Optimization Parameters for Laser-induced Forward Transfer of Al and Cu on Si-wafer Substrate

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Abstract: The research goal is to perform a laser-writing study to deposition of micro/nano particles on the substrate as interconnection usage. The threshold of laser energy, pulses per laser shot, as well as pulse overlapping is crucial to achieve the best deposition results possible. The present study aims to the novel technique by laser deposition of Aluminium and Copper nano particles on silicon wafer substrate. Thin µm films have been deposited from one-side coated glass to Silicon wafers by sputtering nano particles using laser radiation. Distance between donor film and substrate (ε) was up to several 100 µm and it has been optimized as 300 µm. A step-by-step optimization guide for deposition parameters were first developed and presented. The identification of laser energy threshold, pulses per laser shot, in addition to pulse overlapping is essential if the best deposition results are going to be drawn by laser direct writing method. This technique is regarded as the most important direct-write alternative for lithographic processes in order to generate patterns with high-resolution.

1 INTRODUCTION

The goal of this thesis is to perform a complete study of Laser deposition, structuring, and adhesion mechanism as one of the generative manufacturing processes with laser radiation. One of the methods of making thin films is sputter deposition. This procedure is a process that particles will be ejected from the material owing to bombardment of the solid target by energetic atoms.

The deposition of nano particles is demonstrated by the preparation of an Under Bump Metallization (UBM); although, the laser sputtering technique may be used for a multitude of other applications like: bonding technology for microelectronics, as well as micromechanical and micro-optical devices and components (Craig, 2007 and Pique, 2008). Copper and Aluminium based on their chemical properties and different reflectivity, have similar reactions in Infra-red laser for material processing and different behaviour in other laser wavelengths (Azhdast, 2017 and Golnaz, 2008).

For large-scale manufacturing situations, where the parallel creation of identical patterns is essential, pattern-transfer techniques (PTT) are the most economical choice. Here, the pattern of interest is produced onto the substrate in one step at the same time. Micro contact printing (MCP) as well as a photolithography (PL) is considered the most widely applied PTT. Especially photolithography benefitted enormously from recent technological advances such as the launch of extreme UV light sources, which enabled the production of nano structures. However, for both of these techniques, MCP and PL, a number of disadvantages are to be taken into account.

This printing process includes three steps; (1) to ablate material from donor glass with a focused laser pulse. (2) Transition of ablated particles from acceptor to receiver substrate. (3) Deposition of transferring material to be adhered onto the acceptor substrate (Bera, 2007 and Wartena, 2004).

2 PROCESS EXPLANATION

The procedure type which has been used in this paper is to deposition nano metal particle by direct laser radiation from one side coated glass as a donor. Neither mask nor ultra- violet light source will be used in nano particle printing, which is so expensive and they are time consuming method. Compared to

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photo lithography techniques, main advantages include higher flexibility, minimal number of process steps and also no requirements of masks. An Infra-red Nd:YAG laser with 8 picosecond pulse duration and frequency doubled (λ=515 nm) are used for tests. Photons are more energetic with shorter laser wavelengths and they are easier to be absorbed by the materials than photons with longer wavelengths. To decrease the permeation of particles in test substrate and to prevent the diffusion and desorption stages in thin film production, additional high density inorganic layer is used to control the process in adsorption and absorption in deposition level (Lianwei, 2014 and Salminen, 2013). High laser power with short pulses cause very little thermal influence on the substrate. As it can be seen in Figure1 (a) and (b), four lines are made with laser direct writing method. Distance between each laser shot has been optimized by 10µm, 9 pulses per each position and the 100 KHz repetition rate for left and 40 KHz for the right pictures. Pulse energy for both lasers with 40 KHz repetition rate is measured as 137 µJ. The first line in the picture is made by aluminium particles as donor with frequency doubled laser (λ=515nm) which are deposited on the substrate. In the second line infrared laser (λ=1064) is used for aluminium particles as well. In the third and fourth lines, copper is used for positioning of nano particles with green and IR laser respectively. The pulse energy of the IR laser for aluminium and copper with 100 KHz repetition rate and 7W output power is calculated as: 69.5 µJ. The laser intensity with 1.064 µm wavelength for aluminium and copper was: 245 KW/cm².

