Fabricating the Flexible Future
How UV laser systems enable the transition from rigid to flexible in microelectronics manufacturing
Ralph Delmdahl

By leveraging the unparalleled pulsed UV-power of excimer lasers, gossamer-thin functional foils attached to rigid wafer- or panel-type carriers can be detached with high yield and fast rate, increasing productivity and lowering the costs of manufacturing a new generation of thin and flexible components and devices.

Laser processing has always been a key technology in achieving breakthrough developments in microelectronics devices. As the structural dimensions of microelectronics components continuously shrink, there is a trend towards employing short wavelength UV-lasers delivering highest machining resolution, both along lateral and vertical direction. The combination of modern excimer lasers, being the most capable in the UV laser landscape, with large-field projection optics bridges the long-standing gap between “fast processing” and “precise processing” due to an unprecedented effective illumination footprint, some 10,000 times larger than the achievable resolution.

The rigid carrier approach to flexible microelectronics manufacturing
Flexible displays as used in smartwatches, wearables or curved smartphones have enormous commercial potential, but their manufacturing poses significant technical challenges. In particular, the thin plastics substrates used for flexible displays are too delicate to handle with conventional tooling and will typically lose their limited rigidity at the high temperatures experienced in several production steps. One experiences a similar challenge when processing thin wafers which will be thinned down to such extent where they become flexible in order to support space saving vertically stacked logic and memory chip architectures packed inside our highly functional mobile devices. The common approach to volume production of flexible display panels or ultra-thin semiconductor wafers: Fabricating the circuitry on a polymer-coated, rigid glass carrier and detaching the finished devices in the final process step. Technically, the UV excimer laser line beam is shown through the carrier glass substrate on the polymer layer. Due to the short wavelength, only the polymer in the direct vicinity of the glass substrate evaporates. The layer separation using the 308 nm excimer laser occurs within a single laser pulse of circa 25 ns full width at half maximum (FWHM) pulse duration, using about 200 J/cm² energy density. The short wavelength, moreover, eliminates the need for absorption enhancement by means of additional sacrificial layers.

The true value of UV performance and reliability
A number of rigid carrier separation techniques turn out to be unsuitable for mass production purposes. For exam-
Trends in Manufacturing

with high-quality line beam optics:
excimer laser systems in combination
supported by using short wavelengths
importance of the high production yield

In fact, one cannot overestimate the
importance of the high production yield
supported by using short wavelengths
excimer laser systems in combination
with high-quality line beam optics:
- Laser lift-off carrier separation takes
  place on a valuable part
- Laser lift-off processing is among the
  last of a multitude of costly processes
- Many high-value parts and the re-
  sulting microelectronics devices are
  at stake during the lift-off process
- A yield loss of just 1 % during dis-
  play laser lift-off sums up to many
  millions of dollars profit loss a year.

Large-footprint UV laser lift-off
processing

Display manufacturers employ rectan-
gular glass carrier panels from one to
about five square meters in size. The
essential lift-off process steps used for
the fabrication of flexible displays are
shown in Fig. 1. In the first step, a tem-
porary glass carrier substrate is spin-
coated with a thin polymer film which is
cured thereafter. On top of the polymer
layer, the circuit backplane (i.e. the ma-
trix of thin-film transistors) is built, fol-
lowed by the display frontplane which
contains the functional light-generating
layers. Finally, the transition from rigid
to flexible display is realized through
laser lift-off processing.

In order to achieve laser lift-off sep-
oration of large panels on an industrial
scale, line beam scanning based on ex-
cimer laser optical systems has become
the industry proven processing strategy
of choice. Starting with lift-off systems
providing 250 mm long line beams,
nowadays excimer laser systems with
extended line lengths of up to 750 mm
have made it to the flexible display pro-
duction floor (Fig. 2). At a line width of
~ 0.4 mm, the respective processing
footprint, i.e. the substrate area covered
within each laser pulse ranges from
1 cm² for a 250 mm line beam length to
3 cm² for a 750 mm line beam length.
As a single shot per area is sufficient and
the overlap between the applied pulsed
is of the order of a few percent of the
line beam width, the panel throughput
directly scales with the laser repetition
rate. Depending on the panel size and
the applied line beam length, large-foot-
print excimer laser lift-off processing
rates comparable to about 10,000 flex-
ible smartphone displays per hour are
achievable.

