Embedded Trench Redistribution Layers (RDL) by Excimer Laser Ablation and Surface Planer Processes

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This paper reports the demonstration of 2-5 µm embedded trench formation in dry film polymer dielectrics such as Ajinomoto build-up film (ABF) and Polyimide without using chemical mechanical polishing (CMP) process. The trenches in these dielectrics were formed by excimer laser ablation, followed by metallization of trenches by copper plating processes and overburden removal with surface planer tool. The materials and processes integrated in this work are scalable to large panel fabrication at much higher throughput, for interposers and high density fan-out packaging at lower cost and higher performance than silicon interposers.

Keywords-component; embedded trench, excimer laser, RDL

I. Introduction

As the demand for high density packages has increased, wiring technologies have evolved from subtractive/etching process to semi-additive process (SAP). SAP has been shown to scale down wiring features to 5 µm line and space [1-3]. However, SAP faces challenges in miniaturization below 5 µm, because of side etching of the fine Cu traces during seed layer removal. Demonstration of ultra-small line formation down to 2 µm with SAP has been reported by several research groups [4, 5]. These processes utilized liquid dielectrics and CMP processes, which limits the application of the technology to panel scale fabrication. As an alternative wiring process, embedded trench technology has been intensively researched and developed. One of the examples is Via2 technology developed by Amkor, Atotech and Unimicron [6]. It emulated the dual-damascene structure with excimer laser ablation and plating processes. The noticeable advantages of embedded trench approach compared to SAP are the capability of wiring formation with high aspect ratio, and elimination of seed removal process and photo-lithography processes. One of the main challenges of the embedded trench approach is removal of copper overburden after plating process for copper filling inside the trenches. Via2 technology requires a CMP process for removal of copper overburden. Furthermore, resolution of trench widths made by excimer laser is limited by the inclusion of large filler particles inside the traditional dielectrics. Recent study by Unimicron reported the successful trench formation down to 3 µm lines and spaces in a build-up dielectric material with small sized filler [7].

In this research, demonstration of 2-5 µm embedded trenches was conducted by applying new materials and processes. Three different materials were tested; a standard build-up dielectrc ABF GX92, a new build-up dielectric ABF GY50 with smaller filler, and a pre-imidized polyimide which does not include filler particles. Dry films with small or no filler inclusion minimized side erosion to enable smaller trench formation down to 2 µm by excimer laser ablation. This study also examined the effect of cleaning process of surface debris which were created during the laser ablation process. It was found that the cleaning process is critical to achieve strong adhesion between the polymer and copper metallization layers. For the copper overburden removal, surface planer tool by DISCO Corporation was introduced as an effective alternative to CMP. Figure 1 summarizes the process schematic of the embedded trench approach in this study. Process schematic is described as following;

1. Lamination of polymer dry film on the core materials
2. Formation of trenches and vias by excimer laser ablation
3. Seed deposition by Cu electroless plating or Ti-Cu sputter processes
4. Electrolytic Cu plating to fill trenches and vias
5. Planarization to remove copper overburden on the surface