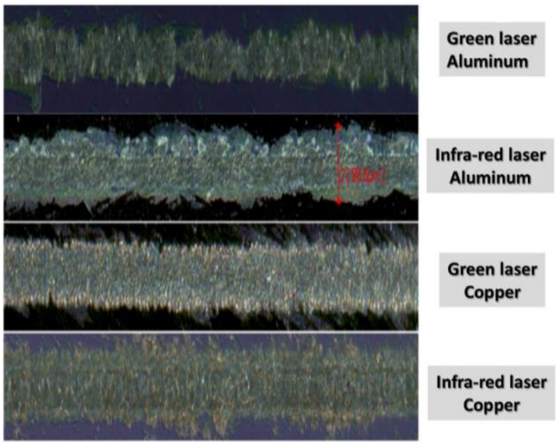

Figure 1(a): Deposition of Al & Cu by laser wavelengths-100 KHz repetition rate.

The silicon wafer has passivized by silicon nitride layer in order to decrease the permeation of particles in Si-wafer substrates and to prevent diffusion phenomenon. The coating thickness of aluminium and copper was 500nm on a normal glass with 250mm diameter and 1.1mm thickness.

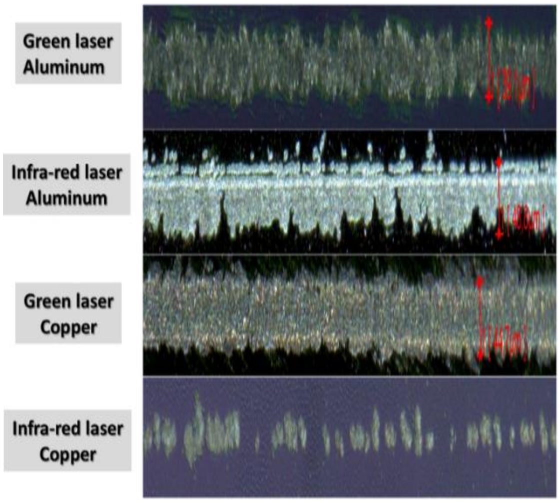

Figure 1(b): Deposition of Al & Cu by laser wavelengths-40 KHz repetition rate.

3 OPTIMIZING PULSES PER SHOT AND OVERLAPPING

In this step pulses per laser shot are subject to optimization. It was determined that a repetition rate of greater than 80 KHz achieves good results (Azhdast, 2015; 2016). Hence, a repetition rate of 100 KHz was used in this optimization step since the overlapping has not been optimized yet, it is set to 80% for this step. The pulses per shot were changed from 1 to 40 for deposition of Al on Si-wafer with silicon nitride passivation. Al has a relatively high and constant reflectance in the visible and infrared wavelength range. Figure 2 (a) and (b) show the results for pulses per shot in the range of 7 to 13. It can be perceived that for less than 8 pulses per shot the particles are not sputtered well on the substrate in which case the samples later fail the adhesion tape test. For 8 to 9 pulses a good deposition can be observed. By increasing the number of pulses to more than 15, the high energy leads to an impaired layer on the substrate. The findings from Al can be confirmed on Cu as optimal results are found for 8 to 9 pulses per shot as well.

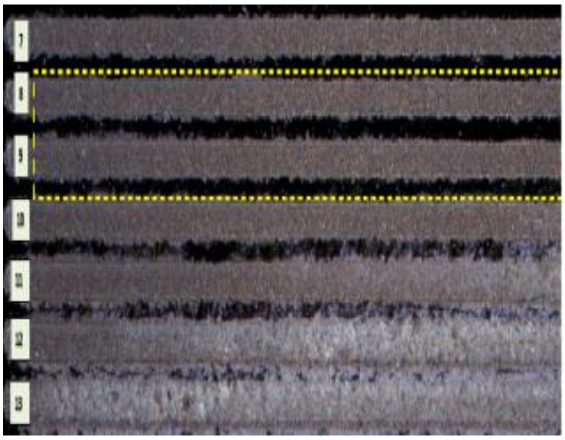

Figure 2(a): Pulses per shot in Aluminium.

