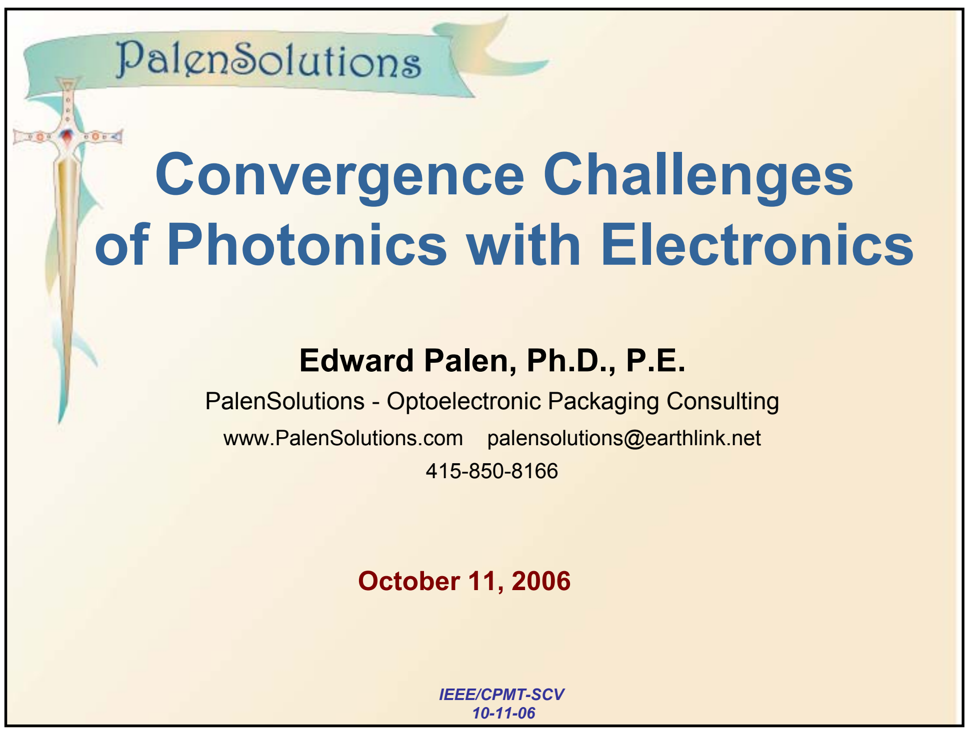
PalenSolutions
Convergence Challenges of Photonics with Electronics
Edward Palen, Ph.D., P.E.
PalenSolutions - Optoelectronic Packaging Consulting
www.PalenSolutions.com palensolutions@earthlink.net
415-850-8166
October 11, 2006
IEEE/CPMT-SCV
10-11-06

PalenSolutions
Why Convergence?
• No Convergence By Competition With Silicon Electronics
• Convergence By Complimentary Functionality
Higher Bandwidth
Lower Signal Latency
Lower Heat Dissipation
• Must Be At Cost Point of Silicon Electronics
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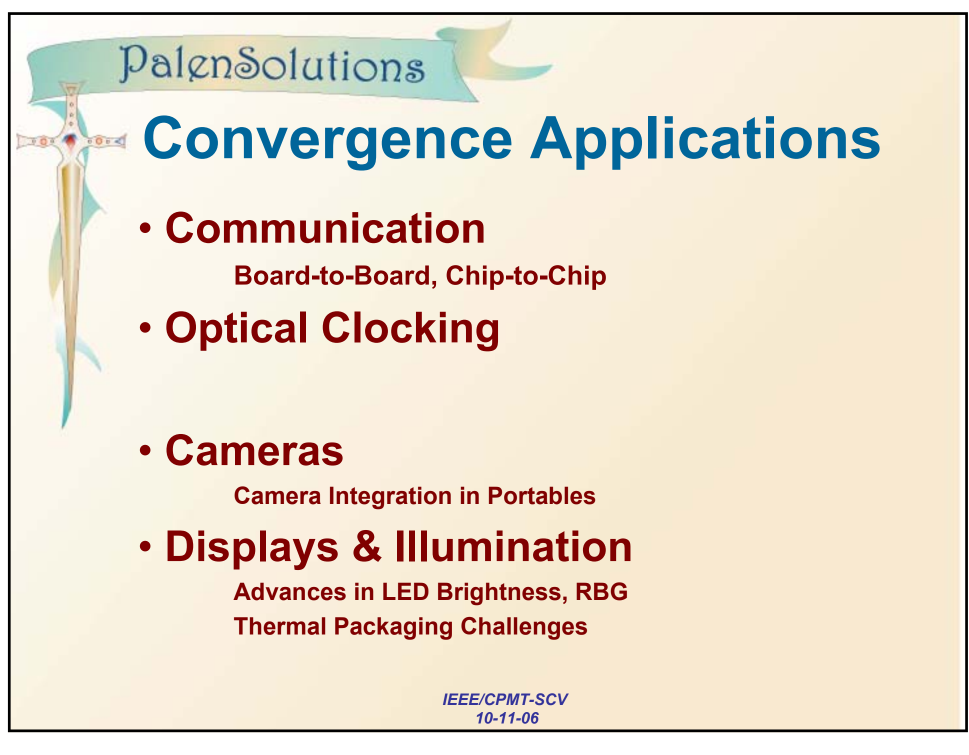
PalenSolutions
Convergence Applications
• Communication
Board-to-Board, Chip-to-Chip
• Optical Clocking
• Cameras
Camera Integration in Portables
• Displays & Illumination
Advances in LED Brightness, RBG
Thermal Packaging Challenges
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PalenSolutions
Communications
Convergence
• Processing Challenges