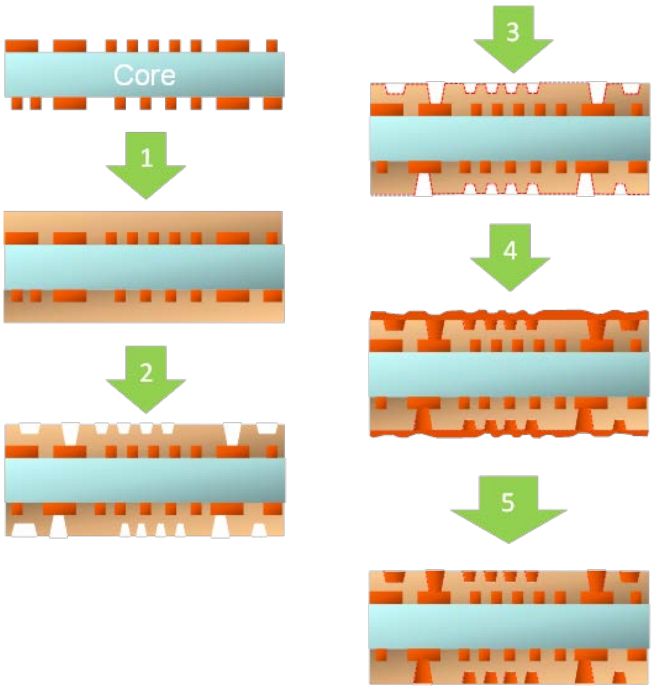

Figure 1. Process schematic of embedded trench processes

II. DIELECTRIC MATERIALS AND EXCIMER LASER TOOL

ABF is a compound material of epoxy polymer matrixes and inorganic fillers, being widely used in the packaging industry. Inorganic fillers were mixed with epoxy polymer for better mechanical and thermo-mechanical properties. However, the inclusion of large size inorganic fillers results in increased roughness, making it difficult to form small trenches [8]. This study uses two different type of ABF materials, GX92 and GY50, having different sized filler particles. Inclusion of smaller filler particles in GY50 is expected to makes it easier to structure smaller trenches in this material while keeping the material's excellent mechanical and thermo-mechanical properties.

As for a non-filled material, a polyimide was studied for comparison. Polyimide materials are also used for variety of packaging applications such as wafer level packaging and flexible packaging [9, 10]. Due to lower CTE of polyimide compared to other polymers, the material can be used without filler particles, which has a large advantage in making small feature by excimer laser processing. Polyimide is well known for its outstanding chemical, mechanical and thermomechanical properties because of the strong imide bonding. However, due to this strong molecular interaction, typical polyimide materials have very high melting point and are non-soluble in most solvents, which makes it challenging to process the materials. Hence, for the industrial use of polyimide materials, precursor polyamic-acid materials are molded or laminated first, then exposed to a thermal baking processat high temperature (>300 °C) to complete polyimide formation. A new pre-imidized polyimide material was recently developed by Fujifilm, which can be manufactured as dry film type, processed by lamination step, and then cured at 200-250 °C [11]. This study tested embedded trench formation in this dry film type pre-imidized polyimide material.

In this study, 308 nm XeCl laser was used due to the inertness in the air and much less damage to the optics compared shorter wavelength lasers while having high processing capability of polymer materials. Figure 2 shows the experimental scheme of excimer laser ablation of the samples with mask projection.

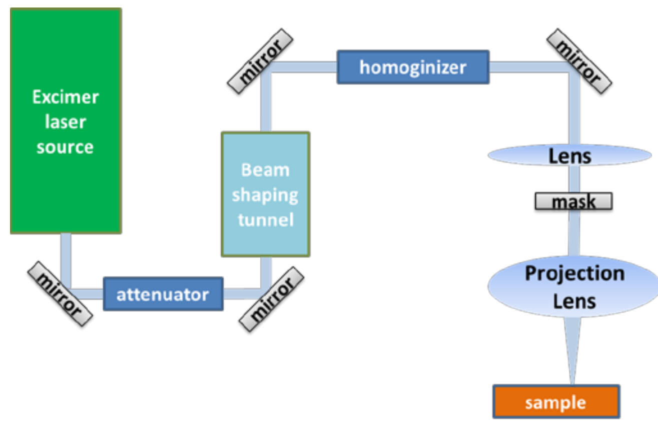

Figure 2. Beam delivery system schematic for excimer laser ablation

III. EFFECT OF FILLER SIZE ON TRENCH FORMATION

First, samples were prepared with dry film lamination on glass or FR-4 core materials. ABF films (15 µm thick GX92 and GY50) were laminated with vacuum laminator at 120 °C, then oven cured at 180 °C. SEM images (5000×) of GX92 and GY50 are shown in figure 4. From the SEM images, most of filler particles with diameter of around 1 µm were found in GX92, whereas filler particles in GY50 were less than 1/10 of the size compared to the ones in GX92. Trench shape was much sharper in GY50 due to the small filler size.

