Factory Information Systems for Photovoltaic Manufacturing

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Objective:
We assist companies increase yield, reduce cycle time and decrease costs by applying emerging technologies to real-world needs.
Measures of Success

- Improved Yield
- New Products Introduced (NPI) Faster
- Increased Machine Utilization
- Decreased Cycle Time
- Seamless Engineering Change Orders (ECO)
- Knowledge of Work in Process (WIP)
Customer Input

- Simple
- Low Cost
- Low Complexity
- Must be Stable
- Deterministic
- Configure Centrally
- Standardized
Manufacturing Information Systems
Technology Challenges

- Processes and faults need to be measured to make improvements
- Obtaining and exchanging information in the factory floor is expensive and difficult
- Most factories make use of proprietary, ad-hoc solutions which are brittle and not easily extended
- Installation cost of a factory applications is several times the purchase price
- Few commercial off the shelf solutions exist
Factory Information Systems for Photovoltaics Manufacturing

- Factory information systems can significantly improve manufacturing yield, cycle time and equipment utilization.
- The electronics industry developed CAMX to significantly lower the cost and complexity of factory information systems.
- Georgia Tech teamed with the electronics industry to develop CAMX.
- Georgia Tech is applying CAMX technologies to photovoltaic manufacturing.
What Is CAMX

- Vendor independent communication standards
- ANSI approved standard
- Designed to exchange data on the shop floor
- Defines messages to encapsulate data
- Defines protocol to exchange messages
- Uses widely accepted protocols: HTTP, MIME, SOAP, XML
- Programming Language Independent
- Operating System Independent
CAMX Message Examples

```xml
<EquipmentAlarm
dateTime="2000-02-02T11:33:22.00-05:00"
alarmId="MotorOilLow"
alarmInstanceId="30465"
alarmType="EQUIPMENTSAFETY"
laneList="1,2"
zoneList="3"/>

<MonitoringLimitZoneTransition
nameId = "Temperature"
transitionType = "LOWERTOUPPER"
upperDeadBand = "51.0"
lowerDeadBand = "49.0">
<Parameter
nameId = "Temperature"
value = "51.1"
units = "Celsius"
minimum = "0.0"
maximum = "110.0"/>
</MonitoringLimitZoneTransition>

<EquipmentError
dateTime = "2000-02-02T11:39:22.00-05:00"
errorId = "EquipmentErrorSubsystem"
errorInstanceId = "12345"
laneRange = "1"
zoneRange = "1">
<Extensions>
  <EquipmentErrorSubsystem>
    <MachineError
      vendorErrorCode = "FSPE1234"
description = "Pressure error">
      <Subsystem
        subsystemType = "PrintApplicator"
        subsystemId = "FrontApplicator"/>
    </MachineError>
  </EquipmentErrorSubsystem>
</Extensions>
</EquipmentError>
```
CAMX Architecture

Application

Application

Application

Application

Message Broker

Equipment

Equipment

Equipment

XML

XML

XML
CAMX Message Structure

HTTP 1.1
SOAP with Attachments MIME Envelope
MIME Block
SOAP Envelope
SOAP Header
IPC 2501, MessageInfo
SOAP Body
SOAP Errors
MIME Block
CAMX Message
Georgia Tech CAMX Implementations
Sample Factory Pilots

- **Motorola**
  - September 3-6, 2002
  - Seguin, Texas, USA
  - Automotive Supplier
  - 40+ Manufacturing Lines

- **NACOM**
  - January 13-17, 2003
  - Griffin, Georgia, USA
  - Automotive Supplier
  - 12+ Manufacturing Lines

- **Nortel Networks**
  - Calgary, Alberta, Canada
  - System House, Final Assembly and Functional Test

- **Solectron**
  - September, 2003
  - Charlotte, NC
  - Direct Communication from Testers in Factory to Supply Chain Partners

- **Jabil Circuit**
  - October, 2005
  - Billerica, MA
  - Presented through Jabil Global Network
  - Operational in 30 minutes
CAMX API Project

- Supported by 14 Companies
- Developing Common CAMX API to Facilitate Plug-and-Play
- Reduces Cost
- Rapid Deployment
- First Release November, 2004
NACOM Flexible Lean Manufacturing System (FLEXS)
NACOM FLEXS Project

