INTRO TO TEREFILM® PHOTOPOLYMER FOR PRECISION PLACEMENT OF MICROLEDS

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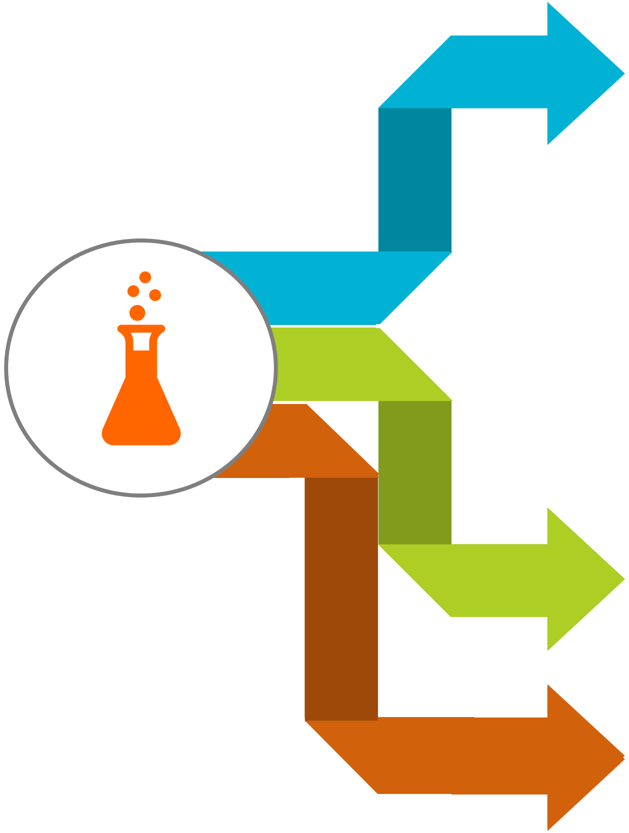
Terefilm®: Adaptable for Multiple Fields of Use

Terefilm® is part of a family of advanced materials and processes being developed to address the **Advanced Packaging** and assembly challenges for the “More than Moore” era.



Precision Placement / Mass Transfer

Securely holds and parallel transfers millions of microscopic components with 1 micron accuracy

Dry Developable Photoresist

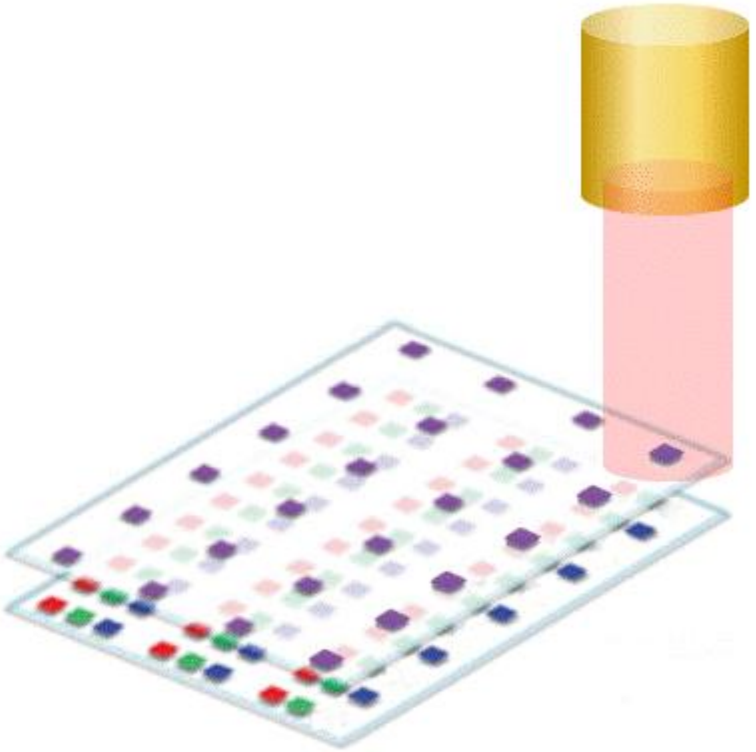
Replaces wet processing and eliminates stripper from maskless lithography