Compatibilities with Integration Level
Materials Platform
• Cost Challenges
Optical Interface Assembly
Integration Levels
Light Source
Market Size - # Units
Photonics is a Relatively Small # Units Market
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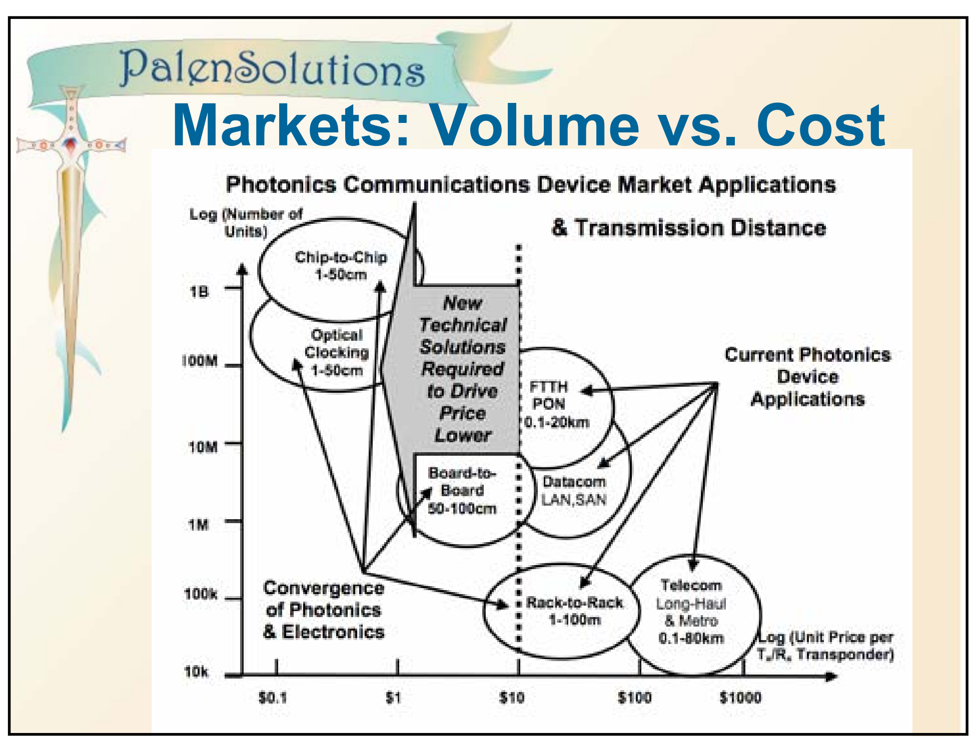
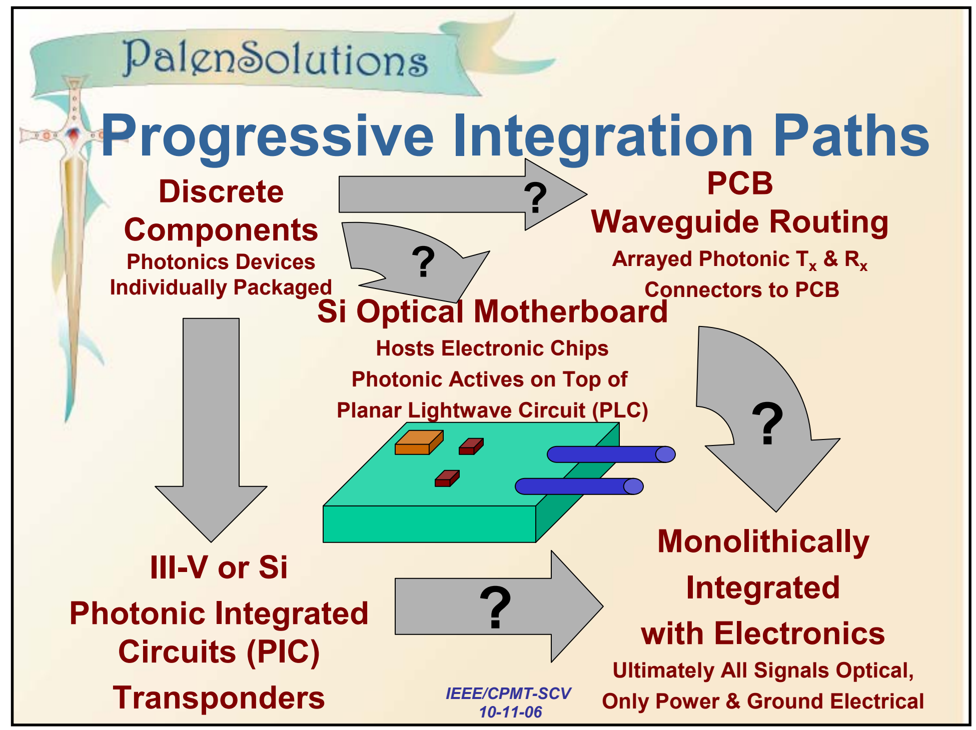

PalenSolutions
Markets: Volume vs. Cost
Photonics Communications Device Market Applications
& Transmission Distance
Log (Number of Units)
1B
100M
10M
1M
100k
10k
Chip-to-Chip 1-50cm
Optical Clocking 1-50cm
New Technical Solutions Required to Drive Price Lower
Board-to-Board 50-100cm
FTTH PON 0.1-20km
Datacom LAN,SAN
Current Photonics Device Applications
Convergence of Photonics & Electronics
Rack-to-Rack 1-100m
Telecom Long-Haul & Metro 0.1-80km
Log (Unit Price per Tx/Rx Transponder)
$0.1
$1
$10
$100
$1000


PalenSolutions
Progressive Integration Paths
Discrete Components
Photonics Devices Individually Packaged
?
