LED Manufacturing Today:

Moving Towards Automation and Optimization

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SEMI

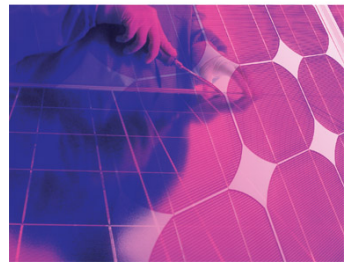
Agenda

- About SEMI
- LED Manufacturing Today
  - Capacity by region
  - Equipment by region
- The Role of Manufacturing Standards in Long-Term Cost Reduction
- Introduction to SEMI Standards
- Current Status of Key HB-LED Standards
  - 6” Wafers
  - Sapphire Defects and Impurities
  - Factory Automation
  - Equipment Safety

About SEMI

- Global industry association
- ~2000 members
- Established in 1970 to serve the semiconductor supply chain
- Today serves members interests in the following industries:
  - Semiconductor
  - Flat Panel Display
  - Photovoltaic/Tech-Energy
  - LEDS
  - MEMS

Bangalore
Berlin
Brussels
Grenoble
Moscow
Shanghai
Seoul
San Jose
Singapore
Taipei
Washington DC



Current SEMI LED Activities

- Major Events:
  - **6th Annual LED Korea**, co-located with SEMICON Korea (Feb. 7-9, 2012)
  - **China HB LED Manufacturing Forum and Pavilion**, SEMICON China (March 20-22)
  - LED/SSL Market Forum, SEMICON Russia, Moscow, (May 15-16, 2012)
  - LED Manufacturing Forum, SEMICON West (July 11, 2002)
  - LED Pavilion and Manufacturing Forum, SEMICON Taiwan (Sept 5-7, 2012)
  - Japan New Technologies Pavilion, LED Symposium, SEMICON Japan (Dec 5-7, 2012)
  - SSL Summit, India (Sept 3-5, 2012)
- Industry Research-Opto/LED Fab Watch and Forecast
- Manufacturing Standards development
- Public Policy

LED Manufacturing Seminar, Taiwan, 2011

LED Manufacturing Forum, SEMICON China

LED Day, SEMICON West, 2010

LED Korea, 2011

Standards Workshop, China SSL, Nov. 2011

LED Forum, Taiwan,

SEMI LED Advisory Committees

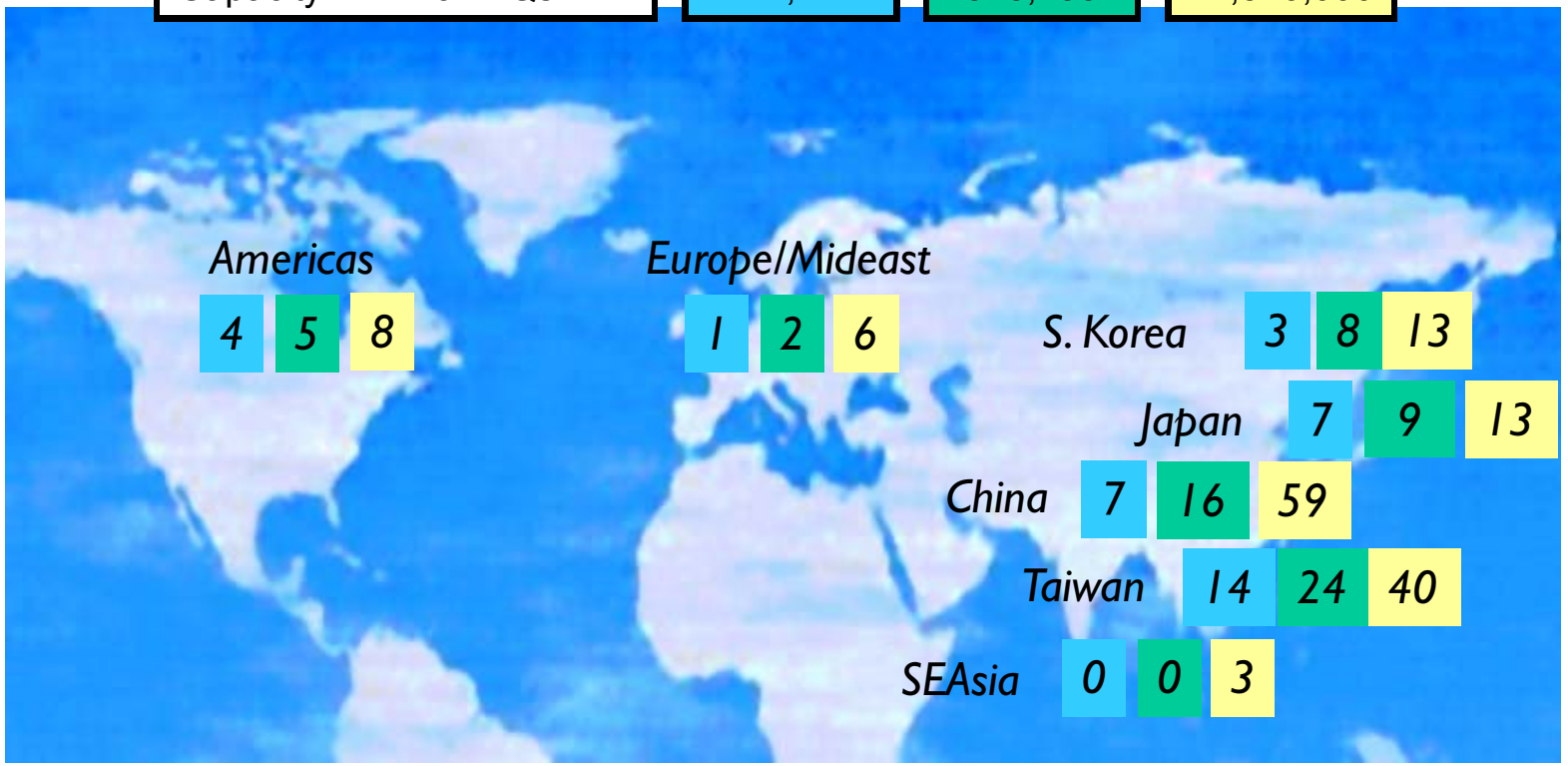
North American and Europe
China
India
Korea