Trenches with 3-4 µm depth were formed in the dielectric layers by excimer laser using a mask with 2, 3, and 4 µm line and space structures. The profiles of the trenches were measured with a laser confocal microscope. Top views and profiles are shown in figure 4. Filler size had a large impact on the surface roughness; roughness factors Ra, Rz (ISO4287) for GX92 were 81 nm and 393 nm and Ra, Rz for GY50 were 24 nm and 140 nm respectively. As a result, trenches in GY50 had a much smoother profile compared to the ones in GX92. Due to the rougher surface in GX92 sample, larger side erosion of the trench was observed and trench width was extended by more than 2 µm each side. As a result, trenches below 5 µm line and space could not yield in GX92. In contrast, side erosion of trenches in GY50 was much smaller, below 0.5 µm each side, which resulted in successful formation of trenches down to 3 µm line and space (6 µm pitch).

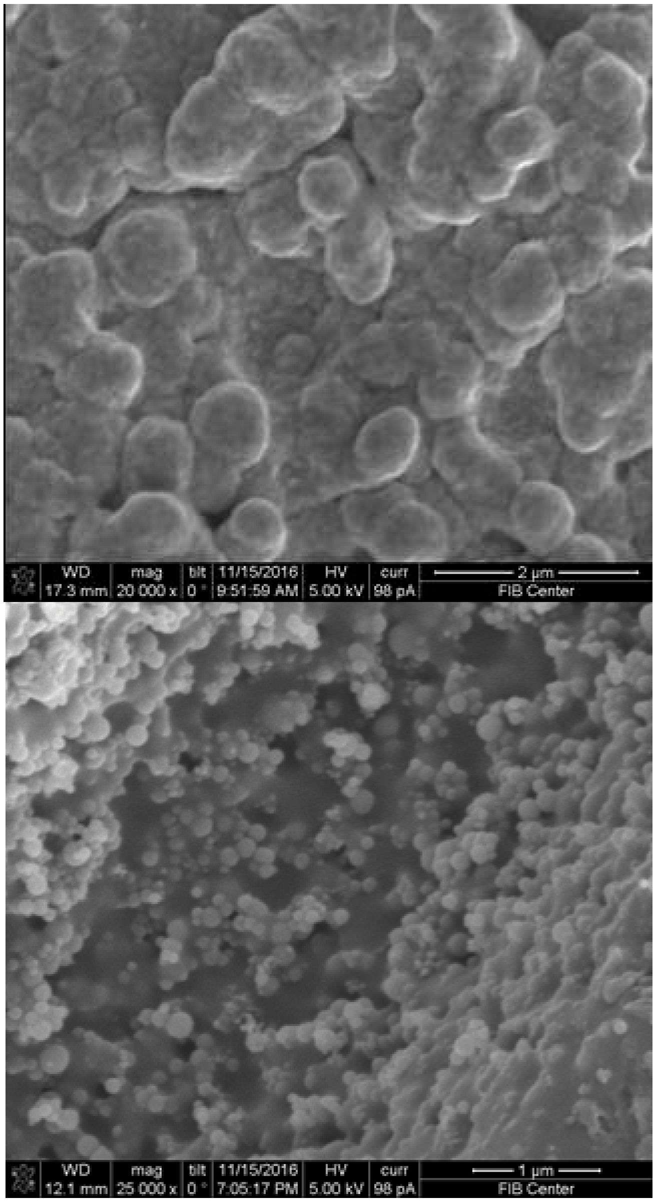

Figure 3. SEM images of filler particles in GX92 (top) and GY50 (bottom)

