# Laser release process to obtain freestanding multilayer metal–polyimide circuits

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**Some applications in microelectronics call for freestanding polyimide films with fine metallic wiring patterns that are thinner than commercially available copper-clad polyimide sheets, which are typically greater than 25 μm in thickness. This work describes a laser-assisted technique to fabricate freestanding multilayer thin-film wiring with polyimide dielectric insulating layers that are less than 10 μm thick. A release layer consisting of a thin polymeric film is first deposited on an optically transparent carrier and the multilayer thin-film structure is then fabricated on this substrate, with the polymeric release layer sandwiched between the transparent carrier and the multilayer structure. Excimer laser light passes through the transparent carrier and ablates the polymeric layer at the transparent carrier/polymer interface, resulting in separation of the sacrificial carrier from the multilayer structure. The optimal release process is carried out using a 308-nm XeCl excimer laser operating at a fluence of about 100 mJ/cm$^2$.**

## Introduction

Conventional thin-film technology is ideally suited for the fabrication of thin polyimide and metal films on rigid substrates. Polymer films are typically deposited by spin-coating, while metallic layers are often applied by physical deposition techniques such as evaporation or sputtering or by chemical deposition techniques such as CVD. When metal wiring features become smaller than 25 μm and the interlayer dielectric layer thicknesses also approach these dimensions, the substrate must be rigid and flat for compatibility with the photolithography tools. When such multilayer structures are fabricated and later removed by a laser process to form freestanding structures, it is very important that the laser separation process does not induce any damage to the fabricated structure. The freestanding multilayer structures can be used as is or subsequently laminated to other carriers as needed.

Freestanding polyimide films with or without metal wiring have several applications in the world of



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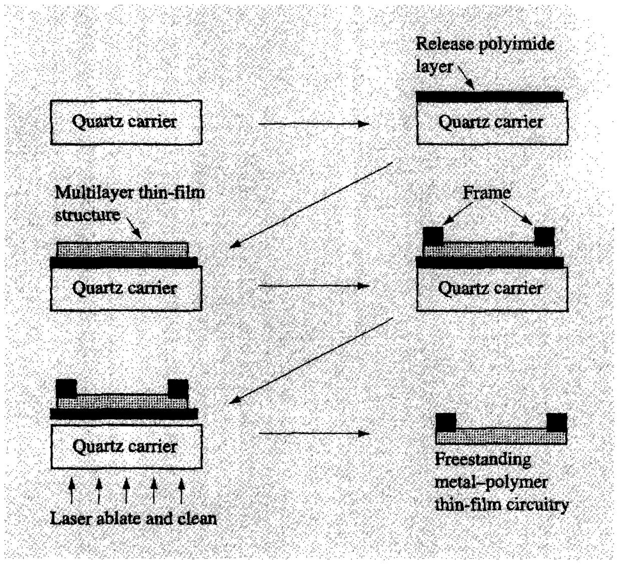


**Figure 1**

Schematic representation of the laser ablation process for fabricating freestanding multilayer thin-film structures.

microelectronics. Applications that benefit from such a decal process include multichip modules [1] and wafer-level testing membranes. The multichip module application is described in some detail in this paper. Very thin films without metal patterns are used as pellicles for encapsulation and protection of masks for deep-UV and X-ray lithography. Multilayer films with wiring patterns are used either as membranes for wafer-level chip testing for known good die (KGD) applications or for wafer-level chip burn-in.

The freestanding film application is a unique, highly flexible, and cost-competitive method of fabricating microelectronic packages that require thin-film interconnections. The method involves fabricating thin-film metal–polymer structures on a reusable glass carrier and later transferring the thin-film stack onto product substrates of choice. If the transferred part is small relative to the glass carrier, several parts can be built on the carrier; this is referred to as a "multi-up process," which further reduces the cost per part. The final product substrate can be silicon, co-fired alumina or glass–ceramic, aluminum nitride, diamond, or a printed wiring board. Optionally, one can also use the released thin-film decal as a flexible high-wirability interconnect by itself or as an interposer. The thin-film wiring structure can be fabricated multi-up on a standardized form-factor carrier (that is independent of the characteristics of the final product substrate) in a thin-film interconnect foundry, thus significantly reducing the manufacturing cost.