Participating Companies (partial list)

LED Manufacturing Today

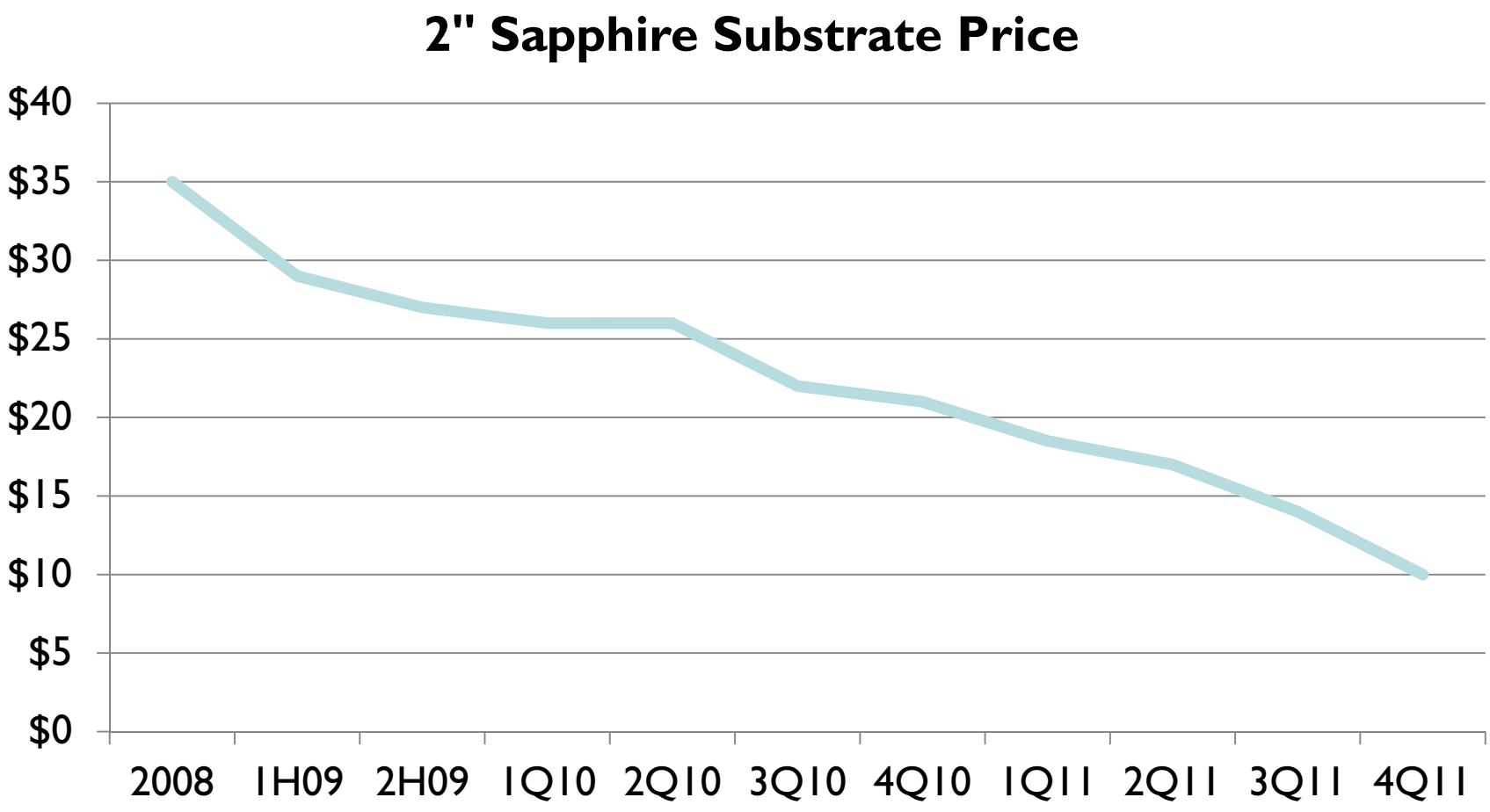
LED Dedicated Fabs
Changing LED Landscape

Year (begin operation)	2001	2006	2011 (est)
Total count of LED fabs	36	64	142
Capacity in 4-inch EQs w/m	127,124	376,400	~1,570,000



