin Hauck, Dr. Michael Töpfer**

Fraunhofer Institute for Reliability and Microintegration
IZM Berlin | Germany

**Prof. Dr.-Ing. Dr. sc. techn.
Klaus-Dieter Lang**

TU Berlin | Germany

Ph.D. Habib Hichri, Ph.D. Markus Arendt

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Robert Gernhardt Fraunhofer Institute for Reliability and Microintegration IZM Berlin, Berlin, Germany

Markus Wöhrmann, Friedrich Müller, Karin Hauck, Dr. Michael Töpfer Fraunhofer Institute for Reliability and Microintegration IZM Berlin, Berlin, Germany

Prof. Dr.-Ing. Dr. sc. techn. Klaus-Dieter Lang TU Berlin, Berlin, Germany

Ph.D. Habib Hichri, Ph.D. Markus Arendt SÜSS MicroTec Inc. Corona, CA, USA

The demands for packaging for either wafer or panel respectively heterogeneous integration in general are rising. New materials and technologies are needed to address the challenges resulting from that demands like better dielectric properties or higher resolution just to name two examples. The excimer laser ablation is able to meet that needs and process the new materials, which are not always photosensitive anymore. The system used for this paper is a combination of a projection stepper platform combined with an excimer laser. The field of application for this system is quite wide. It can be used for laser debonding of supporting substrates or the seed layer removal after galvanic. The main application, however, is the ablation of all types of polymers to generate VIAs for example. In contrast to already known PCB lasers, it is also possible to ablate complex structures in parallel, as it is a mask-based technology. Due to that, it is possible to generate trenches and VIAs within one step. This enables a technology already known from the front end of line (FEOL) to be transferred to the back end of line (BEOL): the dual damascene process.

Within this paper, all the mentioned applications and the experience with a broad variety of polymer materials such as Polyimide, PBO, BCB, ABF, Dry Films are going to be presented. It is going to be shown that the excimer laser system can overcome the limitations of common polymers in terms of resolution and that the laser dual damascene approach can meet the needs for the overall demand towards 2µm lines and space for packaging. Additionally some reliability data is presented that prove that the laser ablation can replace the today common lithography processes without any drawbacks.

Key words: Excimer laser; ablation; dual damascene; FOWLP, wafer level packaging.

INTRODUCTION

Today the demands on wafer as well as panel level packaging are rising due to the overall trend of rising I/O counts and the need of thinner packages for example. One of these demands resulting of the high I/O count is the need of an increasing routing density to avoid a higher number of redistribution layers per package. Besides, the cost aspects of each layer also the technological aspects are rising. The more layers the more stress is generated inside the package, which lowers the reliability. Another aspect is the rising topography added by each layer, which influences the following layers or makes it necessary to integrate cost sensitive planarization steps. Increasing the routing density means to increase the achievable resolution for resist as well as polymer processing. To achieve this, two parts of the process have to be enhanced: the exposure system and the capabilities of the resist resp. polymer system. Both are challenging and sometimes not possible due to chemical limitations of the polymer system for example. Today common polymers allow the photographic realization of 20 to 40µm VIAs. For some applications, non-photo material like ABF becomes attractive and needs to fulfill the same requirements like mentioned before. However, the common technologies used to structure non-photo polymers like dry etching cannot fulfill these requirements as the under-etching does not allow a high resolution and is in case of filled material like ABF not possible.

The newest exposure systems and resists can already address the demand towards two-µm resolution for the redistribution layers (RDL). However, the semi-additive process, which is commonly used to generate the Cu RDL, faces some new challenges. The adhesion of the Cu

lines is lowered due to the small footprint. The under-etching of the seed layer etching gets a more challenging process too. Both rising the risk of lifting the Cu lines. Bringing the lines close to two μm generates a strong electrical field, which enhances the electrochemical migration between the Cu lines. This sets new demands on the chemistry of the polymer to avoid an electrical short over time due to the electrochemical migration.

In the past years the processing and handling of thinned wafers and modules gets a key technology in 2.5D- and 3D-packaging. The supporting technology needs to withstand harsh influences during the processing like high temperatures while enabling a de-bond process with nearly no impact on the supported wafer resp. module at the same time.