BEOL Universal Film

Enables hard carriers as a replacement for transfer films in 3 back-end-of-line processes

How It Works

- A thin layer of our **Terefilm** photopolymer securely holds components on a glass plate
- When activated with **light** and gentle heating, the polymer transitions to an expanding gas which places the component onto the substrate
- A simple ***mask*** can be used to release a single component or **thousands** of components in a single cycle



(slowed for illustration – process occurs in milliseconds)

Optimizing the Laser Subsystem

Laser requirements:

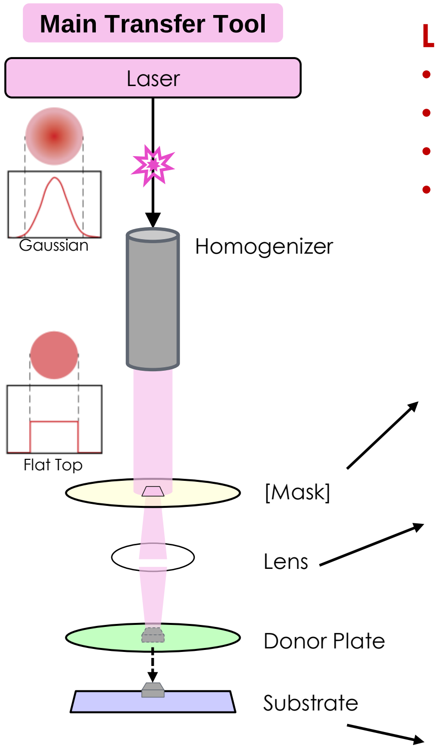
Wavelength: Ideally based on highest reliability, lowest cost, commercially available equipment.

Pulse length and energy: Optimize for lowest achievable fluence to initiate transfer.

Homogenizer:

The beam intensity should be as uniform as possible over the irradiated area in order to see uniform transfer characteristics.

Low activation energy (Fluence) is directly related to the design of the *Transfer Material*



Optimizations:

Low fluence

- **Lower cost & simpler optics**
- **Lower cost lasers / light source**
- **Longer component lifetime**
- **Supports mask patterning**

Optical system:

Optional: opaque film such as normally used in contact lithography. Only practical at low fluence; higher energies ablate mask material

This may be a multi-element system. It should image the component footprint (optionally via mask aperture) accurately onto the die. It may be 1:1 or a reducing system as desired.

A hard carrier coated with a **release material** holds the components securely until the release material is activated by the LIFT process

should be positioned as close as feasible to the donor plate; ~ 5 – 100 µm. Contact between the component and the substrate is *not required* for transfer

Optimizing the Transfer Material

- **Low Activation Energy.** Lower fluence requirements will transfer significantly less heat and can potentially activate with low cost, highly reliable non-laser UV light sources. A low energy requirement also means the same laser that needed to concentrate energy over a smaller area in conventional LIFT can now expose a larger surface area for parallel release. Alternatively, a 10x smaller laser can be used to save costs.
- **Mask Imaging.** Activation energy below the ablation threshold of mask material can provide true patterning without sophisticated optics. Mask-enabled LIFT also preserves the accuracy of the die-to-die relationships of the fabrication pitch.
- **Clean.** An ideal process doesn’t ablate the transfer material. Ablation can leave large residual material on transferred components, requiring additional cleaning. An ideal material will decompose cleanly into gas. The same process used to release the components can also be used to quickly and easily clean the donor plate by removing any residual material.