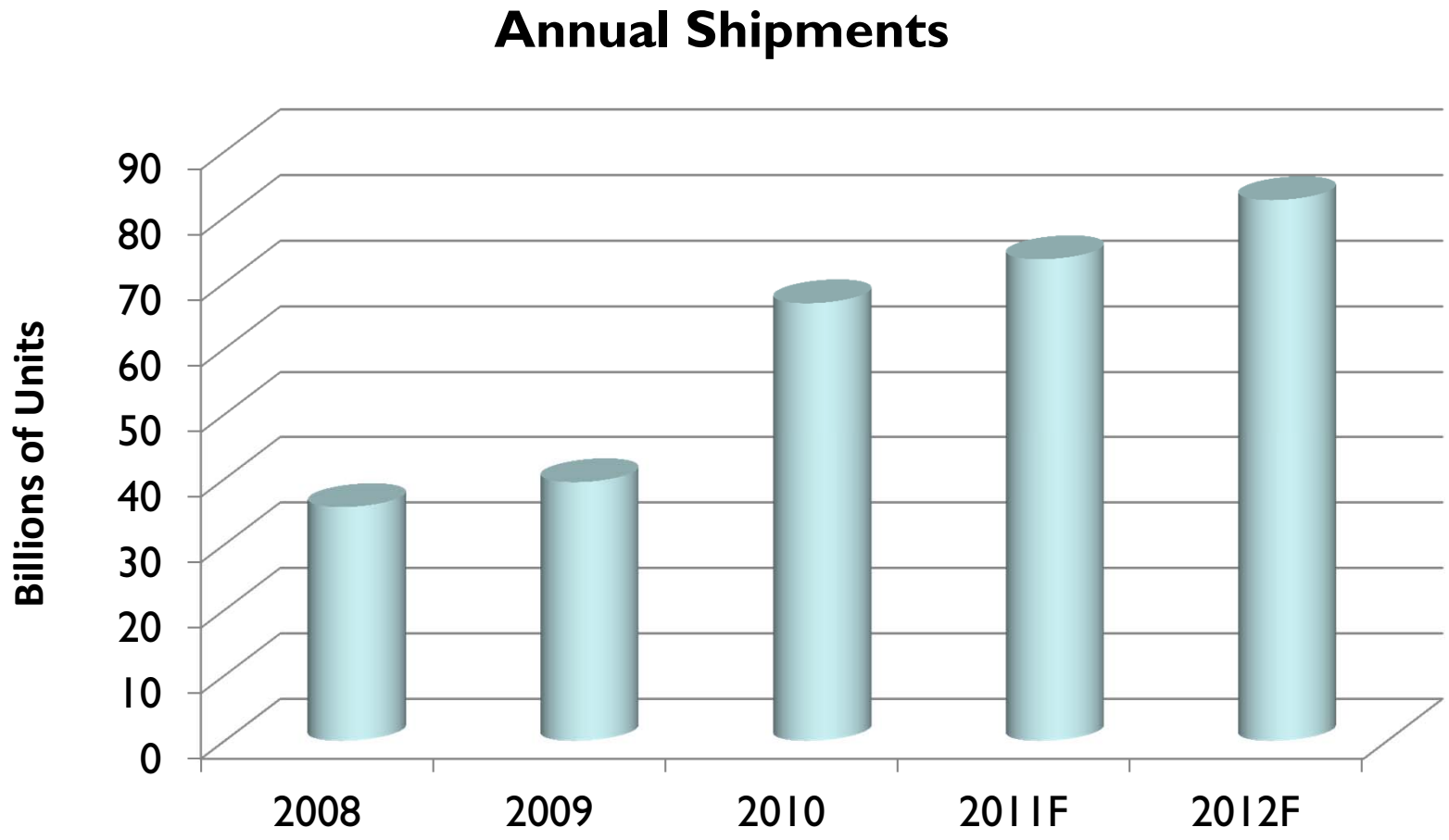
Source: SEMI Opto/LED Fab Forecast, Nov. 2011