The excimer laser ablation in combination with a projection system and a stepper-based platform can address all these challenges or enable new process flows, which allows solving the mentioned problems.

BACKGROUND

ABLATION PROCESS

The laser ablation or pulsed laser ablation is a process in which material is removed by a short laser pulse with high intensity (which is measured as the fluence). This takes place far from equilibrium, which allows suppressing the excitation energy outside of the ablated volume. According to Bäuerle [1], the process is based on two different main mechanisms – the photothermal and photochemical ablation – and a mixed mode of both. The energy of the photons (the wavelength of the laser) and the fluence are mainly responsible for the mechanism. If the fluence of the

laser is below a certain threshold, the energy of the laser is absorbed and transferred into heat. The material starts to melt and gets eventually evaporated. If the fluence of the laser is high enough, the chemical bonds break and gaseous products are formed under an enormous change of volume. This leads to an explosive-like ablation process. The threshold where this happens is defined by the bond energies of the material, which is ablated. For polymers with bonding energies between 3.6 eV and 4.3 eV of C-C and C-H, high-energy ultraviolet photons are able to break most of the interatomic bonds. As a polymer consist of many different interatomic bonds, the mode of ablation is a kind of a mixed mode with the dominance of the photochemical ablation. The threshold of most inorganic materials like metals is different to the threshold of polymers. This allows the structuring of polymers on top of these materials without destroying the material underneath.

The photon energy of excimer lasers of above four eV is sufficient to cause the photochemical ablation process of polymers. Unlike most laser sources, the excimer laser produces a large area beam, which can be widened and formed in optical systems. This allows the usage of excimer laser systems in projection exposure systems for ablation. The light can be directed through a structured mask and projected on a work plane. The glass material has to be transparent to the wavelength. The light blocking material is Al as it has a very high threshold level for ablation. The threshold of the commonly for exposure used Cr is too low. In this work, a laser ablation system from SUSS MicroTec (ELP300) has been used. It combines an excimer laser source with a projection system and a high precision stepper platform. The used laser is a Coherent “LXPpro 305” with an output power of 40W.

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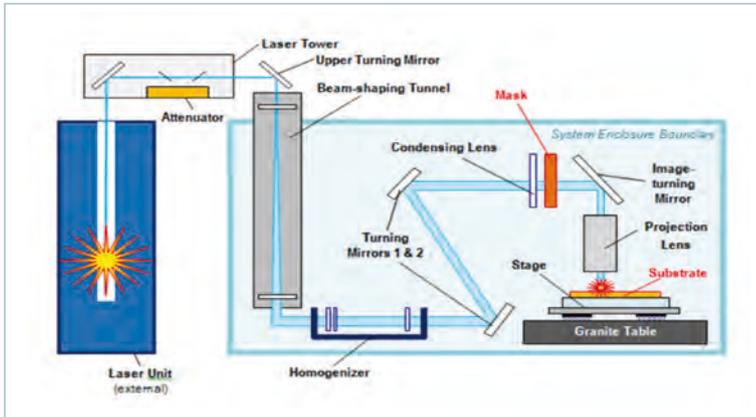


Figure 1 System schematic of ELP300 [2]

It is a KrF laser with 248 nm wavelength and 50Hz repetition rate. The system has a maximum beam spot size of 6.5x6.5 mm² and the fluence can be varied between 70 and 650 mJ/cm². A setup of the system is shown in Figure 1.

The laser light is directed through a mask and projected and focused on the wafer surface. As a result, the pattern in the mask is ablated in the polymer present on the wafer. In principle, the system works like a projection stepper with the big difference that the patterns of the mask are not exposed in the resist or polymer, they are ablated.