The laser separation process is critical for the generation of freestanding multilevel thin-film structures. This process, described below, is based on excimer laser ablation of organic polymers, a phenomenon first observed at IBM in 1982 [2]. That work showed that controlled etching of organic polymers can be achieved by using pulsed ultraviolet laser radiation from excimer lasers. Because of the strong absorption of ultraviolet radiation by most polymers, the laser energy is deposited in a shallow (submicron) surface layer. Furthermore, as a consequence of the polymer's poor thermal conductivity, the deposited energy is constrained within the surface layer for the ~50-ns duration of the excimer laser pulse. When the absorbed energy density exceeds a certain threshold value, a surface layer, typically $<1$ $\mu$m thick, is photo-ablated. The laser ablation process is reported and a comprehensive summary of early studies is given by Srinivasan and Braren [3].

Submicron control of the laser ablation process is an important characteristic of the laser release application, since this guarantees minimal interaction between the ablated polymeric layer and other structures fabricated on this polymer. A crucial characteristic of the thin-film release process is the discovery that a submicron layer of polymer at the interface of a polymer-on-glass structure is ablated when the laser is incident on the interfacial polymer through the transparent substrate [4]. This paper describes the characterization and optimization of this phenomenon to yield a reliable laser release process.

## Laser separation process

The efficacy of the laser separation process is determined by the choice of three interdependent factors. First, a transparent carrier or substrate must be used for the deposition of the thin-film layers; second, a laser radiation wavelength must be selected that is not significantly absorbed by the substrate; and third, a polymer layer must be selected that is easily ablated by the laser radiation and can be used as the release layer between the substrate and the thin-film structure. The thin-film fabrication and laser separation process is schematically depicted in **Figure 1**. The release layer is spun onto the substrate, and the remaining polymer and metal layers that make up the multilayer thin-film assembly are fabricated above it. A ring is attached to the top surface of the structure. The laser is then used to ablate the release layer through the glass, operating at a fluence just above the ablation threshold for the release polyimide layer. One system used for this study consisted of quartz substrates, a 248-nm or 308-nm excimer laser, and du Pont 5878 (PMDA–ODA) polyimide for use as the release layer. The study showed that other polyimides worked equally well. Low-cost pyrex substrates were sufficiently transparent to laser radiation at wavelengths of 308 nm and 351 nm.

When the laser is directed at the interface release layer through the glass substrate with a fluence above the ablation threshold of the release polyimide, a submicron thickness of the release layer is destroyed at the interface. The by-product of the ablation is a mixture of gases and low-molecular-weight fragments of the polyimide. The entire interface is scanned with the laser until the thin-film structure supported by the ring is entirely separated from the substrate, as shown in Figure 1.

## Force measurements

During the laser ablation process, the conversion of the solid release layer to the primarily gaseous by-products results in a sudden volume expansion and a shock wave that is transmitted through the thickness of the thin-film layers in the structure. For this process to be useful, it is critical that the force exerted by this mechanical shock wave be below any damage threshold in the thin-film structure. In an attempt to understand the magnitude of this force, several experiments were conducted which are described in this section.

At the ablation interface, the thickness of polyimide that is consumed by a laser pulse with a fluence near the ablation threshold is about 100 nm. This is determined by the absorption depth for polyimide at the laser wavelength. The volume of "gas" generated at the interface is a product of the laser illumination area and the thickness of the release layer, if the layer is less than about 100 nm thick. For layers thicker than 100 nm, the volume of gas produced is constant for the first pulse. Subsequent pulses produce additional gaseous matter if the fluence is above the threshold. It is interesting to note that for release layers thinner than 100 nm, the force exerted by the ablation process is nearly constant, even though the volume of gas decreases with the layer thickness. The pressure $P$ in the enclosed ablated volume $V$ is approximated using the ideal gas law, $P = nRT/V$, where $n$ is the number of moles of gas generated. In this application, $n$ is directly proportional to the ablated volume $V$, and is written as $n = CV$, where $C$ is a proportionality constant. Substituting $CV$ for $n$ in the above gas equation yields $P = CRT$; $P$ is independent of volume and therefore independent of release layer thickness for laser radiation of a given energy density.