Sapphire Pricing Trend



Source: Company Data, Digitimes, SEMI Industry Research & Statistics

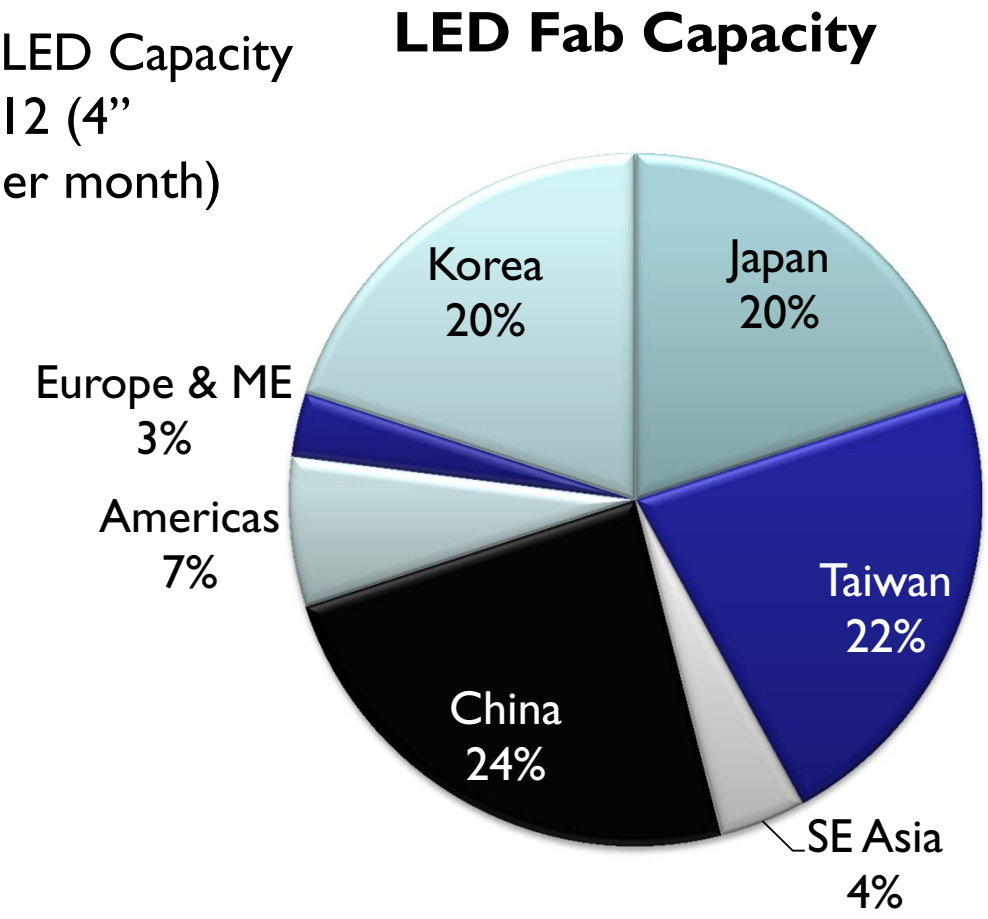
LED Leadframe Market



Source: SEMI Industry Research & Statistics, Global Semiconductor Packaging Materials Outlook