- Continuous operation for over 18 months
- Information and Product Volume
  - Over 15 Million Messages Passed
  - 2704 Pallets, 45,267 Cartons, 500,000+ products
- Benefits
  - Improved Data Integrity
  - Reduced Downtime/Setup/Changeover Time
  - Reduced Manual Data Collection Efforts
  - Reduced Manufacturing Cycle Time
- ROI
  - $100k Investment
  - $283k Documented Savings in 6 Months
Examples of Using CAMX to Monitor Manufacturing Processes
Yield Graph

Why?
Parametric Data (Gripping Forces, Residual Stress)

Gripping Force

<table>
<thead>
<tr>
<th>Time (Minutes)</th>
<th>Force (N)</th>
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<tbody>
<tr>
<td>0</td>
<td>52</td>
</tr>
<tr>
<td>10</td>
<td>54</td>
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<tr>
<td>20</td>
<td>56</td>
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<tr>
<td>30</td>
<td>58</td>
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<tr>
<td>40</td>
<td>60</td>
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<tr>
<td>50</td>
<td>62</td>
</tr>
<tr>
<td>60</td>
<td>64</td>
</tr>
<tr>
<td>70</td>
<td>66</td>
</tr>
<tr>
<td>80</td>
<td>68</td>
</tr>
</tbody>
</table>

Image of robotic arm with text and graph showing force over time.
Root Cause Analysis
(Yield vs. Gripping Forces)
Throughput Difference (Actual vs. Desired)
Alarms from Placement Machines

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Location</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>EquipmentError</td>
<td>24mm/12mm, Slot: 2, Lane: 1</td>
<td>ACTIVE</td>
</tr>
<tr>
<td>EquipmentInformation</td>
<td>Feeder slot validated, Slot: 2, Track: 1</td>
<td>NONE</td>
</tr>
<tr>
<td>EquipmentError</td>
<td>Reel not available, Feeder: Green 16mm/8mm, Slot: 4, Lane: 1</td>
<td>ACTIVE</td>
</tr>
<tr>
<td>EquipmentInformation</td>
<td>Feeder slot validated, Slot: 4, Track: 1</td>
<td>NONE</td>
</tr>
<tr>
<td>EquipmentError</td>
<td>Reel not available, Feeder: Green 16mm/8mm, Slot: 6, Lane: 1</td>
<td>ACTIVE</td>
</tr>
<tr>
<td>EquipmentInformation</td>
<td>Feeder slot validated, Slot: 6, Track: 1</td>
<td>NONE</td>
</tr>
<tr>
<td>EquipmentError</td>
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<td>ACTIVE</td>
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<tr>
<td>EquipmentInformation</td>
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</tr>
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<td>EquipmentError</td>
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<tr>
<td>EquipmentInformation</td>
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</tr>
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<tr>
<td>EquipmentInformation</td>
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<td>EquipmentError</td>
<td>Reel not available, Feeder: Green 16mm/8mm, Slot: 25, Lane: 1</td>
<td>ACTIVE</td>
</tr>
<tr>
<td>EquipmentInformation</td>
<td>Feeder slot validated, Slot: 25, Track: 1</td>
<td>NONE</td>
</tr>
</tbody>
</table>
Machine States
Parametric Data (Oven Temperature)
Use of CAMX in the Georgia Tech Photovoltaic Manufacturing Laboratory
Potential Mini-Demonstration/Pilot

Monitoring Application

CAMX Message Broker

Stress Measurement
Wafer Loader
Conveyor

Handling
Conveyor

Additional Station
Wafer Buffer

CAMX
Georgia Tech Photovoltaics Lab
Information Technology Architecture
CAMX Benefits

- Visibility of production inefficiencies and problems provide opportunities to lower production costs
  
  - Processes are more portable, and can be readily moved between different facilities
  
  - It is not necessary to design and implement a new data collection scheme when introducing a new manufacturing process
  
- Commercial Off-the-Shelf (COTS) CAMX equipment and software will lower integration costs
Benefits to Equipment Vendors

- Common solution for all customers
- Low risk – proven technologies
- Low cost – make use of economies of scale
- Focus on your core mission
- Make money selling equipment and services versus developing pre-competitive technology
Vision for Photovoltaics Industry

• Extend CAMX to meet the specific needs of Photovoltaic Manufacturing
• Apply CAMX to the Photovoltaics Industry
• Conduct Proof-of-Concept at Georgia Tech’s PV Lab
• Use Attendees' Equipment in Lab
• Demonstrate Plug-and-Play
• Showcase to Customers
• Spawn New Opportunities
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