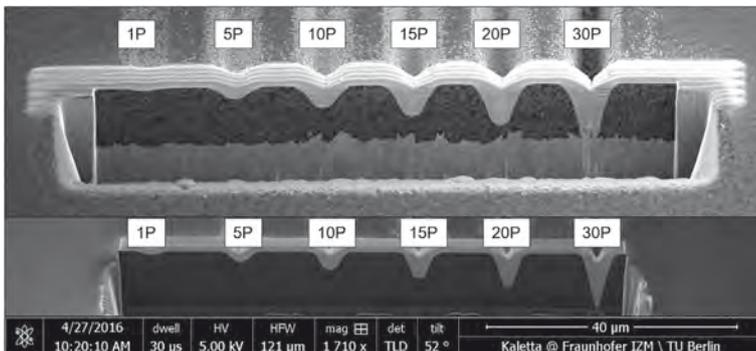


Figure 2 FIB cross section of ablated ABF (top) and PI (bottom)

EXPERIMENTAL RESULTS

Different polymers in different applications and projects have been ablated over the last years. The summarized results and key findings are presented in this section.

As already mentioned in the previous paragraph, every polymer can react to the ablation process a bit different. The ablation results depend on fluence, number of pulses, the patterns to be ablated and the ablation characteristic of the material. Besides the ablation rate (ablated material measured in µm per pulse), the formation of the pattern resp. the cross section of pattern can differ too. A number of test ablations are performed with different parameters (usually number of pulses, fluence) and the results (depth of ablation, side wall angle etc.) are analyzed like shown in Figure 2.

In general, it can be stated the higher the fluence the higher is the ablation rate like shown in Figure 3.

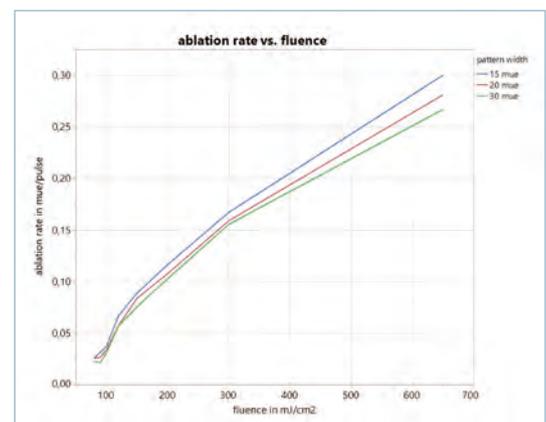


Figure 3 Ablation rate of BCB

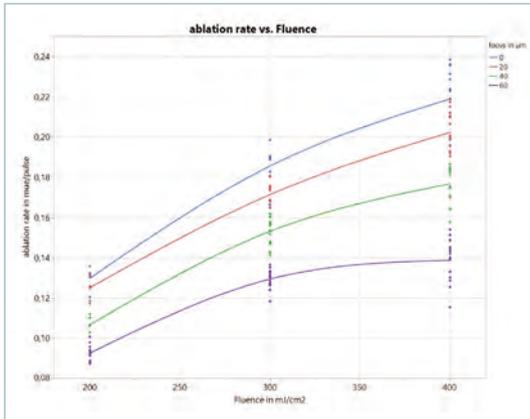


Figure 4 Focus and fluence variation of ablated PI (CD 5 μm)

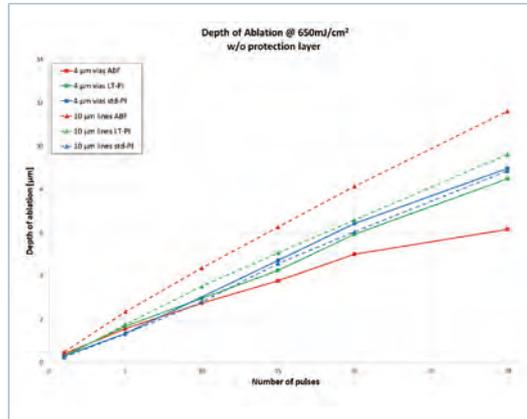


Figure 5 Ablation depths of different polymers and patterns over number of laser pulses

At some point, the ablation rate reaches saturation and is not rising anymore [3]. This effect can be observed, if the focus of the laser is intentionally de-focused like shown in Figure 4. The ablation rate is going into saturation for a focus of +60 μm.