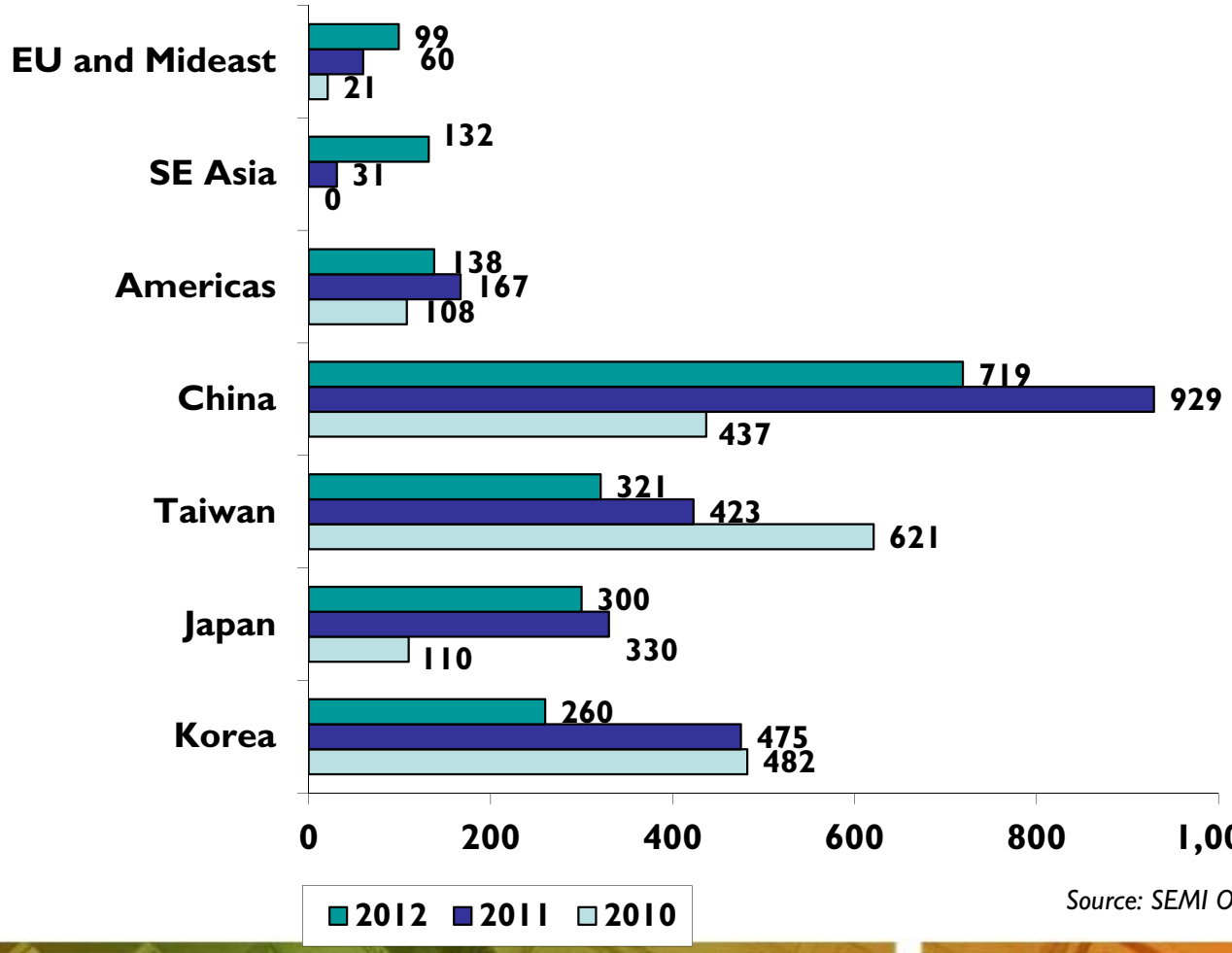
LED Fab Capacity by Region, 2012

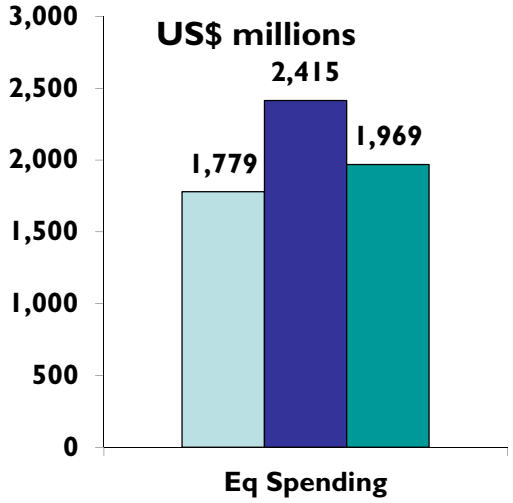
Worldwide LED Capacity 2.33M in 2012 (4" equivalent per month)



LED Equipment Spending

In $US Millions





Source: SEMI Opto/LED Fab Watch Nov. 2011

Summary

- Rapid capacity build-up in China has raised concerns about oversupply and may accelerate China industry consolidation
- Recent market slowdown due to weaker demand for LCD panels and less LEDs per panel:
  - New TV models, and purchasing schedules expected to drive demand pick up from 1Q12 onwards
- 2” sapphire prices to new lows in 4Q11
- MOCVD shipment is expected to slow down significantly next year after two years of aggressive investment
- Opportunities increasing for larger wafers and non-MOCVD equipment

Manufacturing Cost Reduction Through Standards and Collaboration

LED Cost Reduction Roadmap

Solid State Lighting Cost Reduction Roadmap

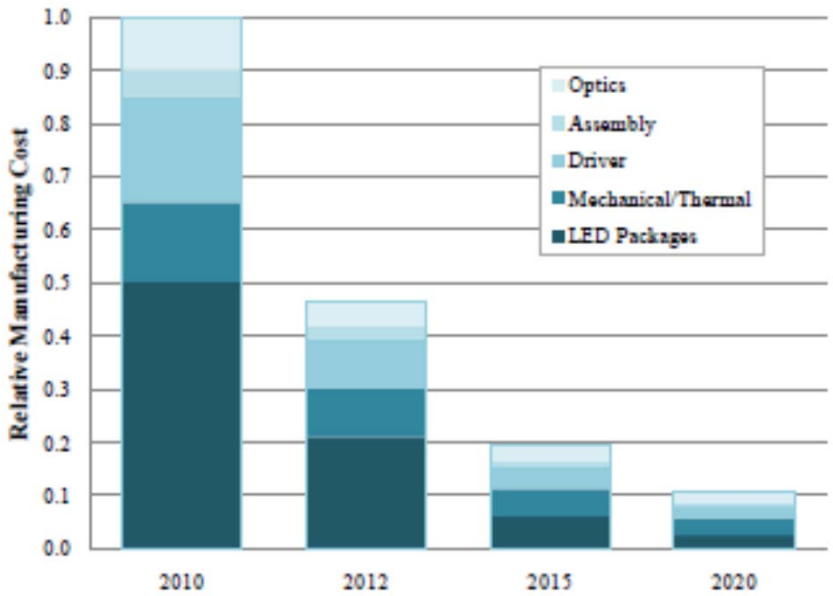


Figure 1. Projected LED-based Cost Track (Downlight Luminaire)
Source: Data provided by the 2011 Manufacturing Roundtable Attendees

LED Package Cost Reduction Roadmap

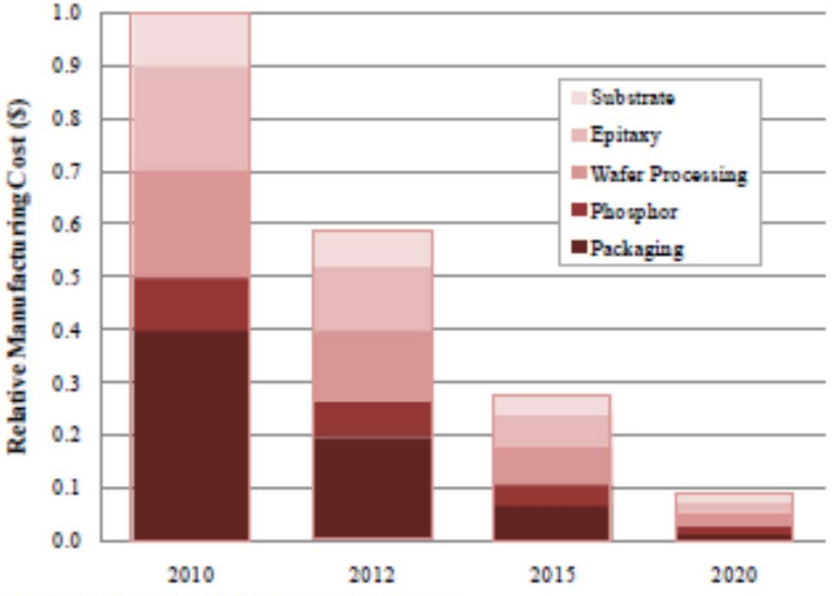


Figure 2. Projected LED Package Cost Track.
Source: Provided by the 2011 Manufacturing Workshop and Roundtable Attendees