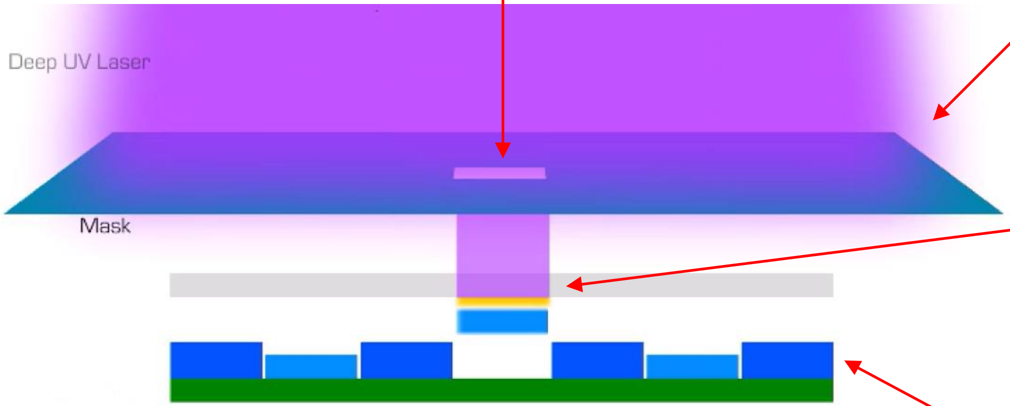
Optimizing the Transfer Material

- **Fast.** The material activation should happen in microseconds. Conventional thermal release materials don’t meet this requirement because they change adhesivity too slowly, cannot be used at an offset from the substrate, and leave residue.

- **Accurate.** Containment materials for blister formation introduce uncertainty in the force profile that imparts kinetic energy to the released component. This directly impacts placement accuracy and yield. Polyimides and thermosetting polymers are ablative materials which require large activation doses, leave residue, and are difficult to control. An ideal material decomposes cleanly while imparting a downward placement force to the component (enabling non-contact placement). It should also have minimal “edge effects” which can bleed into adjacent components.

Terefilm®: Engineering a Material for LIFT

Low Activation Energy. Fluence can range from 2mJ/cm to 50mJ/cm, which is **10% the typical energy required for other LIFT-based mechanisms**. At these levels, significantly less heat is transferred.



Parallel Transfers. **Low energy means we are below the ablation threshold of mask material**. Masks allow us to release multiple components in a single cycle, and exactly match component footprints of **any size or shape**.

Accurate. Since a release layer or blister formation is not required, there is **no uncertainty** in the force profile that imparts kinetic energy to the released component. This directly leads to **greater placement accuracy and yield.**

Fast. The low energy requirement means the same laser that needed to concentrate energy over a smaller area in conventional LIFT can now expose a larger surface area for parallel release. Alternatively, a 10x smaller laser can be used to save costs.

Clean. **Release Material** should completely decompose to a gas without residue. The same process used to release the components can then be used to quickly and easily clean the donor plate for reuse.

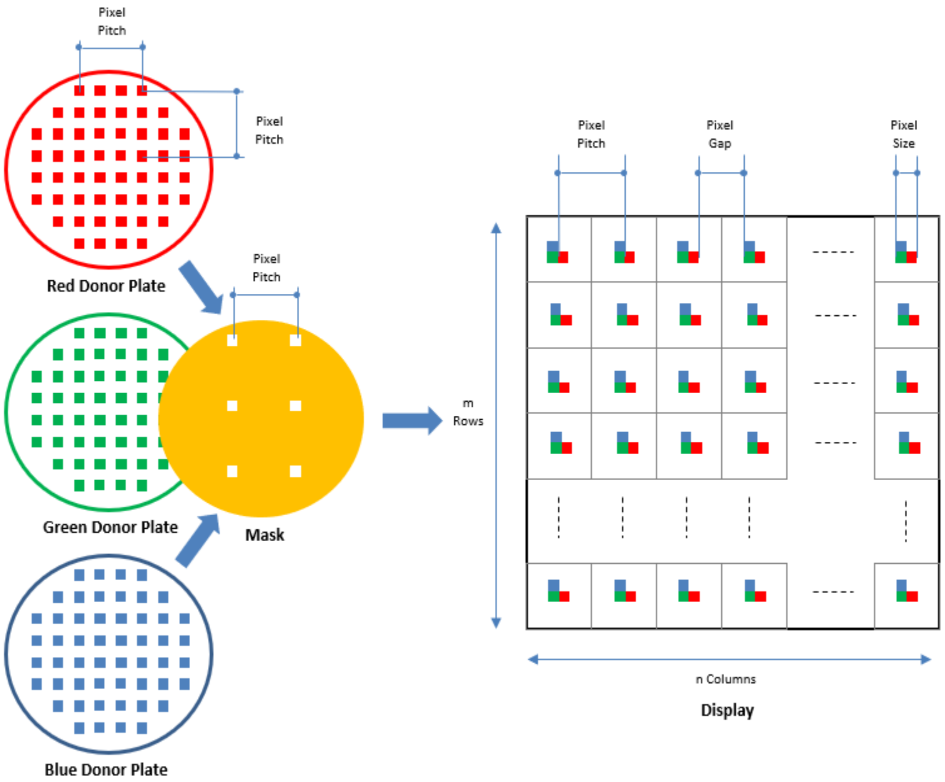
Using a Pixel Mask to Mass Transfer MicroLEDs

