Full-field Projection Scanner Patterning Resolution and Overlay Performance

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AP Market Trends – SUSS Exposure Solutions
Market and Application Overview - ADP

Bubble size represents equipment market size (based on Yole forecast 2015 and 2018)

Exposure Technology:
- Mask Aligner
- Scanner
- Excimer Ablation Stepper

3DIC & 2.5D Interposer (TSV, TGV)
- WLCSP (RDL)
- FO WLP (RDL, via)
- 3D WLP (i.e. CIS Packaging)
- Flipchip (i.e. Cu Pillar)

SEMICON TAIWAN
SUSS – exposure Product Portfolio

**Mask Aligner**
- **MA200 Gen3**
  - Automatic
  - 150/200mm
- **MA300 Gen2**
  - Automatic
  - 200/300mm
- **MA/BA8 Gen3**
  - Semi-Automatic
  - Pieces up to 200mm
- **MA12**
  - Manual
  - 200/300mm (squares)

**Projection Scanner**
- **DSC300 Gen2**
  - Automatic
  - 200/300mm
- **DSC500 / DSC800**
  - Automatic
  - 450x500mm / 650x780mm

**Laser Stepper**
- **ELP300 Gen2**
  - Automatic
  - 200/300mm
- **ELP600**
  - Automatic
  - 600x650mm
DSC300 Gen2 key benefits:

- High Yield due to mask wafer separation
- Projection lithography imaging performance
- High overlay accuracy
- Lower cost and better CoO than stepper
- Full field mask eliminates need for edge exposure, allows not repeated features, and is invariant to die sizes
- Selectable NA and large Depth of Focus

**Cost of Ownership**
DSC300Gen2 Projection Scanner
**DSC300 Gen2 – Technical Characteristics**

**Material Handling:**
- Bridge tool for 200mm and 300mm wafers, warped wafers up to 5mm
- Full field exposure through 14” or 9” photomasks, fully automated
- Fully automated robot handling
- Throughput up to 80 w/h for 300mm wafers

**Optics:**
- 1:1 Wynne Dyson projection optics
- Selectable NA: 0.07 – 0.10 – 0.12 – 0.14
- Resolution <3µm L/S
- Overlay <1.5µm (machine to itself)
- Exposure uniformity <±2%
- Lamp size: 2000W
- Intensity up to 4000mW/cm²
- Wavelength g, h, i-line with automatic filter selection

**Alignment: (off-axis, on-axis)**
- Fully automatic pattern recognition and alignment
- TSA alignment accuracy: <±1µm
- TSA-IR alignment optional
- Thermal run-out compensation thru active mask heating/cooling
- No limitation in number or location of alignment targets

**Miscellaneous:**
- SECSIIGEM
- SEMI S2/S8, CE certified

**Windows Graphical User Interface**

**Footprint:** 2760mm x 2880mm x 3000mm (excluding ECU)
Highly Uniform 30x30mm UV Exposure Beam

300mm Wafer

Received 1st Part of UV Dose
50% Overlap
Received 1st Part of UV Dose on 1st Pass (top of diamond)

Received 2nd Part of UV Dose on 2nd overlapping Pass (bottom of diamond)

50% Overlap

Scanning technique results in excellent image uniformity across 300mm wafer
DSC300 Gen2 – Design Flexibility

Full field exposure of 1:1 mask enables non-repeating patterns
Large depth-of-focus with selectable NA

Selectable NA provides large DoF and flexibility for process optimization.

– Provides optimum balance of high resolution and large DoF
– Large DoF enabled with selectable NA (0.07 to 0.14)
  • Thick resist and photo-definable dielectric imaging
  • Straight sidewalls
  • Non-planar surface

Select DOF with Variable Numeric Aperture

DSC300 Selectable NA: over 50µm of DoF for 10µm feature size with 0.14NA

10µm Via in 50um JSR151N

Typical Stepper Fixed NA: for high resolution in thin resist but low DoF in thick resist.
DSC300 Gen2 – lens protection

- **Lens Protection**

  - Wafer is always moving continuously past the lens. At no point is the wafer stationary while exposure is taking place

  - Constant airflow minimizes risk of resist outgas adhering to the lens

  - Protective window in front of the lens protects the projection optics, which can be removed and cleaned