Manufacturing standards are essential to meet the industry's long term cost reduction needs

Importance of Manufacturing Standards

LED Manufacturers

- Effective global standards allow manufacturers to buy equipment and materials from multiple vendors with minimal adaption

LED Suppliers

- Effective global standards allows suppliers to focus on innovation and critical price and performance variables

Standards: Passport to Global Innovation

SEMI Standards

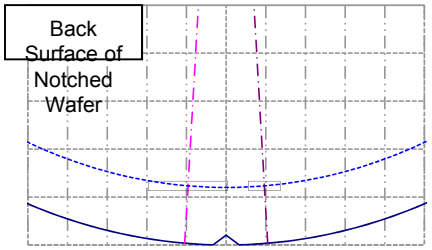
- Standards Development for over 35 years
  - Serving the semiconductor, LED, flat panel display, PV and MEMS industries
  - ~1800 standards
  - 4000 volunteers
  - Over 20 Technical Committees and 200 Task Forces
  - November 2010--**HB-LED Standards Committee** formed with strong industry support (VP-level device makers, key equipment manufacturers, material suppliers)

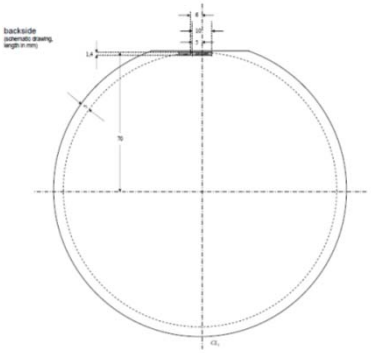
SEMI® International Standards

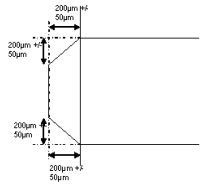
Wafer Task Force

Charter:

- Define physical geometry of wafers used in HB-LED manufacturing starting with 150 mm diameter sapphire wafers
  - Wafer Fiducial (notch vs flat)
  - Wafer ID Mark (location, Content)
  - Center Point Thickness/TTV, Warp, Bow, and other "flatness" parameters
  - Bulk Characteristic Issues







- Participating companies include:
  - OSRAM, GT Crystal Systems, SUMCO, Veeco, Chonqing Silian, AIS Automation, Novellus, Kulicke & Soffa, Oxford Instruments, LayTec

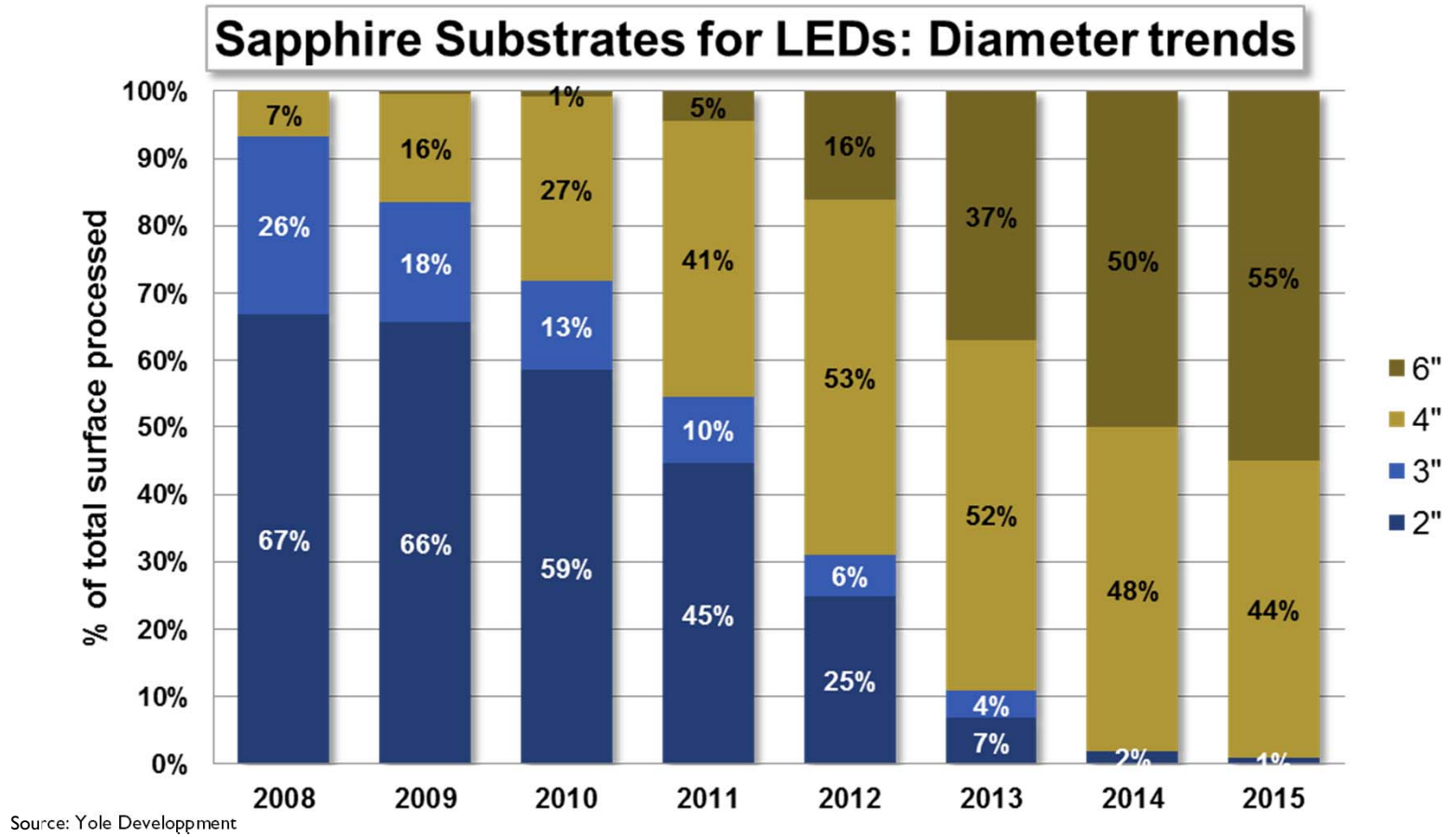
Why 6" Wafer Standards?