Challenges:

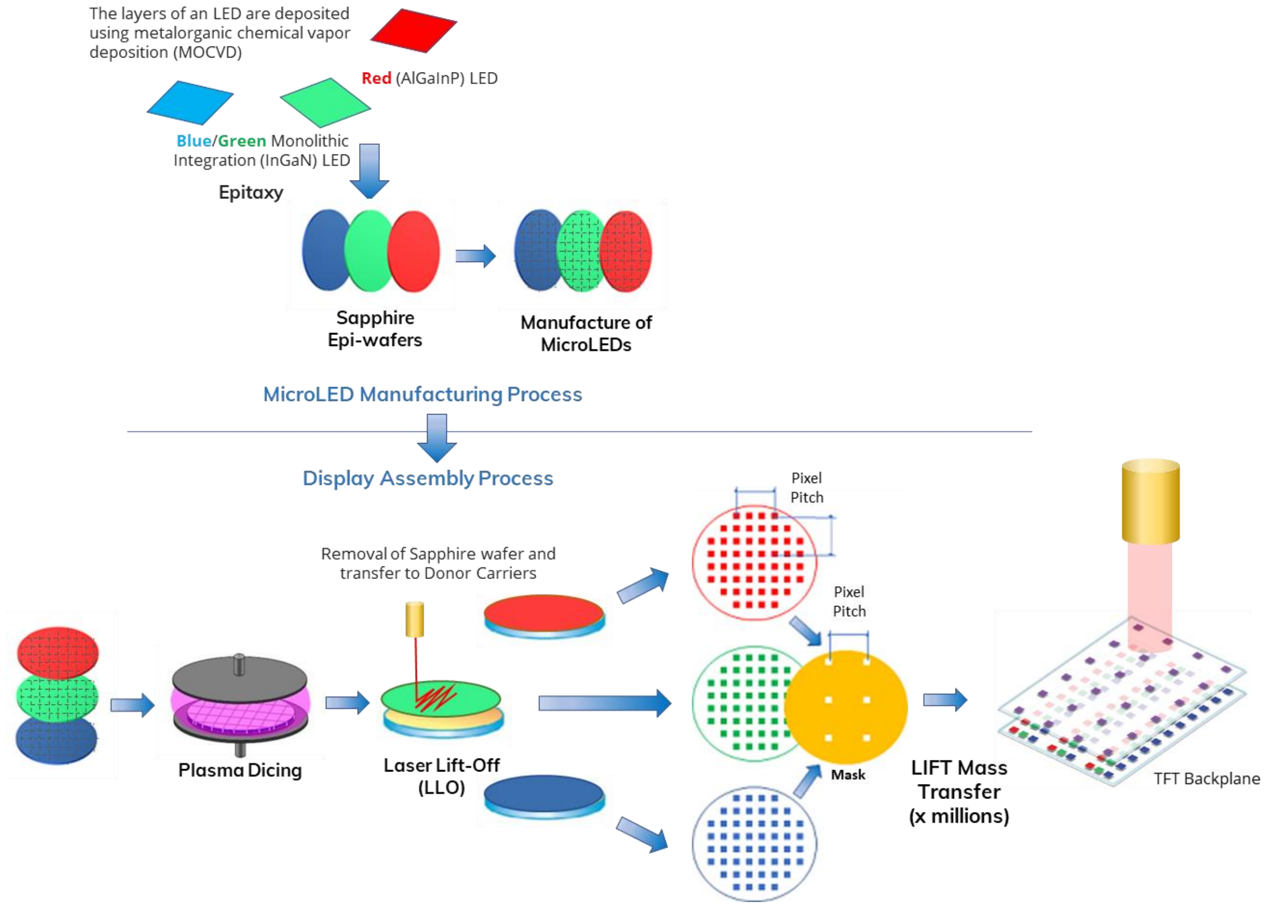
- Millions of Components
- Heterogeneous Assembly from different source epi wafers
- Sub-micron placement accuracy
- Need for speed; 100's of millions of units per hour
- Process should support selective release and defect repair