In the initial force experiments, it was determined that if an excimer laser pulse width of about 20 ns is used, the time scale over which the polyimide film is displaced during ablation at the beam location is of the same order (<50 ns). The physical displacement is caused by the volume expansion at the ablation site. This extremely rapid volume expansion (<50 ns) was monitored with a He-Ne laser and a photodiode detector directed at the reflected beam from the surface. A fast response is expected because the shock wave can traverse a 2-$\mu$m-thick film in about $5 \times 10^{-9}$ seconds, which is significantly less than the pulse width. The force caused by the shock wave that was transmitted through the film was measured using a piezoelectric transducer. The piezoelectric transducer, a poled polyvinylidene film (PVDF) with metal electrodes on both surfaces, responds to the mechanical shock wave with a voltage output which is then recorded using an oscilloscope.

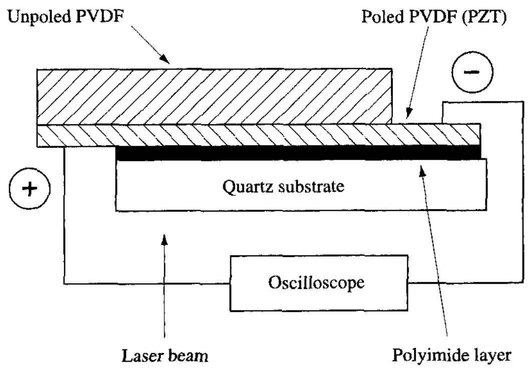


**Figure 2**

Experimental setup used to measure force during ablation.

In this experiment, the release polyimide layer is spun onto a quartz substrate and cured. The active piezoelectric transducer (PZT) film is glued onto the release layer. An additional unpoled PVDF layer is glued to the PZT layer to match the impedance and prevent multiple reflections of the shock wave. **Figure 2** shows a schematic drawing of the setup. The two electrodes of the PZT film are connected to an oscilloscope that is triggered by the laser pulse used for the ablation. Extreme care must be taken to ensure that the glued layers are free of air bubbles at the poled/unpoled PVDF layer interface as well as at the poled PVDF/release layer interface to ensure intimate contact. Gaps at the interface produce multiple reflections in the measurements. In addition, extensive shielding must be placed around the setup to prevent detection during measurements of the electrical noise generated by the excimer laser.

Experiments were performed to measure the force generated during ablation as a function of both the laser fluence and the release polyimide layer thickness. A 308-nm XeCl excimer laser was used for these measurements. The laser fluence was varied from about 10 mJ/cm$^2$ to 0.55 J/cm$^2$. The laser beam spot size was typically of the order of 1 cm$^2$. To ensure a uniform intensity distribution over the entire exposed area, a laser homogenizer based on a

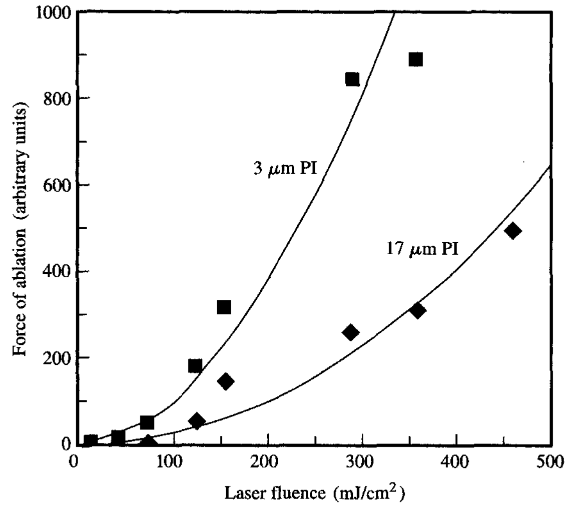


**Figure 3**

Variation of ablation force as a function of laser fluence for two polyimide layer thicknesses.