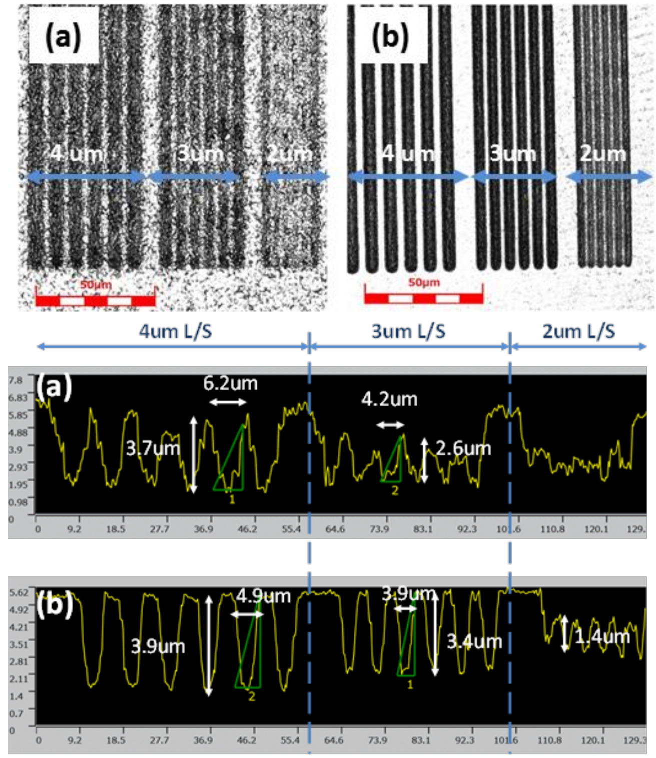

Figure 4. Top view (upper) and line profile (lower) of 2, 3 and 4 µm line and space trenches in GX92 (a) and GY50 (b)

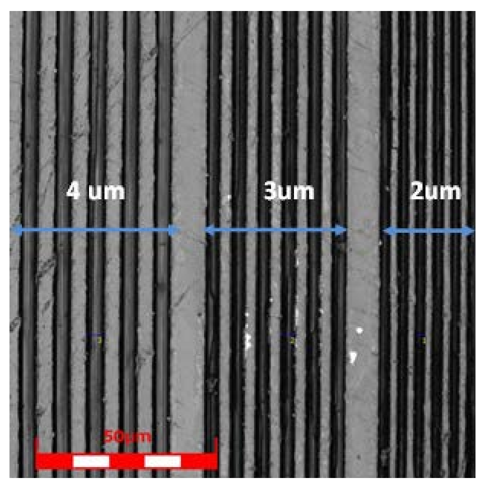

Figure 5. Top view of the 2 – 4 µm ablated trench in polyimide

For comparison, a polyimide sample was fabricated with 8 µm thick film lamination on glass material and cured with hot press at 250 °C. Trenches in polyimide were patterned by the projection excimer laser process as well. Due to the superior processability of the material, 2 µm line and space structure were successfully demonstrated (figure 5).

IV. Metalization of Trenches

After the formation of trenches, cleaning processes were applied for removal of residual debris on the surface. Desmear cleaning with permanganate and sodium hydroxide are known to effectively remove surface debris by laser processes. However, long desmear time can etch the polymer layer to damage trench structures, especially small wiring structure below 5 µm. In this study, short desmear cleaning time for 3 minutes were applied to the sample with ABF GY50. Figure 6 shows the sample surface with trenches before and after 3 minutes of desmear cleaning processes. Surface debris in between the trench structures can be observed as darker stains. After the cleaning, stains were cleaned out. Additionally, no significant side etching or damage was observed in 2, 3 and 4 µm fine pitch trench structures.