Optimization:

- **Pixel pitch is a multiple of the fabrication pitch**
- **Mask enables mass transfer at the pixel pitch *without* redistribution of the components**
- **Subsequent releases only require repositioning of the mask and substrate**



High Level MicroLED Display Manufacturing Flow



The layers of an LED are deposited using metalorganic chemical vapor deposition (MOCVD)

Red (AlGaInP) LED

Blue/**Green** Monolithic Integration (InGaN) LED

Epitaxy

Sapphire Epi-wafers

Manufacture of MicroLEDs

MicroLED Manufacturing Process

Display Assembly Process

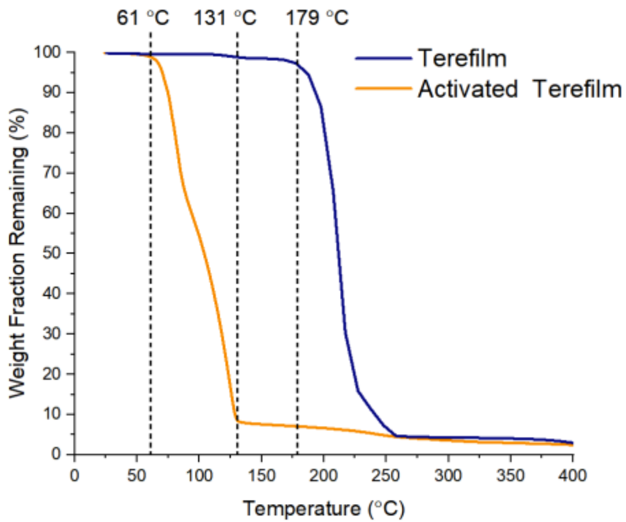
Removal of Sapphire wafer and transfer to Donor Carriers

Plasma Dicing

Laser Lift-Off (LLO)

LIFT Mass Transfer (x millions)

Terefilm® Properties



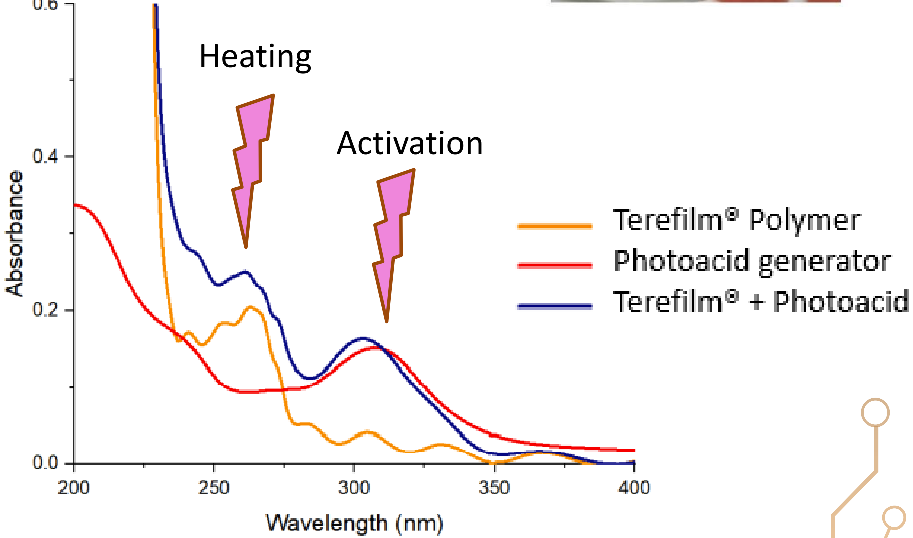
>100 °C difference in decomposition temperature between activated and inactivated Terefilm®.