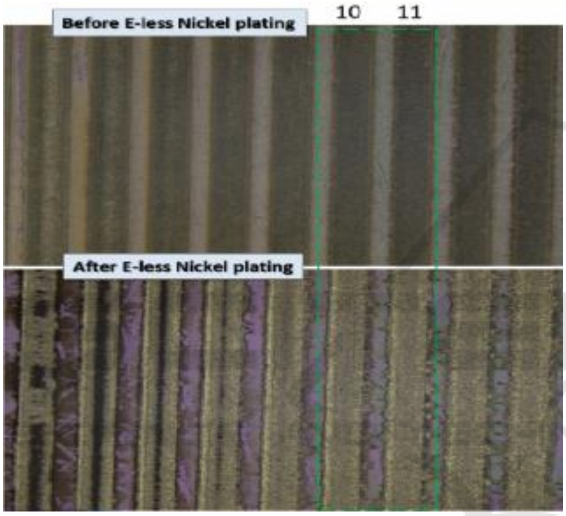

Figure 2(b): Pulses per shot in Copper.

Finally the overlapping is subject to optimization. Knowing from the previous step that 9 pulses per shot achieve good results, this parameter setting was used in this step. The distance between shots is changed from 1-40 µm.

Figures 3 illustrate that a distance of 10-11µm produces perfect lines with smooth edges. The lines are nickel plated in place of better coalescence. For distances well above 20µm distortion on the edges can be clearly noticed. The optimal distance between shots for copper is very similar as shown in figure 3(b). It can be concluded that 80% overlapping guarantees the production of perfect lines. With less than 10µm distances between each laser shot, the lines have more overlap which can be seen in the pictures after nickel plating. The diffusion layer occurs when the distances between each laser pulses are too less.

Figure 3(a): Overlapping of laser shots; Aluminium.

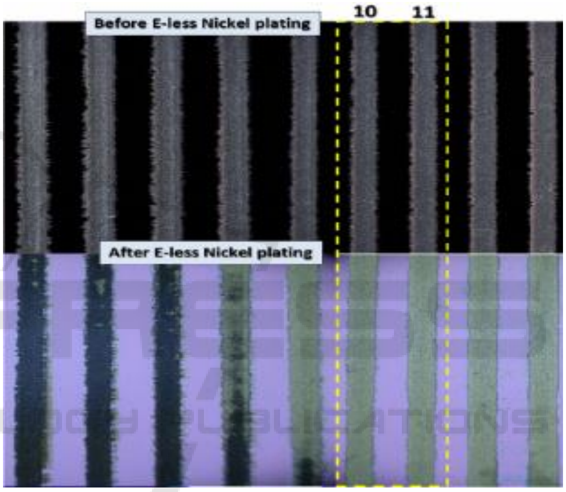

Figure 3(b): Overlapping of laser shots; Copper.

4 CONCLUSIONS

A large number of techniques can be implemented to precipitate a thin layer of film on a surface. Pulsed laser energy should be higher than the threshold energy in order to have the transmission of particles from the coated side of the glass in/on to the target. The chosen technique of thousand seeds, allow for further investigation and additional optimization. It has been found that the smallest features which are ablated from a donor, obtained at a fluence level just above the printing threshold for the sample. This printing threshold is dependent on the sample thickness, quality of focus, and duration of the laser pulse as well as laser intensity. Copper in comparison with aluminium, has a good wettability for both different laser wavelengths. Nevertheless, too high pulse energy at 40 KHz makes an uneven implanted surface. It is obvious that the quality of lines with lower intensity is not as well as higher ones. The higher laser intensity would cause more permeation of particles in the solid membrane and makes desorption structure of the layer. The printing threshold for the 500 nm thick donor sample for copper and aluminium were found to be 83 µJ and 87µJ for the 8 ps pulses respectively.

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