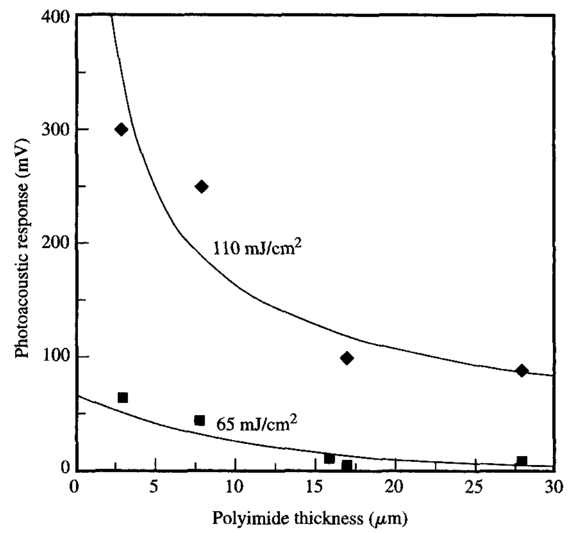


**Figure 4**

Effect of increasing the polyimide release layer thickness on the ablation force experienced by the metal–polymer circuits. The photoacoustic response is a measure of the transmitted force.

"fly's-eye" lens array was used. The dependence of the ablation force on laser fluence is shown in **Figure 3**. As expected, the ablation force increases with increasing fluence. Figure 3 shows typical results obtained for two polyimide layer thicknesses, 3 $\mu$m and 17 $\mu$m. The thicker layer shows a lower force at each fluence than the thinner film. The results show that thicker layers transmit less of the shock wave. It is expected that some mechanical energy is absorbed by the polyimide layer, resulting in a decreased force with increased film thickness. At about 80 mJ/cm$^2$ the measured force is relatively small. The region near this ablation threshold of relatively small force is desirable for the laser release process. **Figure 4** shows the imparted ablation force as a function of the polyimide release layer thickness for a given fluence. Two sets of data are presented, one taken at a fluence of 65 $\pm$ 5 mJ/cm$^2$ and the other at 110 $\pm$ 10 mJ/cm$^2$. It is interesting to note that there is a steady decrease in the force as the layer thickness increases to about 15 $\mu$m, where there is little additional benefit. This is true at very low fluences near the threshold as well as at fluences twice the ablation threshold. This indicates that mechanical shock waves that are created by the ablation process can be adequately absorbed by a polyimide layer that is 15 $\mu$m thick. Although a 15-$\mu$m release layer minimized the force of the shock wave, it may be desirable to operate with thinner release layers to optimize film processing conditions. The above experimental data show that the force exerted on the thin-film layers is controlled to suit the needs of the process. Operating at $<$100 mJ/cm$^2$ substantially reduced the imparted force, even for very thin layers ($<$5 $\mu$m). It is important to note that above the ablation threshold, the release process is equally effective at the low fluence levels (65 mJ/cm$^2$) and the higher fluence levels. From the above measurements, it is clearly desirable to operate at fluence levels near the ablation threshold of about 50 mJ/cm$^2$ in order to minimize the force imparted to the thin-film structure. This allows the use of very thin ($<$5-$\mu$m) release layers, as shown in Figure 4. For example, a laser fluence $\leq$100 mJ/cm$^2$ did not induce any damage on thin-film wiring that was 10 $\mu$m wide on a 25-$\mu$m pitch when using a 3-$\mu$m release layer. From the data, it is clear that the force can be substantially reduced with thicker release layers if the application demands it.

## Multichip-module example

The use of multichip modules (MCMs) for microelectronic packaging is, for the most part, limited to mainframe computers, military applications, and the aerospace industry, where reliability and performance drive the needs and cost is secondary. However, the high-performance workstations and the telecommunications industry will benefit greatly from using MCM technology in their products. In the case of multichip module-deposited (MCM-D) technology, the cost of providing high-density interconnection wiring is still an order of magnitude too high to allow the technology to be used for high-volume applications [5]. Significant cost reductions are achieved by fabricating the thin-film interconnect wiring on standardized glass plates. The laser ablation process can then be used to remove the thin-film wiring structure from the glass plate. The thin-film wiring structure is then supplied to vendors for lamination to a variety of substrates. In this manner, all thin-film fabrication can be centralized in a standardized foundry. Further cost reduction can be achieved by fabricating these structures on large glass plates [5, 6].

