UV laser copper pad surface exposure for Laser Direct Structuring (LDS) of interconnection

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***Abstract*— Microelectronics market demands strong miniaturization and high-quality packages solutions; therefore, companies and researchers start thinking about alternative methods to create more flexible and performing interconnections which are able to reduce package dimensions. Laser direct structuring (LDS) technology creates a conductive pattern on MID (Moulded Interconnected Device) with the combination of laser layout structuring and electroplating bath. LDS can be applied to leadframe based IC packages to realize interconnections in alternative to standard wires connection. Feasibility study on copper (Cu) pad covered by moulding compound is conducted varying laser parameters as power, frequency and scanning speed to obtain a 80µm diameter via on die. Die via is connected through a trace with a 200µm diameter via on lead to realize the interconnection path, filled with copper after plating process. UV 355nm wavelength laser is used to obtain a complete exposition of Cu surface without silicon damage. Visual inspection with optical microscope and SEM analysis method are performed to evaluate the integrity of metal pads and interconnection layout.**

Keywords—LDS (laser direct structuring), DCI (direct copper interconnection), laser, semiconductor packages

I. Introduction

LDS (Laser direct structuring) [1] technology is mostly used to create conductive patterns on MID (Moulded interconnected Device). MID technology is easily adaptable even for a variety of innovative electrical device designs. [2] Special fillers, such an organometallic complex or inorganic spinel compounds, are combined in the MID used in LDS. The filler is exposed by the laser, which causes a physicochemical reaction; the metal atoms that are exposed from this reaction serve as the catalytic nuclei for electroless plating. [3]

With the combination of laser layout structuring, electroless plating and electroplating plating baths it is possible to create interconnections on molding compound surface. Electroplating is an alternative method to realize copper interconnections proved to be better than methods such as stencil printing, dispensing and mechanical pressing using as filling material copper, silver pastes and copper rivets. In fact, these latter methods have shown problems of filling the structures made by the laser due to the size of the particles of the pastes and showed the best results with silver paste. [4]

LDS technology can be investigated as an alternative to wire bonding to realize interconnection for leadframe based packages. Using a laser machine to create vias and traces, which reflect CAD drawings, is crucial for the realization of copper interconnections. To achieve this goal, it is necessary to find laser parameters that allow to remove the amount of resin required to expose the device without damaging it, thus allowing to obtain dimensions that enable copper plating, which completely fills the cavities.

A recent study demonstrated the possibility of realizing vias, with a diameter of 90µm and 250µm deep with an approximate aspect ratio of 3, through resins that contained alumina or silica particles as fillers using a 355nm UV laser.[5]

Since 1995, when solid state UV laser was introduced in the laser drilling market, it has been considered an excellent solution because it couples well with a wide spectrum of materials, especially with most microelectronic materials including copper and dielectrics and also allowing to obtain via diameter lower than 100µm. [6]

Recently B. Tan et al. [7] demonstrate that is possible to obtain micro vias with a diameter of 20µm and 100µm deep always using a UV laser. However, the aspect ratio is too high to allow acceptable structures to be obtained by electrodeposition.

The purpose of this paper is to explore the feasibility of the application of LDS technology for the realization of copper interconnection starting from the developing of the laser process on top of molding compound coupled with copper pad on die. Laser feasibility process has been studied to realize good aperture of the via on molding compound with good exposure of Cu pad metal.

This paper present first the experimental section that deepens into the materials, characterization methods and process used and finally analyzes the results obtained.

II. Experimentral Section

A. *Material preparation*

Bare copper leadframe with LDS molding compound and die with Cu pads metals was used for this investigation. UV picosecond laser with 355nm wavelength is used to obtain laser vias with a target of 80µm diameter for die, 200µm for lead and 10µm depth for traces on molding compound top surface.

B. *Characterization*

Visual inspection on Cu surface is performed with high resolution optical microscope able to detect defectivity as mold residuals, die pad damaging and layout was also investigated.

Optical microscope was used to investigate the morphology of the samples and to measure vias diameter, instead with the usage of profilometer traces depth was measured.

Additional SEM inspection is conducted to double check on Cu surface integrity. Data analysis was carried out with JMP software.