T_gs between 115-135 °C depending on molecular weight.

High hardness modulus 3.9-4.9 GPa below the T_g

Excellent solubility in many organic solvents

Optically **Transparent** and 100% **Amorphous**



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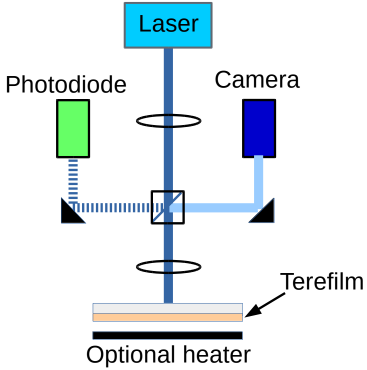
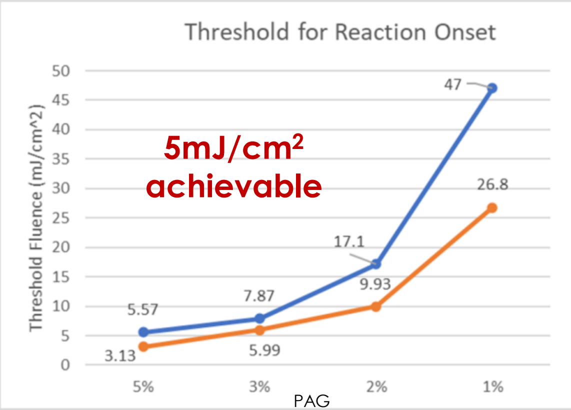
Terefilm® Reactivity Profile

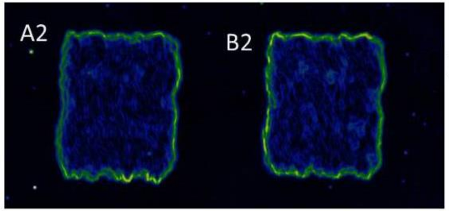
Objective: delineate the reaction parameters of the material without components



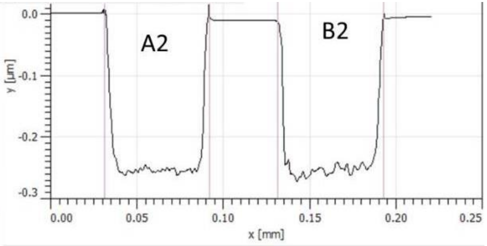
- Irradiation through the fused silica donor plate as in normal process, but without chips.
- Blue line (top): no heat; red (bottom): film at 100C during irradiation.
- “Reaction onset” is the minimum fluence required for component transfers. Good process control would use slightly larger values.



5mJ/cm^2 achievable



(The rough edges come from the mask, which is machined metal.)



Nominal 50 x 60 µm features in 0.34 µm thick film, with heating (A2), 90 mJ/cm^2. No heat (B2) gives a similar profile but with residual catalyst.

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Terefilm® is currently offered in evaluation quantities only and is not yet in general availability.

Terecircuits is working with select partners to develop LIFT-compatible production tools and additional applications for Terefilm®. If you have a use case that could benefit from working with us, we want to hear from you!

Candidates will be evaluated based on market opportunity and experience working with similar materials and processes. Terecircuits may provide direct support for projects with the potential to solve unique market problems or where the partner can contribute significant resources in kind.

For other opportunities, limited quantities of evaluation materials may still be available. To qualify as an early evaluation partner, use the form at http://terecircuits.com/contact/ and enter a brief description of your proposed project.

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