• *Process description*

The process, as described earlier, involves building thin-film wiring on a reusable glass carrier and later transferring it to a substrate of choice. The basic process sequence is as follows:

- Coat and fully cure a polyimide release layer (5–15 $\mu$m).
- Build standard multilayer thin-film interconnect wiring.
- Attach a rigid frame to the top surface.
- Release the thin-film assembly from the glass carrier by laser ablation.
- Align and laminate the assembly to a substrate of choice.
- Excise the frame and attach the die by standard flip-chip or wire-bonding techniques.

The process described above is applicable to cases where the thin film resides on a passive substrate such as Si, diamond, AlN, or an FR-4 epoxy card. The frame attached to the structure prior to the release from the carrier serves two purposes. It provides a means to handle and test the thin-film aggregate after release. Second, it controls the distortion of the thin-film pattern when it is separated from the glass. This is important when laminating to active substrates (e.g., co-fired multilayer ceramic substrates), where electrical interconnection between the thin film and the substrate is achieved during lamination.

• *Demonstration of new technology elements*

Several test vehicles were designed and fabricated to demonstrate the thin-film transfer process. The early experiments were performed on 82-mm-diameter round substrates where the new technology elements (e.g., the laser release process, dimensional control of the released wiring aggregate, and damage-free transfer to various substrates) were clearly demonstrated [7]. The follow-on test vehicles (127 mm × 127 mm) addressed scale-up issues and illustrated the ability to combine large-area surfaces with very high yield. A sampling of data from References [1] and [7] follows. The 82-mm test vehicle was designed as a four-level thin-film structure with 15-$\mu$m-wide transmission lines on a 45-$\mu$m pitch. The level-to-level connection was made with 15-$\mu$m-diameter vias. A Cr–Cu–Cr/polyimide structure was fabricated by a standard thin-film process [8]. Some of the thin-film lines were 4 cm long, some were 2 cm long, and a few were only 2.4 mm long. Each sample contained more than 150 lines that could be electrically measured at each stage of the process. By tracking the lines for opens, it was possible to study the effect of release and transfer on the integrity of the thin-film lines. **Figure 5** shows the multilayer thin-film structure fabricated on a glass substrate and later released onto a metal frame. The relatively less dense quadrants contain the multilayer via chain structure shown in **Figure 6**. The chains run from the lower metal level (M1) to the upper metal level (M2) with a stud or via level (M1M2V) between them. As fabricated, each chain subgroup can be tested. However, the entire chain can be tested only after lamination to the substrate, since the substrate provides the shorting joining pads that complete the full chain, as shown in Figure 6. The other two relatively dense quadrants contain serpentine lines, as shown in **Figure 7**. Lines on level M1

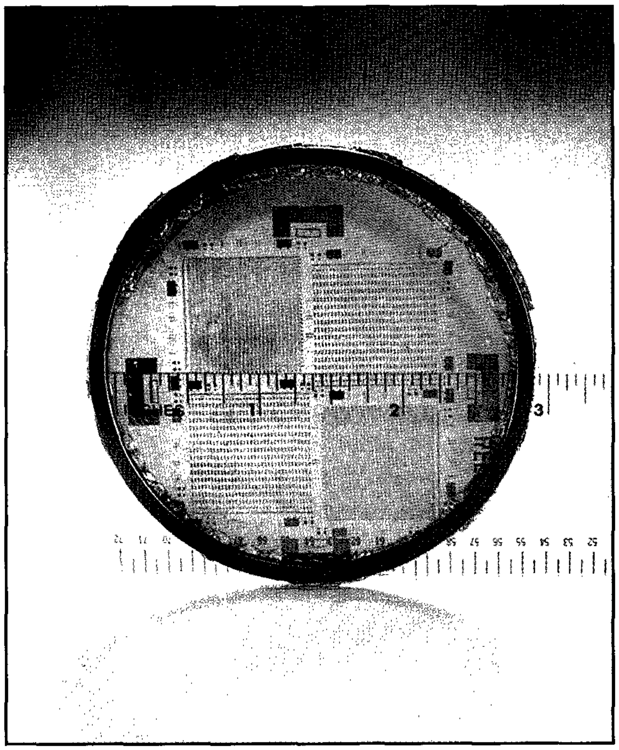

**Figure 5**

Photograph of multilayer metal–polymer circuitry fabricated on a glass carrier and later released onto a metal frame. This is a four-level structure.