The data of the three main structures created by the laser were considered for analysis: Die vias, lead vias and traces (Fig 1). Laser process quality is governed by a lot of parameters related to the laser source itself as wavelength, power, beam diameter, related to hardware, as for example scanner speed along axes, motion table travel velocity and software as programmable drilling strategy, mark delay and so on. Scanning speed, power and number of laser repetitions have been identified as laser parameters which most influence the geometries of the structures. Scanning speed is defined as the speed of scanner head for lasering the layout; laser power is the output power at the end of the optical chain: the combination of laser source radiation with related beam shaping and scanner head focal lens; number of laser repetition indicates the number of laser passes repeated on the same layout. A stable working point to realize the full LDS structure was identified and validated and starting from that condition. a DoE has been designed for process window identification using a classical response surface design with a central composite design model.

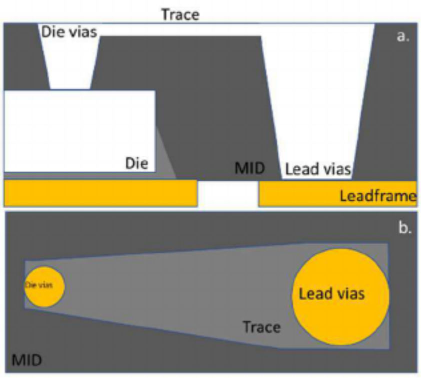


Fig. 1. Side (a) and top (b) view of the three main structure created by laser: Die Vias, Lead vias and traces.

III. Results and Discussion

A. Die vias

Die drilling is the most critical laser process step due to the low thickness of the copper metal on the die so possibility of breakage and damage of the die itself is very high with consequent exposure of the silicon. (Fig 2)

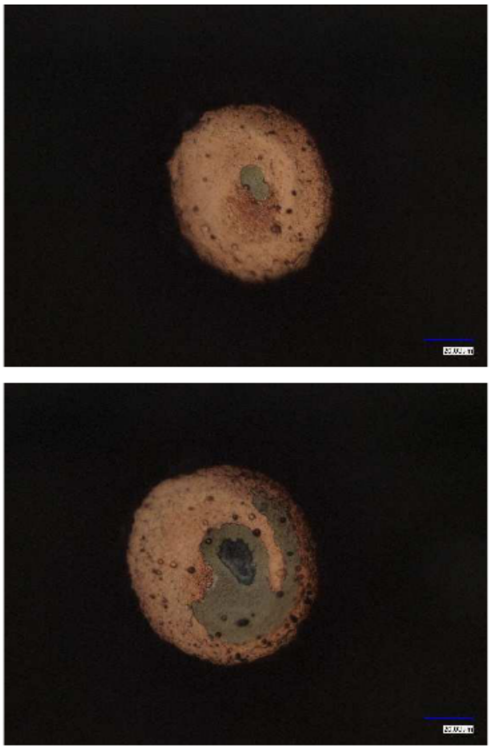


Fig. 2. Microscope images of die breakages detected on the bottom of die vias

Initially, a central laser working point for die drilling was identified using a power of 1.6W, scanning speed of 400mm/s and a number of repetitions equal to 2. To identify a more stable working point, it was decided to set the DoE by varying the Power of 0.6W, the repetitions of 1 and the scanning speed of 100mm/s.

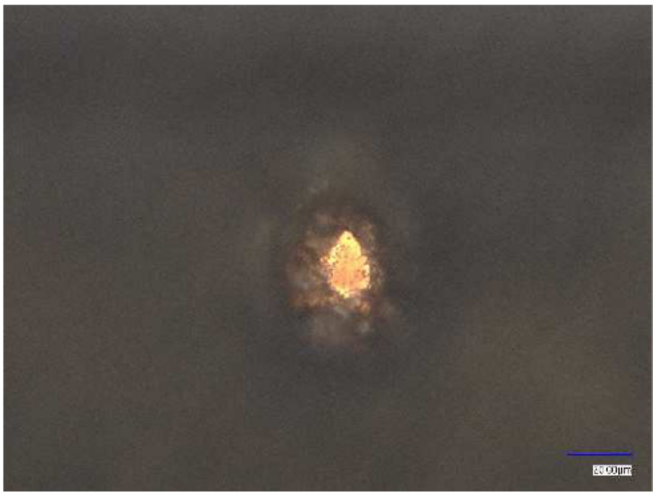


Fig. 3. Microscope image of die vias not fully open by laser due to low parameters

