Abstract
We have been assisting in applying Systems Engineering techniques and methods in a small (tens of persons) start-up company in the semiconductor process and equipment market. We report our observations in this start-up company with an innovative product operating in a dynamic environment. Start-up companies in general explore new applications or new technologies: an environment full of unknowns, uncertainties and other surprises. In the specific case of semiconductor process and equipment the system is highly multi-disciplinary, amongst others: high precision mechanical, control, optics, chemical, signal processing, and power electronics.
1. SE research

2. Start-up at Kista

3. System Modeling

4. Evaluation

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Note: Original diagram was annotated with actual performance figures for confidentiality reasons; these numbers have been removed.
Industry as Laboratory

- source of inspiration
- application playground
- industry

challenging problems
apply new engineering methods
research
hypothesis
improve
evaluate
observe results
Industry as Laboratory (2)

Kongsberg Industry Domains

- SubSea
- Defence
- Manufacturing
- Maritime

intended dissemination and research partners

multi-domain research and expertise

Reliability /Robustness in harsh environments

Innovation /Responsiveness for change

generalization and consolidation to facilitate use in other domains

single domain research focus on industrial problem
Modeling Recommendations as Applied

**principles**
- use feedback
- work incremental
- work evolutionary
- be explicit
- make issues tangible

**objectives**
- support communication
- facilitate reasoning
- support decision making
- create
- maintain
- understanding
- insight
- overview

**recommendations**
- Time-box
- Iterate
- Quantify early
- Measure and validate
- Multiple levels of abstraction
- (Simple) mathematical models
- Analysis of accuracy and credibility
- Multi-view
- System and its context
- Visualize

translate into
help to achieve
translate into...
1. SE research

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The Copper Printer

courtesy Replisaurus
www.replisaurus.com
Example of printed copper structures

courtesy Replisaurus
www.replisaurus.com
ECPR technology replaces 6 process steps by 1 step

courtesy Replisaurus
www.replisaurus.com

courtesy Replisaurus
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Overview of the different scopes
Customer key driver graph

- Pattern quality
  - Pattern resolution
    - Accuracy overlay
      - X-section control
      - Reliability
        - Throughput
          - Integral costs

- Design enabling
  - E.g. CD, separation
    - Early delivery vs volume production

- Cost per layer

- Environmental impact
  - Contamination and climate
    - Uptime
      - High MTBF
        - System cost
          - Operational costs
            - Consumables waste

- Electric power, clean water, ete,
  - N2, air, disposal water, air, ...

Partial graph: many nodes and connections are not shown.
Process flow at fab level, from inspection until testing

<table>
<thead>
<tr>
<th>Step Description</th>
<th>Throughput in Minutes</th>
<th>Wafer</th>
<th>FOUP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. inspection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. seed sputter</td>
<td>1</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>3. Cu print</td>
<td>2</td>
<td>50</td>
<td>target spec</td>
</tr>
<tr>
<td>4. seed etch</td>
<td>1</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>5. coat/develop dielectrics</td>
<td>3..4</td>
<td>50</td>
<td>75..100??</td>
</tr>
<tr>
<td>6. exposure or CMP for polymer vias</td>
<td>1..2</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>7. E-test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step</td>
<td>Description</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.</td>
<td>Loading Master &amp; substrate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Close doors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Align</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Move to proximity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Process incl. rinse &amp; dry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Move substrate unloading position</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Open doors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Unloading Master &amp; substrate</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Formula of printer throughput time

1. Close doors
2. Align $t_{\text{align}}$
3. Move to proximity
4. Process $t_{\text{chamber}}$
5. Move substrate unloading position
6. Open doors

$t_{\text{prepare}} = t_{\text{close doors}} + t_{\text{move to proximity}}$

$t_{\text{print}} = t_{\text{prepare}} + t_{\text{p,align}} + t_{\text{chamber (thickness)}} + t_{\text{p,finalize}}$

$t_{\text{finalize}} = t_{\text{move to unload}} + t_{\text{open doors}}$

$t_{\text{print}} = t_{\text{p,overhead}} + C_{\text{transfer}} \times \text{thickness}$

*note: original diagram was annotated with actual performance figures for confidentiality reasons these numbers have been removed*
Optical path to measure marker position

measurement accuracy determines required resolution

DoF

#pixels \approx 5M

pixel resolution versus maximum Field of View

read-out and processing time

optical resolution

magnification

displacement determines required Field of View

DoF
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Systems Engineering: responsible for customer key drivers and key performance parameters of system.
Levels of Abstraction

- Static system definition
- Multidisciplinary design
- System requirements

Number of details: $10^0$, $10^1$, $10^2$, $10^3$, $10^4$, $10^5$, $10^6$, $10^7$
Lifting Engineers to System Concerns

Number of details

10^0
10^1
10^2
10^3
10^4
10^5
10^6
10^7

100
10
1

Stretch
Senior engineer
Engineer

System architect

Systems Engineering and Modeling at Start-Up Company
Gerrit Muller

version: 0
March 6, 2013
RATWmentalDynamicRange
Systems Engineering at Start-Up companies is applicable

customization is required to adapt to:

- company size
- market and technology maturity

system models help to "lift" engineers to system level concerns
Application of *theory in practice*

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*is required for learning and validation*