  - Distance between protective window and wafer/resist surface is 8mm
Mask mag correction and runout control

+ Mag Correction and Run-Out Compensation with Mask Temperature Control
  - Active cooling and heating by:
    + Air knives & heating elements
    + Closed loop control system
  - Isotropic Mag Correction
    + Compensates up to 30ppm
    + Corresponds to ~5µm die shift on 300mm wafer
  - Run-out compensation
    + For thick resist and high exposure dose processes

Heating elements and air knives are located for effective heating/cooling
DSC300Gen2 Overlay Performance
**DSC300 thick resist overlay: EXPERIMENTAL SETUP**

**Process flow:**

+ **Incoming substrate (18 300mm wafers):**
  - Cr plated Si wafer
  - “First layer” structures defined by DSC300 litho step and transferred into Cr via wet etch

+ **Coating Step:** ACS300
  - TOK PMER P-CR4000
  - Resist thickness = 60±2.8 um

+ **Exposure Step:** DSC300 Gen2
  - Mask: TSC-08474
  - Energy: 300mJ/cm²
  - Focus Offset: +20um
  - Filter: I-line
  - Aperture: 0.14NA
  - Diffuser: #2
  - Alignment: on-axis

+ **Post Exposure Bake Step:** Hot Plate
  - Temperature: 85°C
  - Duration: 180 seconds

**Development Step:** Delta 12AQ

- Developer: AZ 726 MIF (2.38% TMAH) @ 25°C
- Time: 300 sec
- Recipe: CR4000_5X

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17 Overlay measurement sites per wafer

**“Box in a Box” overlay structure**

- **“First Layer”** structure in Cr (400 µm x 400 µm)
- **“Second Layer”** structure in 60 µm TOK PMER P-CR4000 (450 µm x 450 µm)
DSC300 Thick resist overlay: Statistical analysis

<table>
<thead>
<tr>
<th>Overlay Term</th>
<th>Mean</th>
<th>Mean+3*σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Overlay-Raw (µm)</td>
<td>0.74</td>
<td>2.03</td>
</tr>
<tr>
<td>Total Overlay-Shift/Rot Adj (µm)</td>
<td>0.025</td>
<td>1.63</td>
</tr>
<tr>
<td>Total Overlay-Shift/Rot/Mag Adj (µm)</td>
<td>0.5</td>
<td>1.44</td>
</tr>
<tr>
<td>X-Shift (µm)</td>
<td>0.02</td>
<td>1.07</td>
</tr>
<tr>
<td>Y-Shift (µm)</td>
<td>-0.12</td>
<td>0.83</td>
</tr>
<tr>
<td>Rotation (deg)</td>
<td>-0.00014</td>
<td>0.00018</td>
</tr>
<tr>
<td>X Mag (ppm)</td>
<td>0.7</td>
<td>7</td>
</tr>
<tr>
<td>Y Mag (ppm)</td>
<td>4.1</td>
<td>10.4</td>
</tr>
</tbody>
</table>

Up: Mean + 3 σ analysis of total overlay and specific overlay terms.
In high-volume production environment, non-zero contributions from Rotation, Shift, and Magnification may be further dialed in. Centering Shift and Rotation terms around zero would bring mean +3 σ of overlay to ~1.6 µm.

Right: Vectorial representations and density distributions of individual overlay vectors a) raw overlay data as presented on Slide 3. b) overlay vectors corrected for non-zero Shift and Rotation contributions c) overlay vectors corrected for non-zero Shift/Rotation/Mag contributions.
DSC300Gen2 Exposure Performance
DSC300Gen2 for Cu Pillar process

TOK-PMER-CR4000 60µm: 80µm and 100µm CD uniformity ~1%

30µm via HD 4104, 10µm thick

20µm via HD PBO 8820, 10µm thick
DSC300Gen2 for 7µm TOK – PW1000T

- 7µm TOK-PW1000T resist, 0.10 NA; ghi-line
- Depth of Focus of 15µm at Exposure Energy 500mJ/cm²: Profile similar for 2µm, 3µm & 5µm L&S
  => 87deg sidewall angle
**DSC300Gen2 for 15µm AZ3DT-102M**