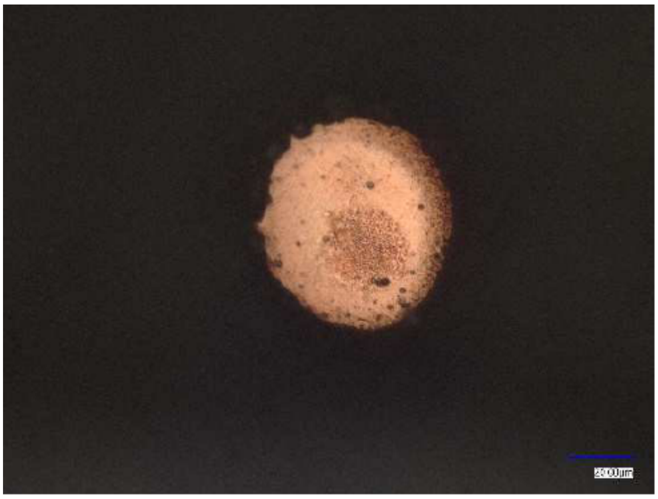


Fig. 4. Microscope image of die vias realized with the set of best laser parameters

The best repetition parameter to obtain the desired die vias dimensions has been found to be 2, as a repetition is not able to guarantee a sufficient opening of the MID and in some cases not to expose the copper of the pads properly (Fig 3), while 3 repetitions increase the risk of damaging the die and exposing silica (Fig 2).

From the response of the DoE, it can be deduced that the variability is too high as regards the analysis of mold residuals and die breakages. On the contrary JMP analysis of bottom and top diameter showed a good prediction. (Fig 5)

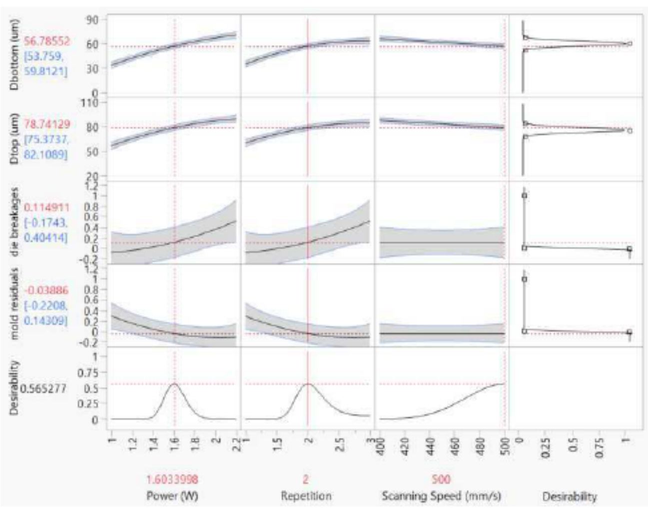


Fig. 5. JMP prediction profiler for die vias

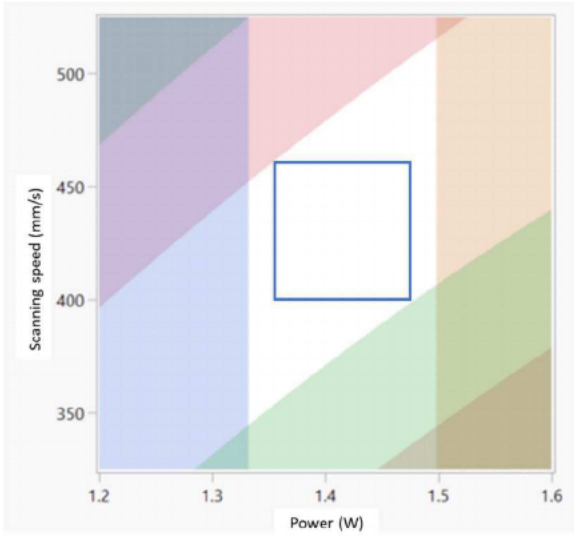


Fig. 6. JMP contour profiler for die vias. The blue square identifies the process window found by DoE

Therefore, by fixing 2 repetitions, the DoE showed that the best parameters to use to meet the dimensional requirements of the die vias are 1.6W and 500mm/s. However, it was possible to identify a process window, the blue square on figure 6, with scanning speed varying from 408 to 450mm/s and power from 1.33 to 1.5W.