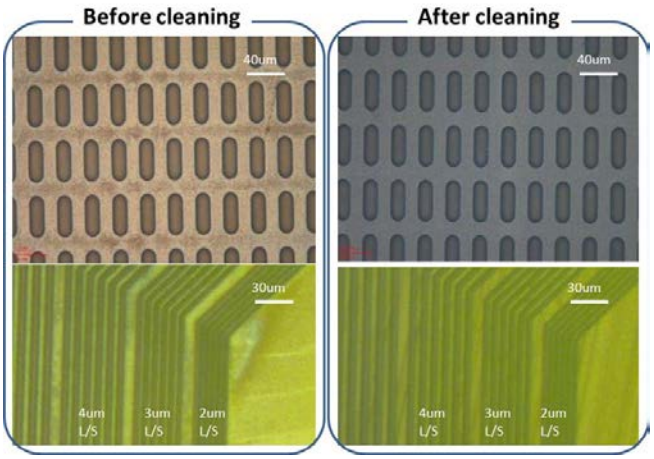

Figure 6. Removal of surface debris by 3min chemical desmear of laser trenches without damaging fine trenches

After the cleaning, metallization fill processes of the trenches were carried out with metal seed deposition, followed by electrolytic plating. For seed layer deposition, electroless Cu plating was used for ABF samples to form 0.2 µm thick Cu seed layer. For polyimide samples, Ti-Cu sputtering seed (0.03 µm Ti and 0.1 µm Cu) was deposited. After the seed deposition processes, trenches were filled with copper by electrolytic plating. To achieve effective filling in the trenches, right selection of plating chemistry and electrolyte flow is very critical and two different configurations of plating processes were examined in this research. One configuration used Cupracid TP by Atotech and nozzles facing parallel to the samples (process tank A), while the other configuration used Inpro THF by Atotech and nozzles facing perpendicular to the samples (process tank B). Nozzles with parallel direction creates a laminar flow on the surface, whereas one with perpendicular direction creates turbulence. The samples had trenches with 20 µm width, 60 µm length and 5 µm depth. After 40 minutes of electrolytic copper plating at 10 A in each process, profiles of the plated trenches were observed with an optical profiler (figure 7) and thickness of copper on the sample surface was measured with an electrical thickness gauge. From tank A, plated copper thickness on the surface was 5 µm and the depth of the dimple was 3.2 µm. From tank B, copper thickness on the surface was 6 µm and the depth of the dimple was 0.2 µm. This result indicates the process with tank A was closer to conformal plating, whereas tank B process was more trench filling plating. Plating with tank B has an advantage in effective copper filling in trenches without depositing thick copper on top of the surface.

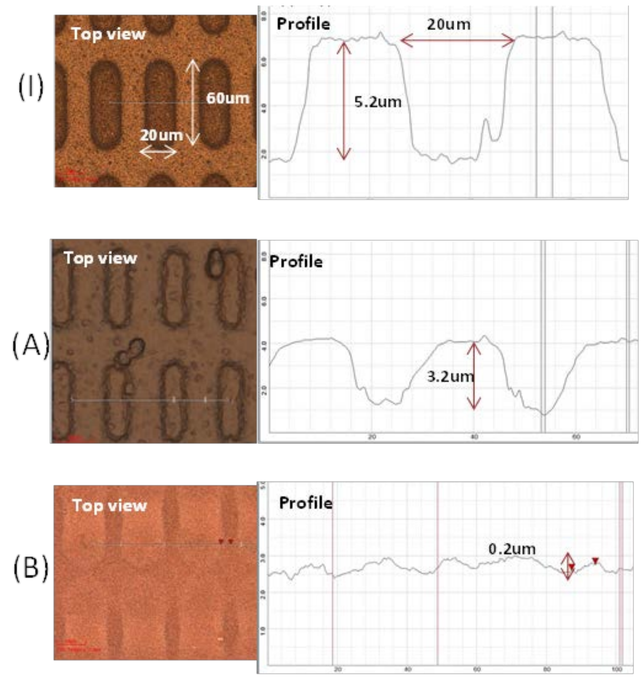

Figure 7. Trench filling by different electrolytic plating processes. (I): before plating, (A): after 40 min plating at 10 A with tank A, (B): after 40 min plating at 10 A with tank B