?
PCB Waveguide Routing
Arrayed Photonic Tx & Rx Connectors to PCB
Si Optical Motherboard
Hosts Electronic Chips
Photonic Actives on Top of
Planar Lightwave Circuit (PLC)
?
III-V or Si
Photonic Integrated Circuits (PIC)
Transponders
?
Monolithically Integrated with Electronics
Ultimately All Signals Optical, Only Power & Ground Electrical
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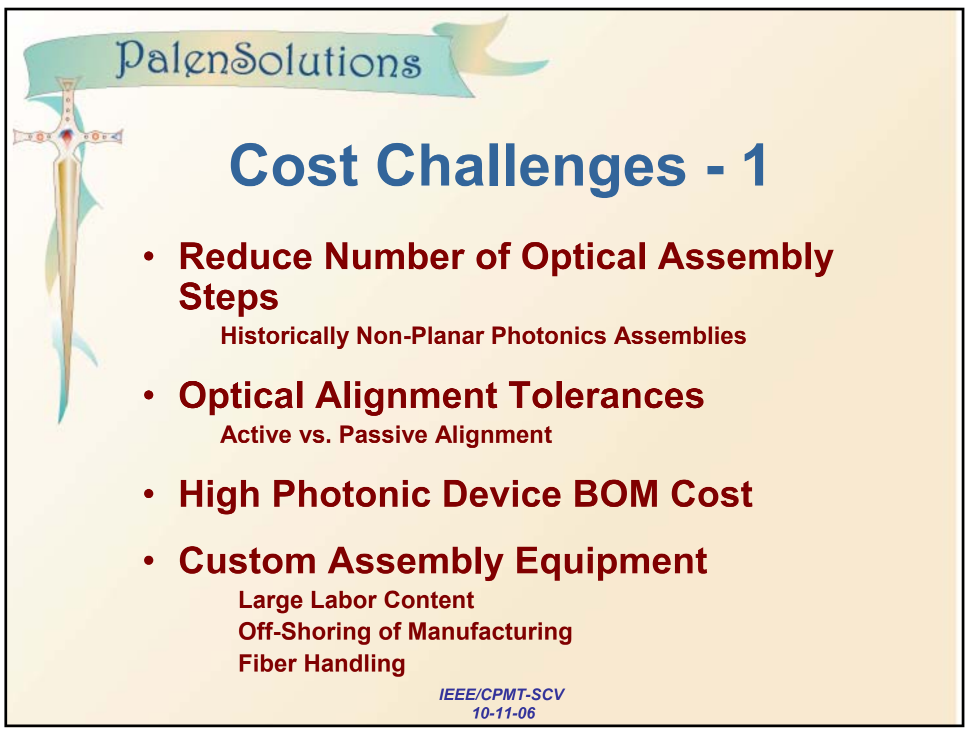
PalenSolutions
Cost Challenges - 1
• Reduce Number of Optical Assembly Steps
Historically Non-Planar Photonics Assemblies
• Optical Alignment Tolerances
Active vs. Passive Alignment
• High Photonic Device BOM Cost
• Custom Assembly Equipment
Large Labor Content
Off-Shoring of Manufacturing
Fiber Handling