Powers and scanning speeds lower than those determined by the DoE, similarly to 1 repetition, have shown limits to meet the minimum size requirements of the die vias and in opening the MID, which in some cases was not completely removed or opened (Fig 3).

On the contrary, parameters greater than those found thanks to the DoE showed damage of the die (Fig 2) due to the overetched of the copper pads and geometric dimensions of the vias above the design limits, considering to maintain usual die pad dimensions and geometries combined with the new Cu metal finishing.

B. *Lead vias*

With a copper thickness of over 200µm of the leadframe available, the realization of the Lead Vias, compared to the Die Vias, proved to be less critical.

After identifying a laser working point using a power of 5W, a scanning speed of 500mm/s and a number of repetitions equal to 5, to identify a feasibility windows, it was decided to set the DoE by varying the Power of 1W, the repetitions of 1 and the scanning speed of 50 mm/s.

In this case the number of repetitions turned out to be a non-significant parameter. The laser parameters that guarantee to match the target size of the diameters of the Lead Vias in the most accurate way are a Power of 4.8W and a Scanning speed of 550 mm/s.

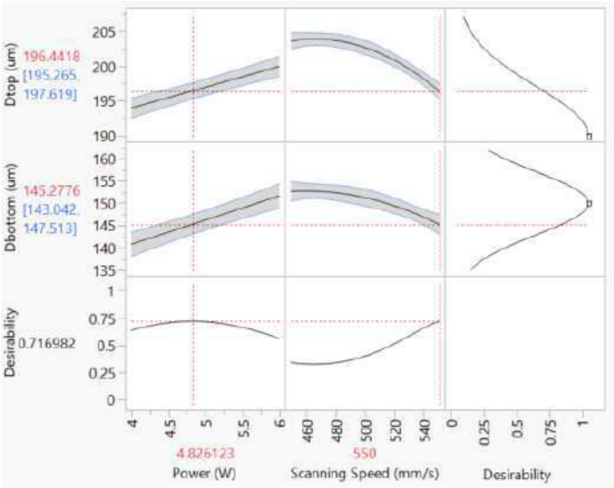


Fig. 7. JMP prediction profiler for lead vias

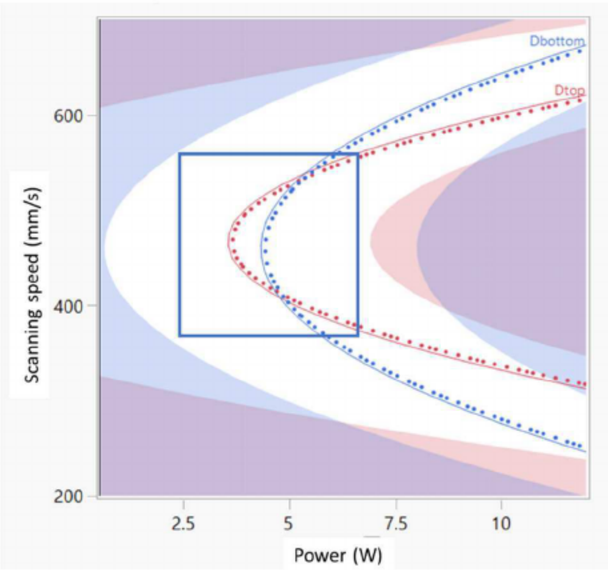


Fig. 8. JMP contour profiler for lead vias. The blue square identifies the process window found by DoE

Figure 8 shows a wide process window that could be identified thanks to the DoE and that allows to meet the dimensional requirements. Compared to the Die Vias in this case no copper breakages or mold residuals were detected, and the variability is quite different from the Die Vias prediction profiler. For the lead vias the variability of diameters, shown in the prediction profiler (Fig 7), is better. Also, the desirability is better compared to die vias due to the absence of mold residuals and die breakages. However, using a low power and a high scanning speed it's possible to observe a very small amount of mold residuals (Fig 9), which allow to obtain a good quality of vias and connections, made by plating.