In Figure 3 can already be seen that the ablation rate is sensitive for the width of the ablated structure. Besides the opening width, there is also dependency of the form of the ablated structure. The ablation rate of VIAs is in some cases different to the ablation rate of trenches for example. In Figure 5, you can see the ablation depth over the number of pulses of different polymers and patterns. Four μm VIAs and 10 μm trenches have been ablated. The analyzed PI – one low temperature and one conventional PI – show only a slightly difference between VIA and trench ablation. The ABF material shows a significant difference between the ablated patterns. The trenches are ablated much faster than the VIAs. One reason could be the filler particles in the ABF, which may inhibit the material transport out of the ablated structure.

The calculation of the ablation rate shows this more significant (Figure 6). The difference between the ablation rate of 10 μm line and 4 μm VIA ablation of ABF is nearly constant at 150 nm/pulse. The difference for the low temperature PI is only about 40 nm/pulse and the difference for the standard (high cure) PI is neglectable as it is in the range of measurement accuracy.

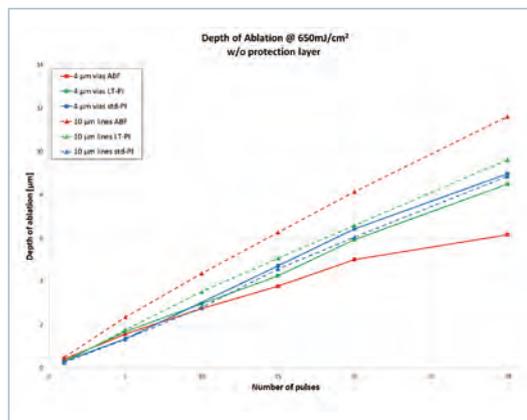


Figure 6 Ablation rate of different polymers and patterns over number of laser pulses

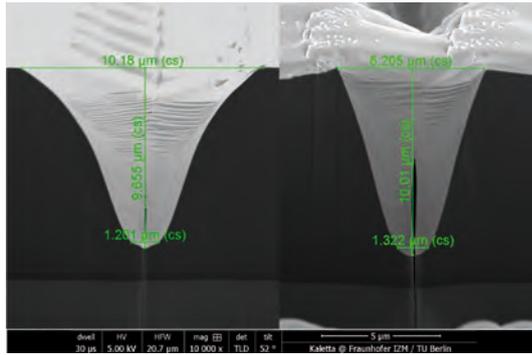


Figure 7 Ablated trench in PI without (left) and with protection layer (right); 4 μm mask size (trenches filled with Pt during FIB preparation)

Besides the ablation depth, the sidewall angle of the ablated structures as well as the flaring at the top of the structures are important information to setup a proper ablation process. Both values depend much on the material and the used fluence. A prediction model was presented by Paterson [3]. While the sidewall angle can be controlled with the fluence and wavelength (if possible), the flaring at the top of the structures can be reduced by using a protection layer on top of the ablated material. The protection layer should ideally be a thin film on top of the polymer, which should be easy to ablate with a low number of additional needed pulses and easy to strip after ablation. The flaring on top of the opening is pushed into this protection layer, which results in straighter sidewalls at the top like shown in Figure 7. The ablation parameter in both sample are the same. The resulting depth is nearly the same with about 10 μm but the flaring on top is highly reduced (6.2 μm instead of 10.2 μm). The protection layer has additionally another benefit. During ablation, residues are generated (material dependent) called debris. Most of them are removed by a high efficient vacuum cell, but some debris is deposit around the ablated structures. There are several possibilities to remove it. With the help of the protection layer, the debris is removed together when the protection layer gets stripped.

APPLICATIONS

VIA GENERATION

One of the benefits of the used laser system is the massive generation of VIAs in parallel due to the use of the mask technology in contrast to sequentially working laser ablation systems known from the printed circuit board technology. The ablation process is setup to the polymer thickness and the under-laying metallization. As already described in the previous section, the ablation process stops on the metal layer if the fluence is adjusted correctly. A cleaning step is performed afterwards to remove the generated debris. In previous works the characteristics of ablated VIAs in different polymers has been studied [4],[5]. Kelvin structures with VIA openings from four μm to 30 μm were realized to measure the contact resistance of a single VIA. The achieved resistances are comparable to lithographic generated VIAs (Figure 8). The resistance rises with smaller VIA diameters. The film thickness was kept constant, which means that the aspect ratio of the VIA is rising with smaller diameters. This could cause that the metallization gets thinner at the bottom of the smaller VIAs and could be one root cause for the rising resistance.