- **3µm L-S**: 500mJ/cm² & +5µm
  - Cu coated wafers
  - Optimum process conditions: 700mJ/cm², +10µm offset
  - 3µm L/S, 5µm vias can be cleared
  - A/R 5:1
  - Depth of focus at 15µm
  - Exposure latitude 100mJ/cm²
  - Sidewall angle >= 89°
  - No sign of resist scumming
  - Trench and vias are open
  - Wafers inspected by optical profiler, SEM X-section, and Optical Microscope

- **5µm L-S**: 500mJ/cm² & +5µm

- **5µm Via**: 500mJ/cm² & +5µm

- **3µm L-S**: 700mJ/cm² & +5µm

- **5µm L-S**: 700mJ/cm² & +5µm

- **5µm Via**: 700mJ/cm² & +5µm

- **3µm L-S**: 700mJ/cm² & +10µm

- **5µm L-S**: 700mJ/cm² & +10µm

- **5µm Via**: 700mJ/cm² & +10µm

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**Cu coated wafers**
**Optimum process conditions:**
- 700mJ/cm², +10µm offset

- **3µm L/S, 5µm vias can be cleared**
  - A/R 5:1

- **Depth of focus at 15µm**
- **Exposure latitude 100mJ/cm²**
- **Sidewall angle >= 89°**
- **No sign of resist scumming**
- **Trench and vias are open**
- **Wafers inspected by optical profiler, SEM X-section, and Optical Microscope**
DSC300Gen2 for 12µm AZ4620

880mJ/cm²/20µm
∠81.529°
FT: 11.360µm
5µm Trench CD
  Bottom: 4.560µm
  Top: 7.840µm
  Pitch: 9.800µm
10µm Trench CD
  Bottom: 9.036µm
  Top: 12.651µm
  Pitch: 19.578µm
10µm Via CD
  Bottom: 8.507µm
  Top: 12.651µm
  Pitch: 20.694µm

880mJ/cm²/-20µm
∠84.78°
FT: 10.85µm
10µm Line & Space
  FT: 10.85µm

Trench CD: X-11.56µm & Y-11.56µm
DSC300Gen2 Solutions for Fan-Out
FO-WLP Lithography Challenges

+ Fundamental Challenges for FOWLP Lithography:

- Large Exposure Field Size
  + to handle fan-out and die size increase

- Warpage and Non-Planar Surface
  + due to molded wafer with different materials

- Steep Side-Wall Angle
  + to handle thick PR and photo dielectrics

- Die Position Shift
  + due to die placement error and drift

Source: Infineon

Source: ASE
**DSC300Gen2 Tool-Box for Fan-Out**

Die-First Fan-Out Applications face a particular overlay challenge

**Pick and Place accuracy: up to 10µm die-placement error**
- Usually 2 robots are used (upper/lower half)
- Die Placement accuracy of the robot itself

**Runout (compression) during molding process up to 10µm**
- Often depending on ratio Si/Epoxy
- Shrinking epoxy during curing

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**Die Placement Error Compensation**
DSC300 uses a dynamic algorithm based on data from
- Actual die locations
- Location of fiducials
- Nominal die positions
Our proprietary software (Suss_AutoAlignToExposeChecker.exe) is used to optimize the wafer handling to achieve either the “best yield” or “best overlay”, as specified by the user. The software can be interfaced with DSC300 for automated operation.

Two versions of the analysis is available:

1) “Best overall overlay”: This is achieved by a least-square fit for all dies
2) “Best yield”: This is achieved by a clustering algorithm
DSC300Gen2: mix-and-match for FOWLP exposure

DSC300 provides excellent performance for FOWLP with:

- Full field exposure with continuous scanning
- Large DoF and Warped Wafer Handling Capabilities
- Global Exposure Offset based on die placement data
- Isotropic Mag Correction and Run-Out Control

Mix & Match of Scanner and Stepper

- Use scanner as the baseline tool
- Use steppers only for the layers when overlay control is more critical
- Maximize the benefit with the best combination of performance and cost
  + Lowest CapEx and CoO
  + Highest Yield and Productivity

Example for RDL structure:
- Scanners for 3 layers (initial, 1 RDL, UBM)
- Stepper for 1 layer (1 RDL)
DSC300Gen2: Cost impact of mix-and-match approach for FOWLP exposure