In figure 10 it's possible to observe that using high power and low scanning speed in the middle of the vias an overetched copper zone is present.

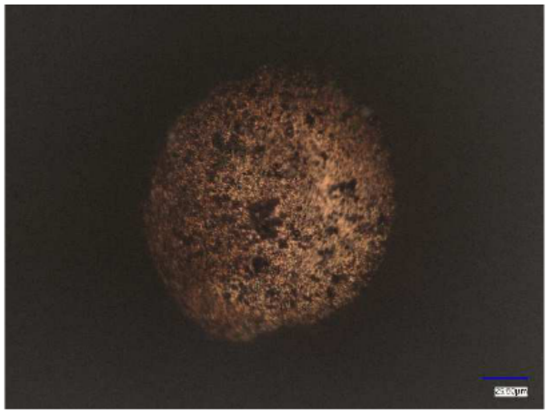


Fig. 9. Microscope image of mold residuals on the bottom of lead vias

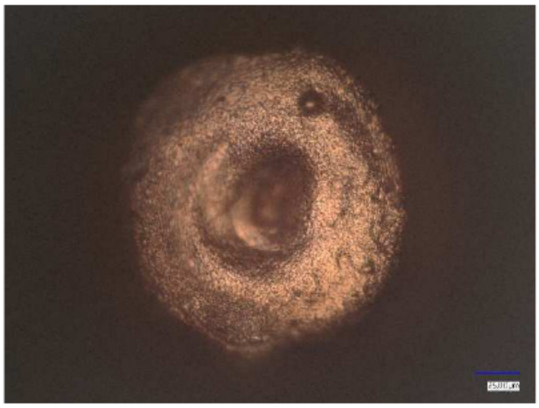


Fig. 10. Microscope image of lead vias realized with HH parameters

C. Traces

Traces are made by hatching MID and then applying plating to deposit copper directly on it. It differs from vias structures realization in which laser drills on a copper substrate to expose it.

A laser working point was initially identified using a power of 1.5W and a scanning speed of 1000 mm/s. In comparison to the die and lead vias a lower power and a much higher scanning speed were used because there is no copper but only MID.

The repetitions have been set at 1 to better investigate power and scanning speed as it has been verified that by setting 2 repetitions it is possible to obtain the same size, in terms of depth, that by setting double power and half scanning speed.

The depth of the traces made was investigated, setting a DoE by varying the power of 0.5W and the scanning speed of 500 mm/s.

The prediction profiler (Fig 11) showed the best desirability between JMP analysis, of the three structure realized by laser, performed and also a good depth variability. It also showed a linear power trend with low slope and a parabolic scanning speed trend with the best parameter, identified by the DoE to meet the target depth, at the least inclined point of the curve.

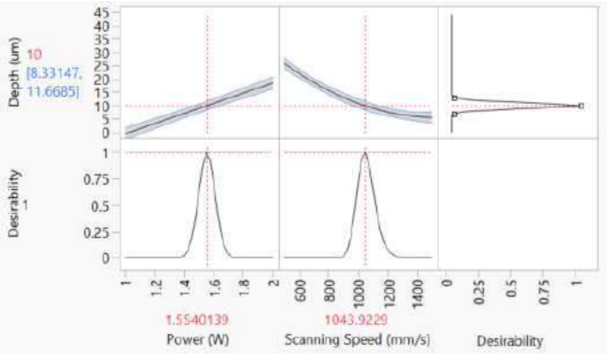


Fig. 11. JMP prediction profiler for lead vias

It was also possible to identify a large working area on the contour profiler in which was possible to obtain the target depth of the traces. However, the best and wide process windows was identified by the blue square in figure 12.