V. COPPER OVERBURDEN REMOVAL BY SURFACE PLANAR

After filling of the trenches, copper overburden on the surface needs to be removed for process completion. Copper etching is the simplest method, however, control of the etching thickness is extremely challenging. Given the as-plated complex surface profiles, wet etching process poses a high risk of over-etching in the trench. CMP is a well-established process to remove the overburden from the surface. However, as mentioned earlier, the process cost of ownership (CoO) is high and scaling for panel manufacturing is extremely challenging. In this research, DISCO's surface planer process equipment was used for the planarization overburden removal step because of lower CoO and scalability to panel-base manufacturing due to its simplicities in the equipment kinematics. The surface planer process can effectively remove ductile materials such as metals and/or polymers from the surfaces of substrates. The process point consists of a single bit made of diamond, which is mounted on a spindle rotating at high speed at a fixed height. The substrate is fixed on a flat chuck table that is creep-fed under the rotating bit, which is barely contacting the surface (figure 8). The surface of the chuck table is in precise parallelism with the plane defined by the rotation of the processing bit. As the tool shaves the substrate, the unevenness of the ductile material on the surface is carved off, leaving an extremely flat surface with excellent total thickness variation (TTV) control across the substrate. In case of this study, the copper overburden was removed in this fashion.

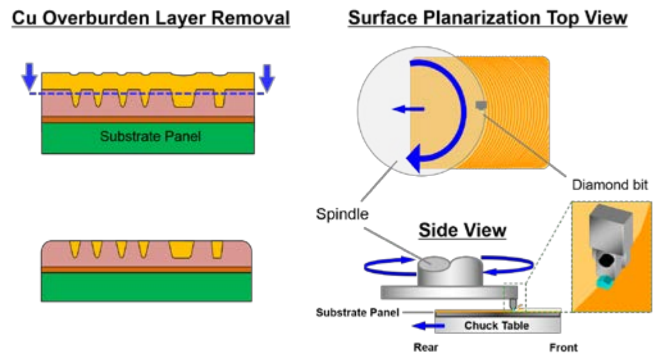

Figure 8. Illustration of Cu overburden removal by a surface planarization process

The surface planarization process was applied to the samples with or without the desmear cleaning before the metallization processes. Figure 9 shows the metallized trench structures of these samples. Large amount of copper delamination was observed in the sample without desmear cleaning processes. On the other hand, no delamination was observed in the sample with desmear cleaning process. This result supports the effectiveness of 3 minutes of short desmear cleaning before the metallization step.

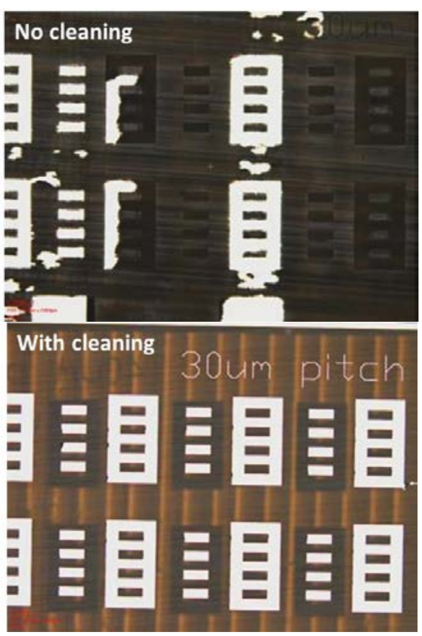

Figure 9. Trench structures after surface planariztion process. Sample without desmear cleaning (top) and with desmear cleaning (bottom)

To demonstrate small trench structures, samples with polymer dielectrics on glass panels were prepared and embedded trench processes were applied. Cleaning process were applied before metallization to all of the samples. Figure 8 shows the top view of the small trenches made by the processes. Trench structures with 5 µm width on GX92, 3 µm on GY50 and 2 µm on polyimide materials were successfully achieved.