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Cost Challenges - 2
• Wafer Scale Integration
Materials Platform
Waveguides & Photonic Elements
• Processing Compatibility
CMOS, III-V, SOB, Assembly
• Light Sources
Optical Coupling
Hermetic Seal & Reliability
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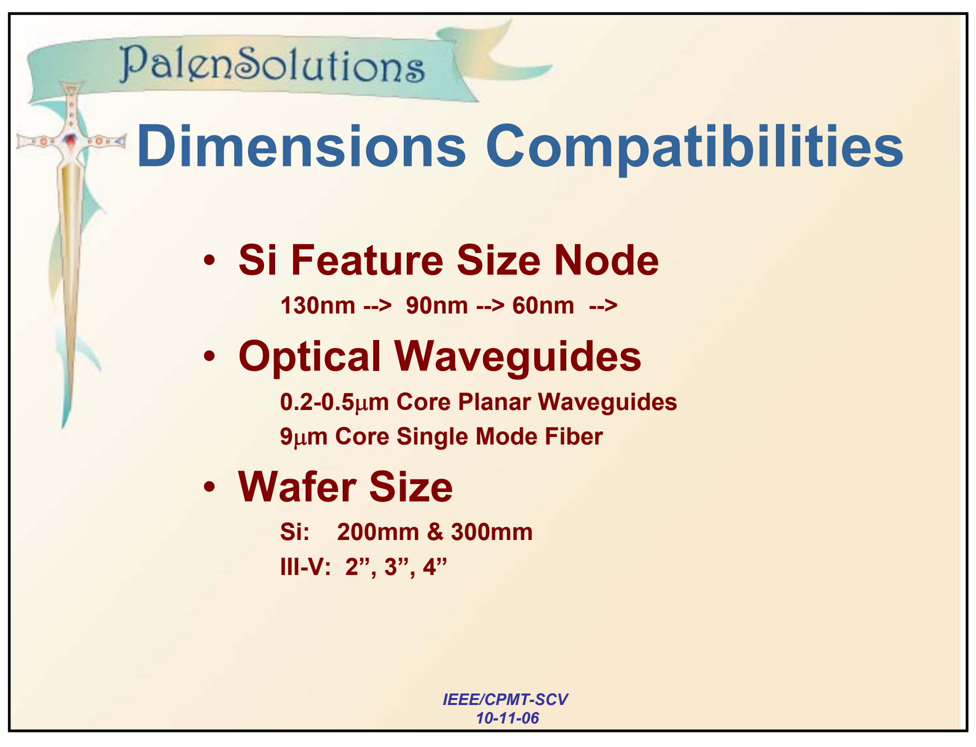
PalenSolutions
Dimensions Compatibilities
• Si Feature Size Node
130nm --> 90nm --> 60nm -->
• Optical Waveguides
0.2-0.5µm Core Planar Waveguides
9µm Core Single Mode Fiber
• Wafer Size
Si: 200mm & 300mm
III-V: 2”, 3”, 4”
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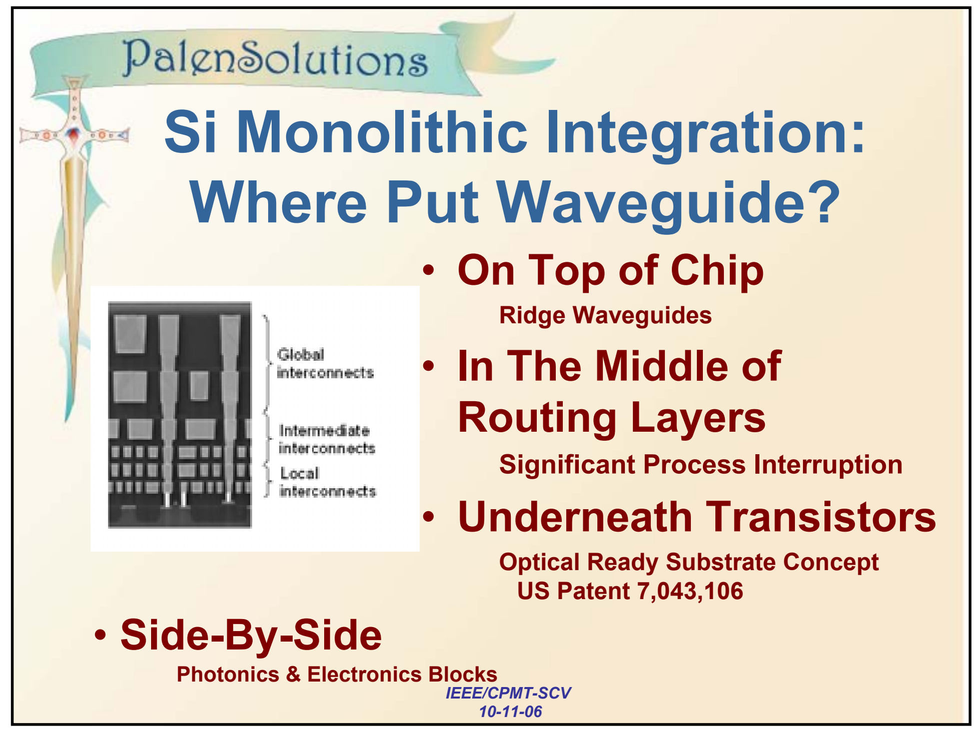
PalenSolutions
Si Monolithic Integration: Where Put Waveguide?