Wafer Size and CoO

56x2" → 14x4"	56x2" → 8x6"	56x2" → 5x8"
1. Investment ♦ Capacity $A = n \cdot \pi \cdot r^2$ A(4")/A(2") = 1 => same capacity ♦ with 3mm edge exclusion $A = n \cdot \pi \cdot (r-e)^2$ A(4")/A(2") = 1.14 => +14% capacity ♦ System investment $/1.14 = 0.88 => 88%	**1. Investment** ♦ Capacity $A = n \cdot \pi \cdot r^2$ A(6")/A(2") = 1.29 => +29% capacity ♦ with 3mm edge exclusion $A = n \cdot \pi \cdot (r-e)^2$ A(6")/A(2") = 1.53 => +53% capacity ♦ System investment $/1.53 = 0.65 => 65%	**1. Investment** ♦ Capacity $A = n \cdot \pi \cdot r^2$ A(8")/A(2") = 1.43 => +43% capacity ♦ with 3mm edge exclusion $A = n \cdot \pi \cdot (r-e)^2$ A(8")/A(2") = 1.74 => +74% capacity ♦ System investment $/1.74 = 0.58 => 58%
2. Running Cost $/1.14 => 88%	**2. Running Cost** $/1.53 => 65%	**2. Running Cost** $/1.74 => 58%
3. Chip Process Assume 150% processing time of 4" compared to 2": $(4^2/1.5)/(2^2/1)$ = 2.7x Throughput	**3. Chip Process** Assume 200% processing time of 6" compared to 2": $(6^2/2)/(2^2/1)$ = 4.5x Throughput	**3. Chip Process** Assume 250% processing time of 8" compared to 2": $(8^2/2.5)/(2^2/1)$ = 6.4x Throughput

Source: AIXTRON

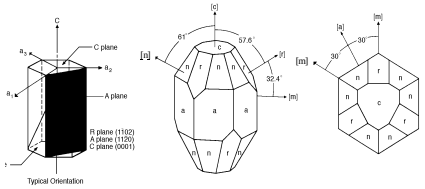
Substrate Trends

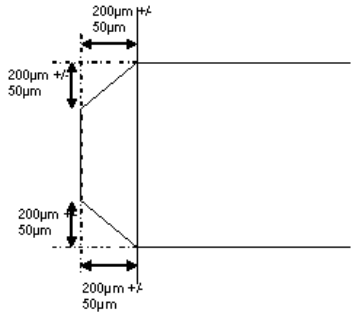


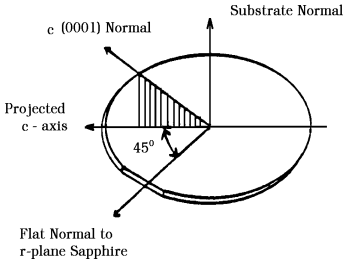
Source: Yole Developpment

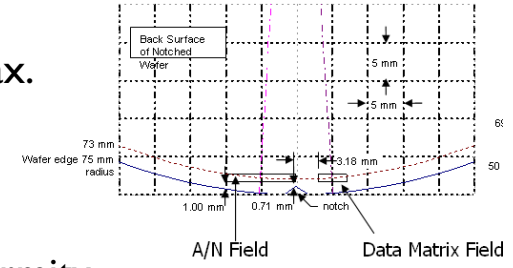
150 mm Wafer Standards

- Critical for factory automation and other standards
- Currently in ballot
- Covers 4 150 mm wafer geometry options
  - Flat and Notched
  - 2 thickness options
- 17 Key Parameters
  - •Total Impurity Content
  - •Wafer ID Marking
  - •Front Surface Condition
  - •Edge Surface Condition
  - •Back Surface Condition
  - •Diameter
  - •Fiducial Type
  - •Fiducial Dimensions
  - •Flat Length
  - •Fiducial Notch Depth & Notch Angle
  - •Fiducial Orientation
  - •Edge Profile Template
  - •Thickness, Center Point
  - •Total Thickness Variation, Max.
  - •Bow and Warp, Max.
  - •Inclusions or Bubbles
  - •Dislocations
  - •Thermal Conductivity Uniformity