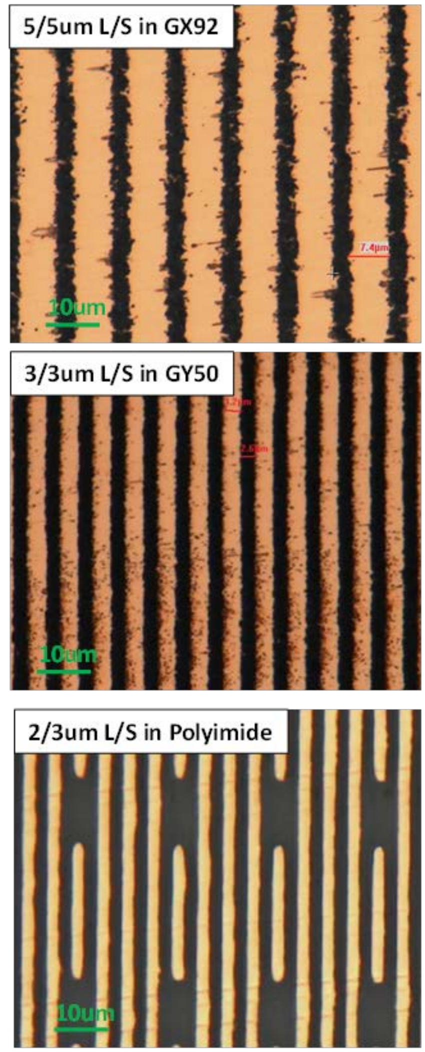

Figure 10. Fine pitch trenches formed in GX92 (top), GY50 (middle), and polyimide (bottom)

An initial demonstration sample with a multi-layer RDL structure was fabricated by repeating the process steps on GX92. After the first embedded copper layer formation on GX92, a second metal layer was fabricated from lamination of 15 µm thick GX92 film on top of the first layer. Thereafter, both trenches and vias were formed in the top dielectric layer by two steps of laser ablation. Then Eless copper plating and electrolytic copper plating were used for filling in the trenches and vias, followed by surface planarization to complete multi-layer fabrication. Top view and cross section view of the fabricated daisy-chain structure with 20 µm pitch micro-vias is shown in figure 9. Via diameter was 8 µm and pad width was 15 µm.

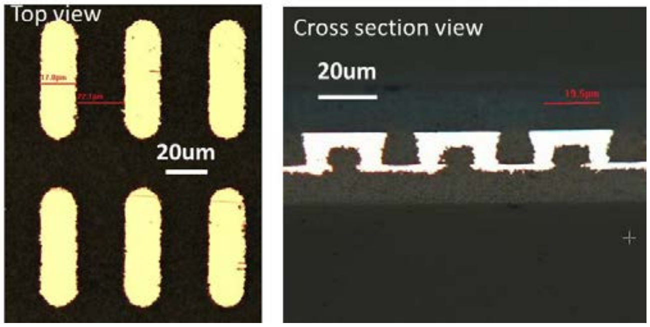

Figure 11. Top view (left) and cross section view of the daisy-chain structure with 20 µm via pitch by embedded trace processes

VI. Conclusion

High density RDL with 2-5 µm trenches was demonstrated using advanced dry film dielectrics with excimer laser based embedded trench approach. The approach comprises excimer laser ablation, copper seed layer formation and electrodeposition, and surface planarization process steps. The effect of filler particles in the polymer dielectric materials on fine pitch trench formation was investigated. It was concluded that dielectrics with smaller fillers have an advantage in fine pitch trench formation. The effect of desmear cleaning process was examined, and it was revealed that the desmear cleaning was critical for proper adhesion between polymer and copper layers. By down selecting the suitable materials, small RDL copper transmission lines down to 2 µm was successfully demonstrated. The initial multi-layer RDL structures with 20 µm via pitch was successfully fabricated. The materials and RDL formation processes discussed in this paper can be scaled to large panels, providing a path for high volume manufacturing of high density interposers and fanout packages at lower cost than wafer-based silicon interposers.

Acknowledgment

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