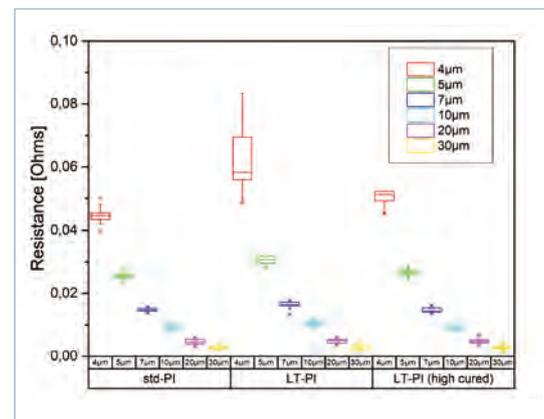


Figure 8 VIA resistance of different polymers and openings sizes (polymer thickness: 7 μm)

Nevertheless, the formation of high aspect ratio VIAs allows increasing the routing density without reducing the polymer thickness. Common lithographic generated VIAs below $10\mu\text{m}$ are usually limited to a maximum aspect ratio of one [6]. For the ablation technology, high aspect ratio VIAs with VIA depth three times bigger than the opening size could be demonstrated in dry film BCB [5].

The other benefit of the used laser ablation system is the stepper platform. It allows a sub-micron alignment accuracy, which can be performed global or site-wise. This is a necessary feature for fan-out wafer or panel level packaging to increase the yield resp. to enhance the routing density. One of the bigger issues in fan-out packaging is the shift of the dies during molding. This makes it necessary that the landing pads for the VIAs are 1.5 to three times bigger than the VIA opening to hit the pads of the shifted dies in commonly used mask aligner technology. The ablation tool can perform the alignment site-wise, which is time-consuming. It can also ablate at the real position given in advance by an automated optical inspection (AOI) performed after molding and the use of a global alignment. Both allows to reduce the needed landing pad size to just a few um bigger than the VIA size.

DUAL DAMASCENE

As the ablation depth can be controlled by the number of pulses, it is possible to stop inside of the polymer layer. The high alignment accuracy allows ablating trenches and VIAs within the same process step, which enables to bring a front end of line process into the back end of line: the dual damascene process. The trenches are going to be ablated first, followed by the

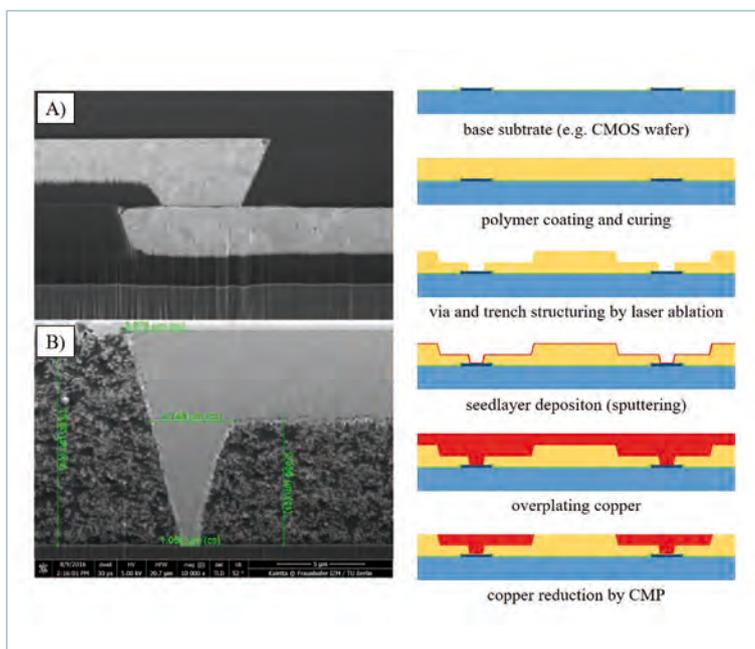


Figure 9 Left side: cross sections of dual damascene RDL (A: LT-PI / B: ABF); right side: process flow

VIA ablation inside of the trenches. The VIA can have the same size as the trench. The created structures are filled with Cu and the overburden on top of the polymer is removed by chemical mechanical planarization (CMP). Some sample pictures of cross sections in low temperature polyimide and ABF and the schematic process flow can be seen in Figure 9. Different test samples were generated to analyze the process capabilities. A daisy chain structure was built-up to analyze the contact between two dual damascene layers with 960 VIAs within one die. These samples had an overall good yield [7]. The second realized test sample was an interdigital finger structure (capacitor IDC).