• On Top of Chip
Ridge Waveguides
• In The Middle of Routing Layers
Significant Process Interruption
• Underneath Transistors
Optical Ready Substrate Concept
US Patent 7,043,106
• Side-By-Side
Photonics & Electronics Blocks
Global interconnects
Intermediate interconnects
Local interconnects
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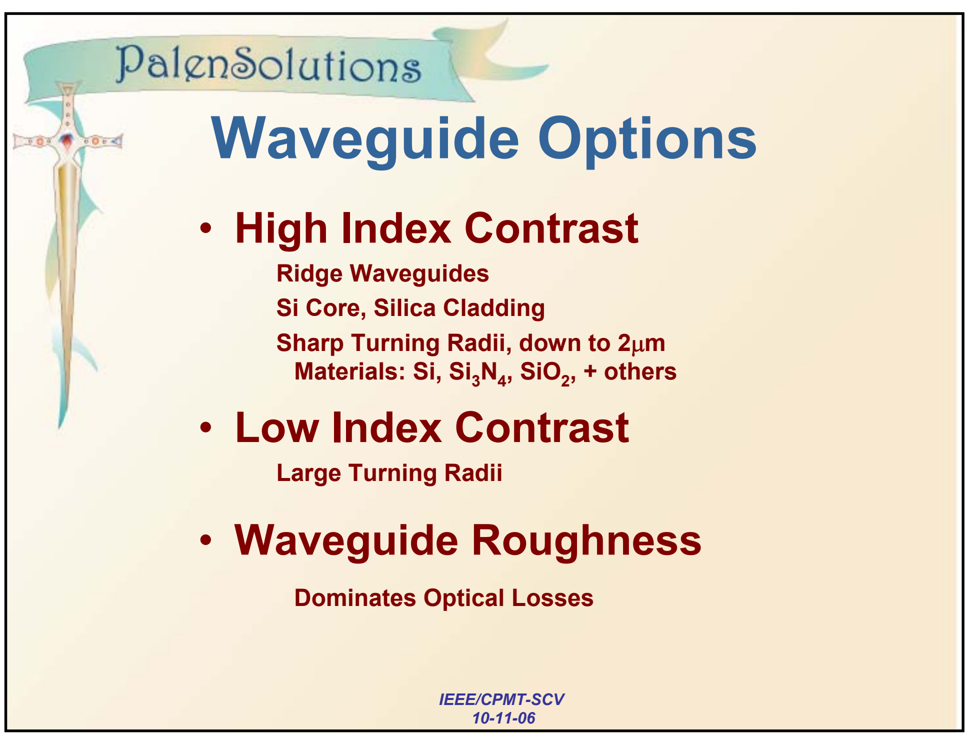
PalenSolutions
Waveguide Options
• High Index Contrast
Ridge Waveguides
Si Core, Silica Cladding
Sharp Turning Radii, down to 2μm
Materials: Si, Si3N4, SiO2, + others
• Low Index Contrast
Large Turning Radii
• Waveguide Roughness
Dominates Optical Losses
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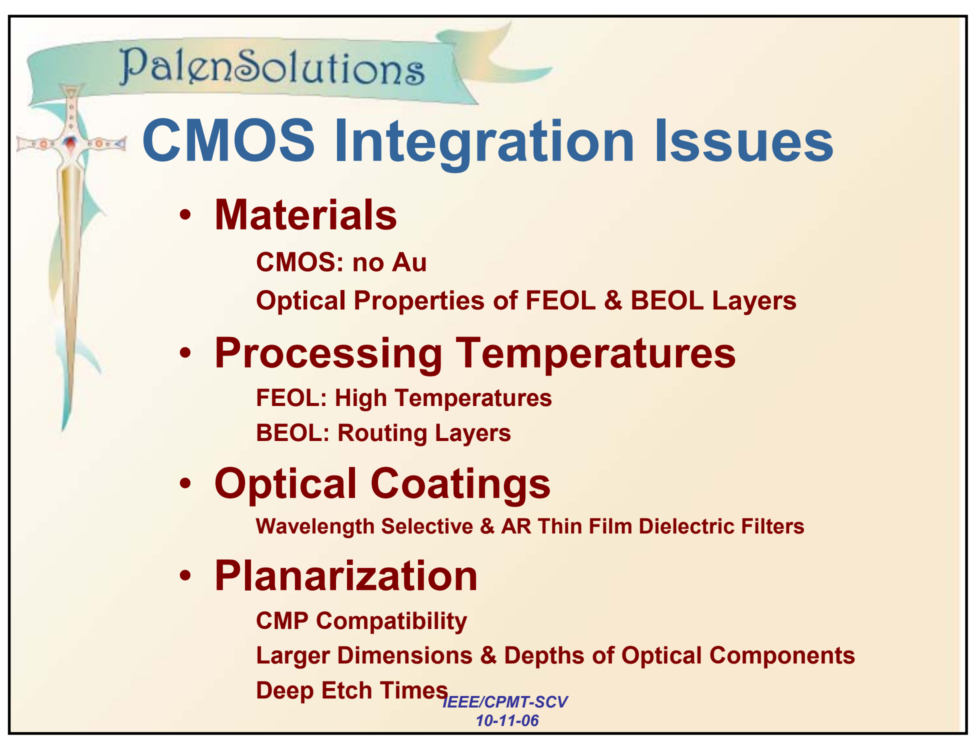
PalenSolutions
CMOS Integration Issues
• Materials
CMOS: no Au
Optical Properties of FEOL & BEOL Layers
• Processing Temperatures
FEOL: High Temperatures
BEOL: Routing Layers
• Optical Coatings
Wavelength Selective & AR Thin Film Dielectric Filters
• Planarization
CMP Compatibility
Larger Dimensions & Depths of Optical Components
Deep Etch Times
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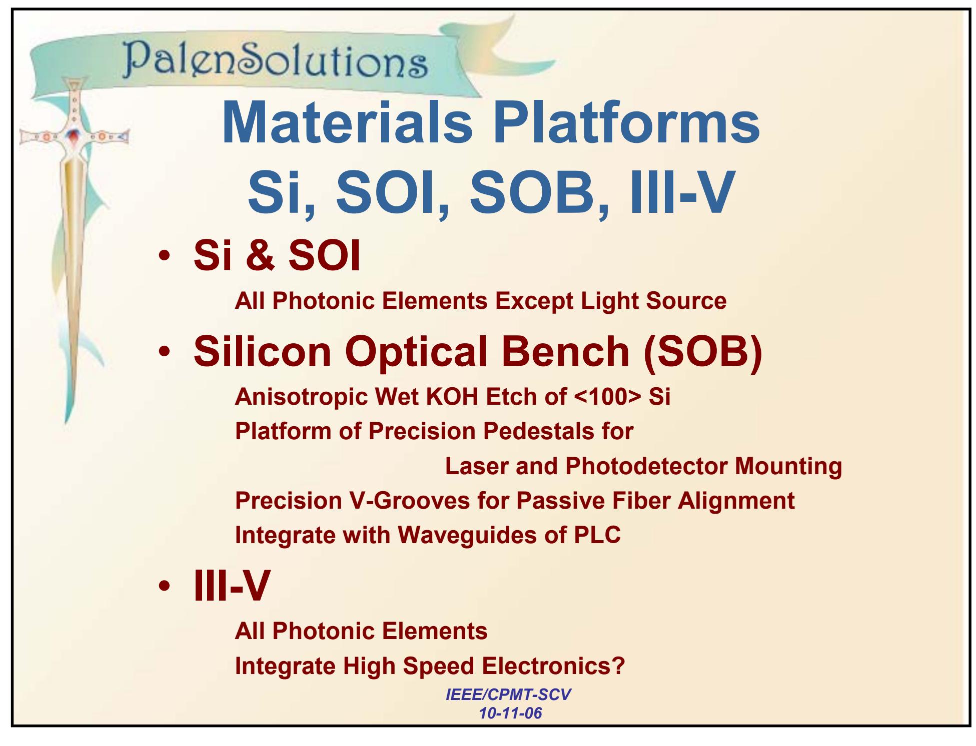
PalenSolutions
Materials Platforms