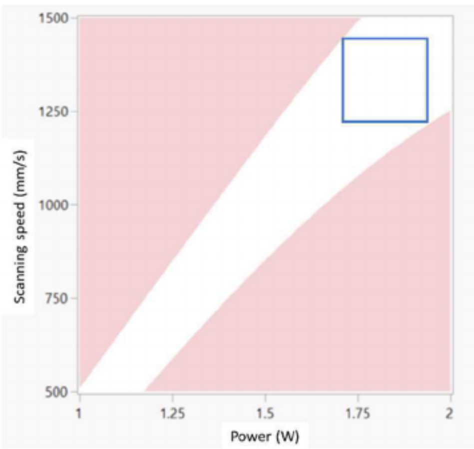
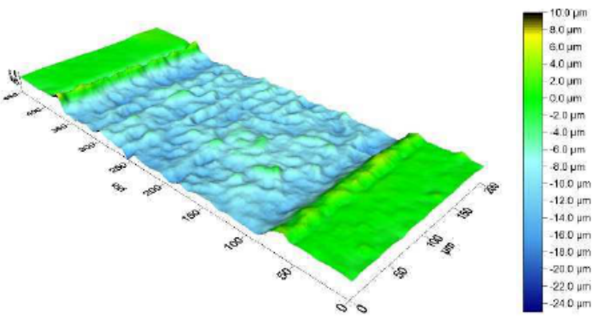


Fig. 12. JMP contour profiler for lead vias. The blue square identifies the process window found by DoE

A more accurate analysis of the depth of the traces was carried out using a profilometer.

Figure 13 shows an average depth of 10µm on top and a deeper average depth, around 40µm, on bottom.



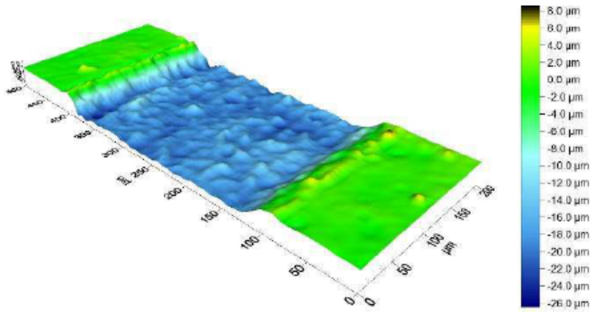


Fig. 13. Profilometer images of traces

Feasibility investigation showed good results in terms of laser patterning consistency respect to CAD drawing and vias opening for some laser parameters combination. One set up of laser parameters has been identified for realization of the interconnection and plating process of laser structures shows good results. Figure 1 shows the result of via opened with laser and filled with Cu plating

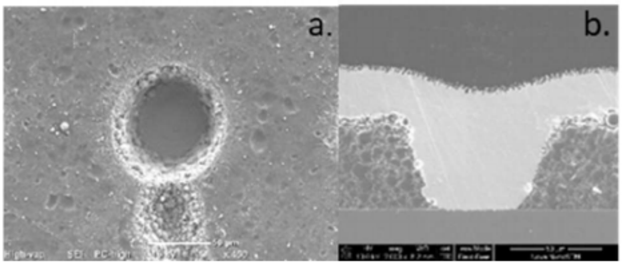


Fig. 14. Die laser via through moulding compound (a) and laser vias filled with plating bath (b)

IV. Conclusions

Application of laser direct structuring technology on leadframe based packages allows to obtain new type of interconnection without wires with this methodology,

Laser direct structuring technology can be applied in leadframes based packages solution to create customized interconnections which allow to exploit wider die surface and reduce package size. The application of this innovative technology for semiconductor interconnection is the results of a consistent combination of design rule from molding, laser and plating. Laser process parameters identification to realize traces, lead via and die via involved great effort, starting from the preliminary working point to the investigation of the process window, with the definition of quality acceptance criteria. Wide working area have been identified for traces and lead realization matching the target need to test plating process: 10µm depth of trace and 200µm diameter for lead. Die vias process parameters identification was the most critical because of the high risk of Cu metals breakages and mold residuals. In any case also for die vias a small stable working area has been identified to obtain 80µm diameter dimensions without defects. The identification of laser process parameters for each structure necessary to create the interconnection represents the first step for the creation of more efficient and flexible leadframe based packages.

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