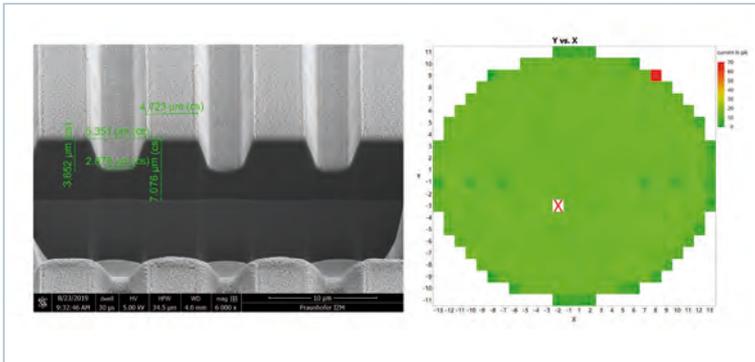


Figure 10 Left: cross section of the ablated trenches; right: wafer map of leakage current of 5 μm L/S IDC in PI

The purpose of the IDC is to check the electro-migration behavior between dense Cu lines and it allows judging the wafer yield by measuring the leakage current between the IDC fingers. A cross section of the ablated trenches and a wafer map of IDC with five μm resolution is shown in Figure 10. Only one die had an electrical short and at one die at the wafer edge the leakage current was marginal higher (70 pA instead of ~10 to 25 pA).

The samples were subjected to a temperature humidity bias test (THB: 85 % relative humidity; 85 °C; 5 V bias) and showed no electro-chemical migration during the test period [8].

A reduction of the resolution down to two μm lines and space can be shown with the laser dual damascene technology (Figure 11). Two-μm Samples, which were generated with mask aligners in semi-additive technology (SAP) to compare both technologies, showed a significant worse yield. The reduction of the Cu line density down to two-μm resolution sets new demands regarding the electro-chemical migration. The damascene approach has the benefit that the seed layer is not only under the Cu lines (like in SAP technology). The seed layer clades the Cu lines and can be used as a diffusion barrier. Investigation regarding that are currently ongoing.

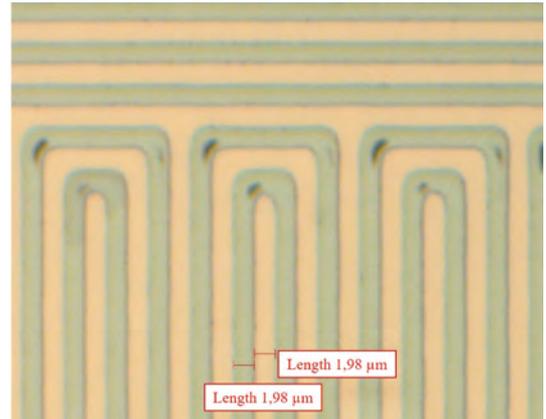


Figure 11 Two μm L/S Cu lines in LT-PI

SEED LAYER REMOVAL

Another application for the excimer laser can be the seed layer removal on top of polymers. When a laser pulse hits the substrate an energy shock impulse is introduced in the polymer under the seed layer, which results in a lifting of the thin metal film and some amount of polymer. This can be done mask-less with only one laser pulse. The embedded Cu lines are not affected. EDX analysis of the surrounding polymer (Figure 12) showed no presence of metal ions and electrical measurements confirmed the results. During the sputtering process, metal ions get into the upper nm of the polymer layer resulting