Si, SOI, SOB, III-V
• Si & SOI
All Photonic Elements Except Light Source
• Silicon Optical Bench (SOB)
Anisotropic Wet KOH Etch of <100> Si
Platform of Precision Pedestals for
Laser and Photodetector Mounting
Precision V-Grooves for Passive Fiber Alignment
Integrate with Waveguides of PLC
• III-V
All Photonic Elements
Integrate High Speed Electronics?
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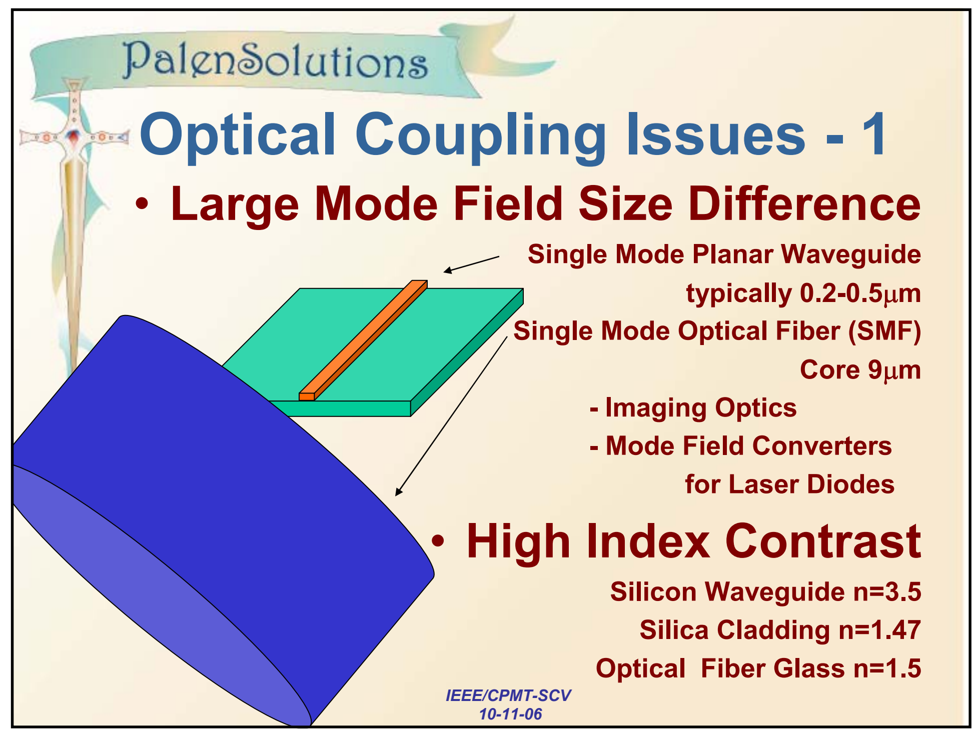
PalenSolutions
Optical Coupling Issues - 1
• Large Mode Field Size Difference
Single Mode Planar Waveguide
typically 0.2-0.5µm
Single Mode Optical Fiber (SMF)
Core 9µm
- Imaging Optics
- Mode Field Converters
for Laser Diodes
• High Index Contrast
Silicon Waveguide n=3.5
Silica Cladding n=1.47
Optical Fiber Glass n=1.5
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Optical Coupling Issues - 2

- High Coupling Efficiency
- Low Cost Requirements
  - Compatibility with Surface Mount Assembly
  - Alignment Tolerances
  - Passive Align & Attachment Processing
- Solutions:
  - Grating Couplers, PDL Sensitivity
  - Spot Size Converter (SSC) & Tapered Waveguides
  - Silicon Optical Bench (SOB) Configurations,
    V-Groove Fiber Butt Couple to PLC Waveguide