Scenario:
1. All 6 lithography steps are performed on a UV stepper system
   -> a total of 4 steppers required to match output target, with almost no buffer capacity remaining
2. Mix and Match: first two steps are performed in the UV stepper, remaining 4 steps are performed on the DSC300 Gen2
   -> 1 stepper and 2 DSC300 Gen2 required for output target
3. All 6 lithography steps are performed on the DSC300 Gen2
   -> a total of 3 DSC300 Gen2 required to match output target

Conclusion and summary:
+ Significant cost reductions can be achieved through the use of the DSC300 Gen2 in WLP processes
+ 40% lower ($4.4M) investment expenses needed to match the same output due to lower Capex and higher throughput performance of the scanner
+ 50-75k$ savings per month due to lower cost of ownership when using the DSC300 Gen2 (→ $600k - $900k / year!)
+ Even a mix and match of steppers and DSC300 Gen2 provides already significant cost reduction potential

Case study:
- 2 RDL layer
- 20,000 wafer per month
DSC300Gen2 Throughput and CoO
Performance of DSC300Gen2:
62 WPH @ 1,000mJ
## COO for AZ4620 exposure @ ~800mJ/cm²

<table>
<thead>
<tr>
<th>Cost per wafer</th>
<th>MA300</th>
<th>DSC300</th>
<th>UV Stepper</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CAPEX</strong></td>
<td>$1.3M</td>
<td>$2.0M</td>
<td>$2.8M</td>
</tr>
<tr>
<td>Throughput (WPH)</td>
<td>80</td>
<td>65</td>
<td>55*</td>
</tr>
<tr>
<td>Initial Investment</td>
<td>$0.71</td>
<td>$0.97</td>
<td>$1.60</td>
</tr>
<tr>
<td>Mask costs</td>
<td>$0.63</td>
<td>$0.25</td>
<td>$0.12</td>
</tr>
<tr>
<td>Service (5% per year)</td>
<td>$0.18</td>
<td>$0.24</td>
<td>$0.40</td>
</tr>
<tr>
<td>Consumables</td>
<td>$0.13</td>
<td>$0.42</td>
<td>$0.53</td>
</tr>
<tr>
<td>Labor</td>
<td>$0.02</td>
<td>$0.02</td>
<td>$0.02</td>
</tr>
<tr>
<td><strong>Costs per exposure</strong></td>
<td>$1.67</td>
<td>$1.89</td>
<td>$2.68</td>
</tr>
<tr>
<td>CoO comparison</td>
<td>88%</td>
<td>100%</td>
<td>141%</td>
</tr>
</tbody>
</table>

* Does not consider additional OEBR step

- Market Price of MA300, DSC300 and stepper
  - Initial Investment with 5 years depreciation
  - Photo Mask and Mask Cleaning Cost incl.
  - Consumable Cost
  - Labor Cost
  - Out of warranty Service Cost is 5% per Year

- Thick Resist Process (800mJ/cm²)
  - WPH: 80 (MA300), 55 (stepper), 65 (DSC300)

- Mask Cost and High Product Variation
  - Four new masks per month, 50 new masks per year
  - MA300 mask clean every 25 wafers
  - Four MA300 masks replaced per month

- Productivity:
  - Uptime: 92%
  - Availability: 86%
  - Utilization: 80%
  - Rework Rate:
    - MA300: 1%, stepper 0.5%, DSC300: 0.5%

More than 40% cost savings compared to a UV Stepper
DSC300Gen2

- Lower cost: lower CapEx and lower CoO than UV Stepper
- High throughput: 62wph @ 1,000mJ/cm²
- Full field exposure with continuous scanning
  - Invariant to die sizes
  - No need of a separate tool for edge exposure or bead removal
  - Enables to image non repeated patterns (e.g.: plating ring)
- No contamination of mask through Non-Contact Imaging
  - Mask and wafer are separated by ~200mm
  - No mask contamination resulting in repeated defects
- Resolution capability identical to 1xUV stepper (< 3µm) without jeopardizing yields
  - No incidental mask to wafer contact or alignment shifts due to contact
  - Steep side wall angle > 80°
  - High aspect ratios in thick resists for Cu pillar and RDL application
- Mag correction and exposure offset for Fan-Out and high dose applications
  - Run-out compensation
  - Die shift compensation
- One lithography supplier (coat, expose, develop)
- UV Scanner technology also available in larger formats (up to 650x780mm²)
Thank you!