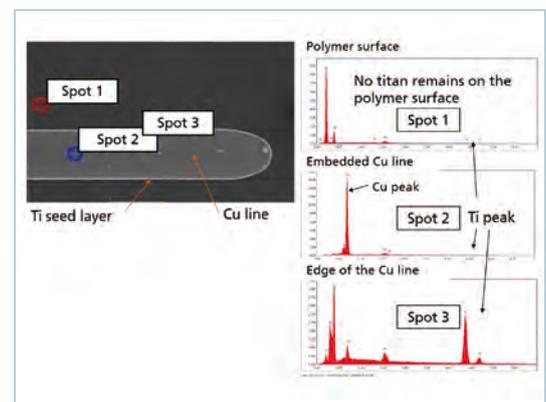


Figure 12 EDX analysis of laser seed layer removal

in a higher conductivity at the surface. A plasma de-scum step after wet etching of the seed layer is usually necessary to remove these upper layer. The EDX analysis and the electrical measurement after laser seed layer removal shows that no additional plasma de-scum is needed as the upper nm of the polymer are also removed by the laser pulse.

LASER ASSISTED DE-BONDING

Besides the structuring of dielectric layers, the direct bond breaking effect of the laser ablation can be used for another application: the laser assisted de-bonding. The 2.5D- and 3D-integration demands for thinner and stacked packages. Therefore, a supporting (temporary bonding) technology is needed which is able to handle thinned wafers and withstand the different processing technologies used for wafer processing. Thermoplastic polymers have been used for a long time but they suffer from high temperature processes like the curing of RDL polymers for example. They melt at higher temperatures, which limits their usage. The de-bonding of such supported wafers introduces additional thermal and mechanical stress at the end of the process chain and increases the risk of damaging the devices. The excimer laser enables the usage of other polymers with higher glass transition temperatures. The device wafers are bonded to a glass support carrier. This glass carrier has to have a high transmission at the wavelength of the excimer laser to enable a proper laser assisted de-bonding. The tests have shown that at least 15 % transmission is needed at the wavelength of the used laser system (248 nm) for this work ^[9]. The de-bonding is performed by exposing the used bond polymer through the backside (glass side) of the wafer stack. The adhesion bonds are broken and after the whole wafer is exposed, the glass carrier can be lifted easily with nearly no need of force. Afterwards, the device wafer

needs to be cleaned as most of the polymer remains on it. During the whole laser de-bonding process the wafer is less exposed to thermal and mechanical stress as compared to conventional thermal mechanical de-bonding technologies while the usage of other polymers enables the usage of more aggressive process technologies. The support carrier can even be left on the device during dicing. This allows the flip chip bonding of very thin devices without risking a break and the glass carrier can be de-bonded afterwards ^[9].

CONCLUSION

The versatile application of excimer laser ablation from VIA generation to fine pitch dual damascene as well as seed layer removal and the usage in support bonding technologies could be shown within this paper. The technology is independent from substrate sizes as the projection principle can be scaled to nearly every substrate size in contrast to mask aligner technology for example. This makes the technology attractive for the use in fan out panel level packaging, where large mask sizes and the lack of flexibility of the mask aligner technology are getting a problem. The dual damascene approach together with the laser seed layer removal enables additionally to skip many wet chemistry process steps like development and wet etching. The usage of other material as the seed layer to use it as a barrier layer in the dual damascene process could be a promising approach to reduce electro-chemical migration between dense Cu lines and is going to be further investigated.

Acknowledgements

The project on which this publication is based was partly funded by the Federal Ministry of Education and Research under the funding codes 16FMD01K, 16FMD02 and 16FMD03.

The author would like to thank the colleagues of Fraunhofer IZM and TU Berlin, which were not mentioned as co-authors. Furthermore the author would like to thank the teams from SUSS MicroTec, Ajinomoto, Fujifilm Electronic Material and Dow for their support.

Robert Gernhardt received a diploma degree in Microsystems Technology from the University of Applied Sciences in Berlin in 2007. Afterwards he started as a working student at Fraunhofer Institute for Reliability and Microintegration (IZM) while studying Electrical Engineering at the Technical University of Berlin. After receiving his master's degree, he started as a research engineer at Fraunhofer IZM. He works as process development engineer in the field of Wafer Level Packaging with focus on high density redistribution layers and 3D integration. Until now he has authored and co-authored several technical publications in the area of laser ablation and Fan-Out Wafer Level Packaging.



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This article was originally published in the proceedings of the IWLPAC in October 2019