  - Pluggable Ferruled Fiber into Injection Molded TOSA

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Optical Coupling Issues - 3

- Optical Alignment Tolerances
  - <1μm Custom Photonics Equipment, Slow & Very Expensive
  - 1-5μm Flip-Chip, Expensive
  - 10-20μm Standard Pick & Place Equipment, Low Cost
- Scalability for High Volume
  - Low BOM
  - Fast Assembly Times
  - Cost of Assembly Equipment
  - Ability to Use Industry Infra-Structure
    of Standard Electronics Assembly Equipment
- Innovative Solutions Needed
  - To Meet Lower Cost Points
    for Integration with Electronics

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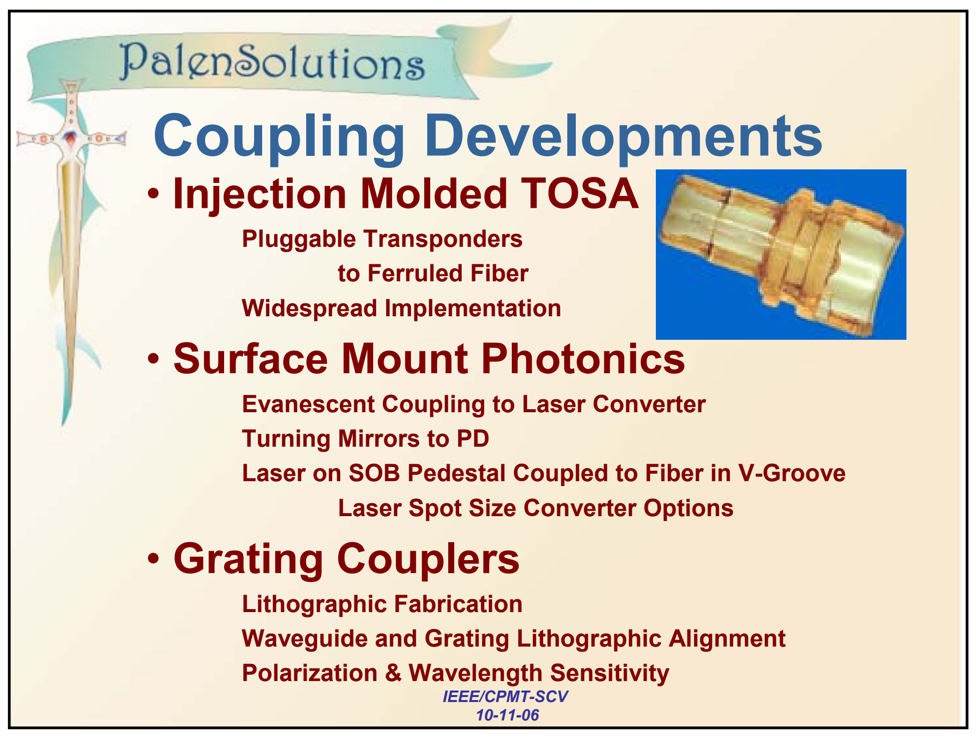
PalenSolutions
Coupling Developments
• Injection Molded TOSA
Pluggable Transponders
to Ferruled Fiber
Widespread Implementation
• Surface Mount Photonics
Evanescent Coupling to Laser Converter
Turning Mirrors to PD
Laser on SOB Pedestal Coupled to Fiber in V-Groove
Laser Spot Size Converter Options
• Grating Couplers
Lithographic Fabrication
Waveguide and Grating Lithographic Alignment
Polarization & Wavelength Sensitivity
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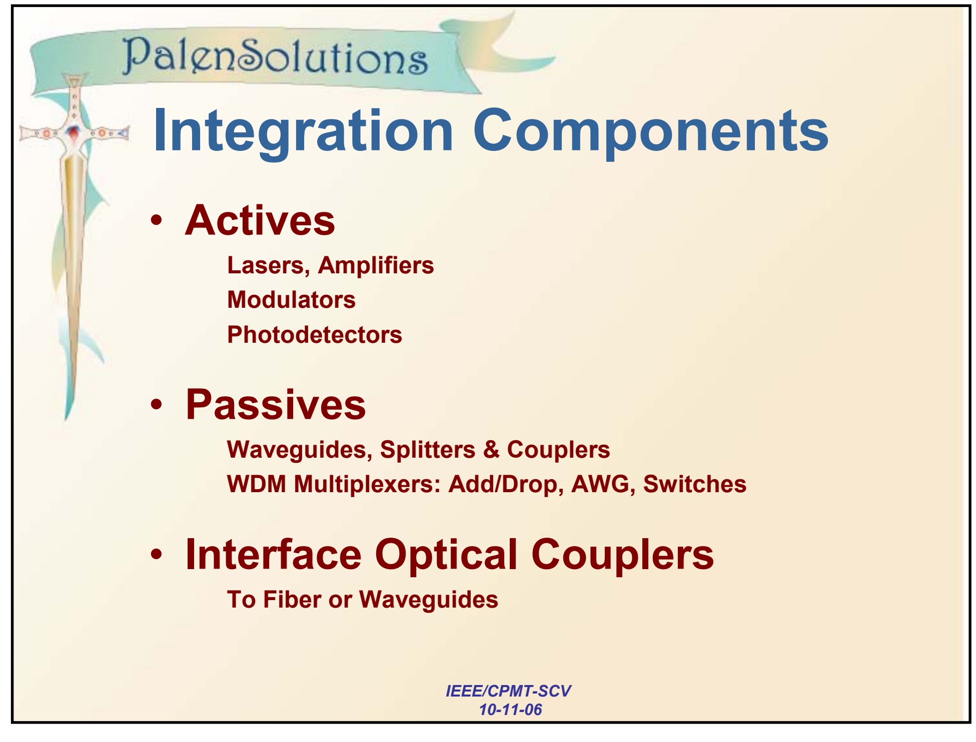
PalenSolutions