Automation/Interfaces Task Force

- Charter
  - Define physical interfaces of substrate carriers as well as process and metrology tools of wafer/substrate carriers used in HB-LED manufacturing
    - Leveraging existing SEMI Standards for Communications (e.g., SECS/GEM, Interface A), identifying gaps
    - To establish agreement on types of carriers used as well as terminology
  - Participating Companies include:
    - Brooks Automation, Entegris, OSRAM, Aixtron, Veeco, AIS Automation, Novellus, Applied Materials, MKS Instruments, Oxford Instruments, and Kulicke & Soffa.

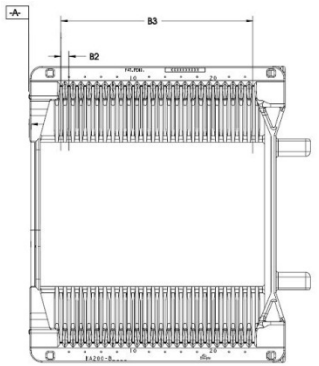
Factory Automation Interfaces

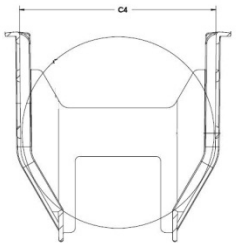
- **Critical Requirements:**
- Cassette
  - Open cassette
  - Process tray cassette
- Load Port
- Automated tracking
  - Cassette/wafer
  - Process Tray
- Shipping Carrier

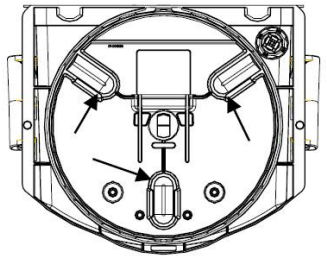
Ballot Expected Mid Year 2012

Cassette Specifications Identified for Industry Standard

Pitch
Capacity
Loadport coupling
Material
ID type and location (for automated tracking)
Wafer support
End effector exclusion
First wafer height
Pocket volume
Windows / open sidewalls
Wafer plane
Overall dimensions
Manual grips
Electrical continuity
Automated gripping features
Wafer orientation features
Mapping







Kinematic Coupling

New Task Force

Impurities and Defects in HB-LED Sapphire Wafers Task Force

- Charter
  - Investigate the allowable impurities and defects in HB-LED sapphire wafers.

- Scope
  - This Task Force will define and/or measure critical impurities and defects in sapphire waters and the metrology intended to measure them.
  - The Task Force will create standards related to these impurities and defects for use by HB-LED sapphire wafer makers and producers of related devices.
  - Topics to be considered may include, but are not limited to:
    - Bulk Crystal Defects
    - Bulk Crystal Impurities
    - Surface Defects
    - Surface Impurities

Environmental Health & Safety

- **LED Wafer processing involves:**
  - Hazardous precursor materials
  - Substrates are compounds of hazardous materials
  - Generators for high power electromagnetic fields
- **LED manufacturing processes are sensitive to:**
  - Oxygen or other constituents of atmospheric air
  - Moisture
  - Contaminations introduced through loading and unloading operations
  - Contaminations through missing integrity of the reaction chamber
- **Improper system usage, application and deployment may result in:**
  - Explosion, fire and other potential hazardous situations
  - Release of hazardous compounds into the atmosphere of surrounding environment.

Current SEMI Safety Standards

- SEMI S2
  - Environmental, Health, and Safety Guideline for Semiconductor Manufacturing Equipment
- SEMI S5
  - Safety Guideline for Sizing and Identifying Flow Limiting Devices for Gas Cylinder Valves
- SEMI S6
  - EHS Guideline for Exhaust Ventilation of Semiconductor Manufacturing Equipment
- SEMI S26
  - Environmental, Health, and Safety Guideline for FPD Manufacturing System

While often followed in the LED industry, SEMI EHS Guidelines and Standards have not been developed specifically for Group V compounds and LED manufacturing environments. The industry needs dedicated EHS Standards, Conformance Training and Best Practices knowledge. A Standards Task Force in Taiwan has been formed to address the need. In addition, training workshops and education have been scheduled in China to meet the needs of new LED fabs.

Summary

- A 20X improvement in $/klm at the packaged LED level is required to support widespread adoption of solid state lighting
- The majority of this cost reduction will occur through yield, throughput, productivity, and materials cost reduction
- Manufacturing Standards will accelerate cost reduction in packaged LEDs and will become the platform for advanced, automated LED manufacturing in the future
- Significant standards progress is underway in wafers, factory automation interfaces, and equipment safety
- This is just the beginning. Join us.

Thank You