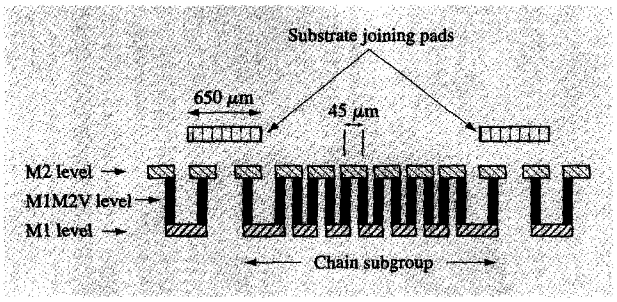


**Figure 6**

Schematic cross-sectional view of the via chain portion of the circuitry shown in Figure 5. M1 and M2 are two line levels, while M1M2V is the interconnecting via or stud level between the two line levels.

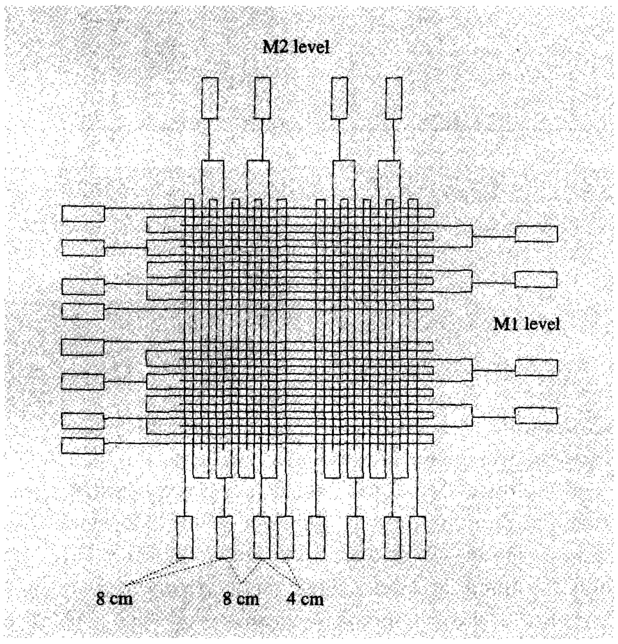


**Figure 7**

Schematic plan view of the serpentine line portion of the circuitry shown in Figure 5. M1 and M2 are two line levels separated by a via level.

run orthogonally to lines on level M2. Both sets of lines can be tested from the top through stud columns that bring the test pads to the top surface. The serpentine section has lines of varying lengths which are tested for opens through pads on one side of the structure. Using pads on both sides of the structure enables testing for shorts between the interdigitating lines. **Table 1** shows data from a typical sample that was measured after thin-film fabrication and later after release from the glass carrier. No measurable damage was detected after release. In the large-area test vehicle demonstrations, the yields that were obtained ranged between 99.94 and 99.97%, indicating the robustness of the process.

**Table 1** Electrical test data on a test sample with single-layer circuitry that had metal lines embedded in a polyimide layer. The lines were tested in the as-fabricated state on the glass carrier prior to release and retested as a freestanding film after laser release.

| *Sample ID* | *Line type tested* (cm) | *Number of lines tested* | *Number of good lines in as-fabricated structure* | *Number of good lines in structure after release* |
|---|---|---|---|---|
| #1 | 8 | 96 | 81 | 81 |
| #1 | 4 | 48 | 45 | 45 |
| #1 | 0.2425 | 18 | 17 | 17 |

## Summary

An excimer laser ablation process is described to fabricate freestanding multilayer thin-film structures that find a variety of applications in the microelectronics industry. The ablation process has been carefully optimized to minimize the force experienced by the thin-film layers to prevent damage during their release from a carrier. An MCM application based on this technology has been described in some detail. Here the thin-film structure is built on reusable glass carriers and later transferred to a product substrate. The technology elements that make this process possible are outlined, and results from technical feasibility demonstration studies are presented. Such a thin-film transfer process can effectively couple with and leverage any low-cost interconnect fabrication process developed in the future [5, 6] to facilitate low-cost MCMs on a variety of different product substrates for many microelectronic and communication applications.

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