The merits of an all flat-top beam
profile

The high UV pulse energy of the exci-
mer laser reaching up to one joule in the
energy stabilized operation mode, sup-
ports shaping large beams with a flat-top
density distribution as demanded by the
individual process window for relia-
ble single-pulse laser lift-off. Us-
ing insufficient energy density results
in incomplete lift-off release whereas
too high of an energy density leads to
too high heat-load and potential warpage
or carbonization of the thin film. These
are typical problems observed with sol-
id-state based UV laser systems where
at least one beam axis has a Gaussian
cross-section with only 25 % lift-off
effectivity. The entirely flat-top beam
characteristics of excimer laser lift-off
systems (Fig. 3), also along the short axis
of line beam systems, provide an 80 %
effective beam area and support fast rate
laser lift-off at uniform energy density
applied across the entire carrier with
smallest beam overlap and hence a min-
imum number of UV pulses per carrier.

Fig. 2 Carrier panel moving below an excimer laser line beam during laser lift-off separation of flexible displays.

Pulse-on-demand – saving laser
pulses in practice

Laser pulses and those in the UV spec-
tral region in particular come at a cost.
These costs are associated with the
pulse-limited wear and tear of certain
laser consumables such as optical com-
ponents. At Coherent, excimer laser lift-
off systems such as the UVblade family
are designed for operation in the pulse

Fig. 3 Cross sections along the horizontal axis and the vertical
axis of a 750 mm long excimer laser line beam.
saving pulse-on-demand mode. In practice, during laser lift-off processing in a flexible display fab, the UV laser system only fires less than 40 % of the machine's tact time. With the pulse-on-demand mode, selectable for the excimer laser the laser lift-off system only fires during panel exposure and not during the times required for stepping or panel loading and unloading and other idle times (Fig. 4). Pulse-on-demand thus greatly reduces the number of laser pulses per panel and consequently the cost of operation per panel. The manufacturer can thus directly relate the laser operation costs to the generated value. By virtue of the minimized pulse accumulation of pulse-on-demand excimer laser systems are typically operated over periods in excess of five years under industrial production conditions without significant maintenance and with an overall equipment uptime of more than 95 %.

**Summary**

In conclusion, laser lift-off in conjunction with the enabling UV power of modern excimer lasers has become a key technology for high yield thin layer release in the manufacturing of the next generation of lightweight and flexible microelectronic devices. In excimer laser-based lift-off systems, both, large depth-of-field, all flat-top beam characteristics, and the superior pulse stability of a native pulsed UV laser technology unite to the perfect carrier separation tool. Excimer lasers uniquely provide the necessary pulse energies and optical performance characteristics to support square centimeter scale processing areas with optimum beam geometry for fast debonding of carrier wafers up to 300 mm diameter as well as for detaching large display glass substrates.

**Depth-of-field – compensating height deviations over large areas**

One of the most important factors in achieving high yield when large display carrier panels is the depth-of-field of the laser lift-off system. Due to the high pulse energy available from state-of-the-art excimer lasers, a line beam imaging system is designed with low numerical aperture resulting in a very high depth-of-field of the order of ± 150 µm (Fig. 5). Changing the substrate plane in vertical direction relative to the line beam focal plane results in a line width change of about 2 % when measured at 50 %, 90 % and 96 % line width levels. Substrate height variations during panel scanning are thus largely unnoticed. On the contrary, frequency-tripled solid-state lasers need higher focusing as they deliver low pulse energy at UV wavelengths. As a consequence, solid state systems have depth-of-field of only some 20 µm. This severely reduces the process window margin in the case of larger carriers and suboptimal stage accuracy.

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