Integration Components
• Actives
Lasers, Amplifiers
Modulators
Photodetectors
• Passives
Waveguides, Splitters & Couplers
WDM Multiplexers: Add/Drop, AWG, Switches
• Interface Optical Couplers
To Fiber or Waveguides
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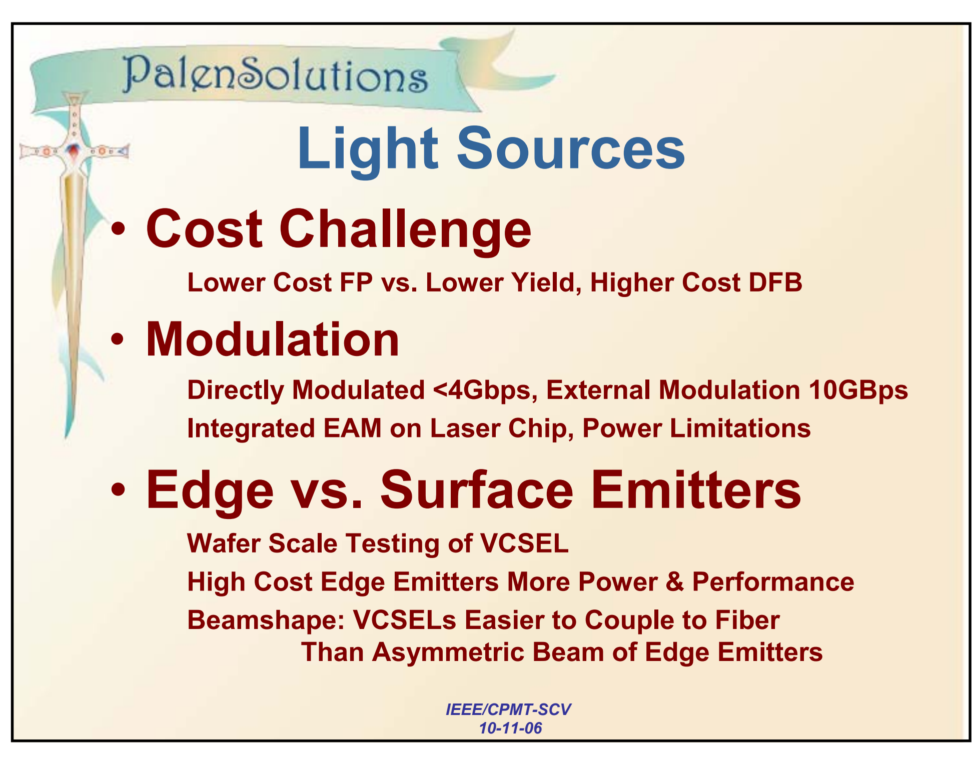
PalenSolutions
Light Sources
• Cost Challenge
Lower Cost FP vs. Lower Yield, Higher Cost DFB
• Modulation
Directly Modulated <4Gbps, External Modulation 10GBps
Integrated EAM on Laser Chip, Power Limitations
• Edge vs. Surface Emitters
Wafer Scale Testing of VCSEL
High Cost Edge Emitters More Power & Performance
Beamshape: VCSELs Easier to Couple to Fiber
Than Asymmetric Beam of Edge Emitters
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PalenSolutions
Light Sources
Hermetic Packaging
• Packaging Cost
Individually Packaged vs. Arrayed Configurations
Hermetic Packages: Low Cost TO-Can to High Cost Butterfly
• Surface Mount Photonics - Xponent
Sealed Optical Path
of Adiabatic Coupling Method
• SOB Solution
Hymite Hyshell™ Small Footprint SOB Cavity
with Hermetically Sealed Top Window
& High Speed Electrical I/O
Through SOB Backside
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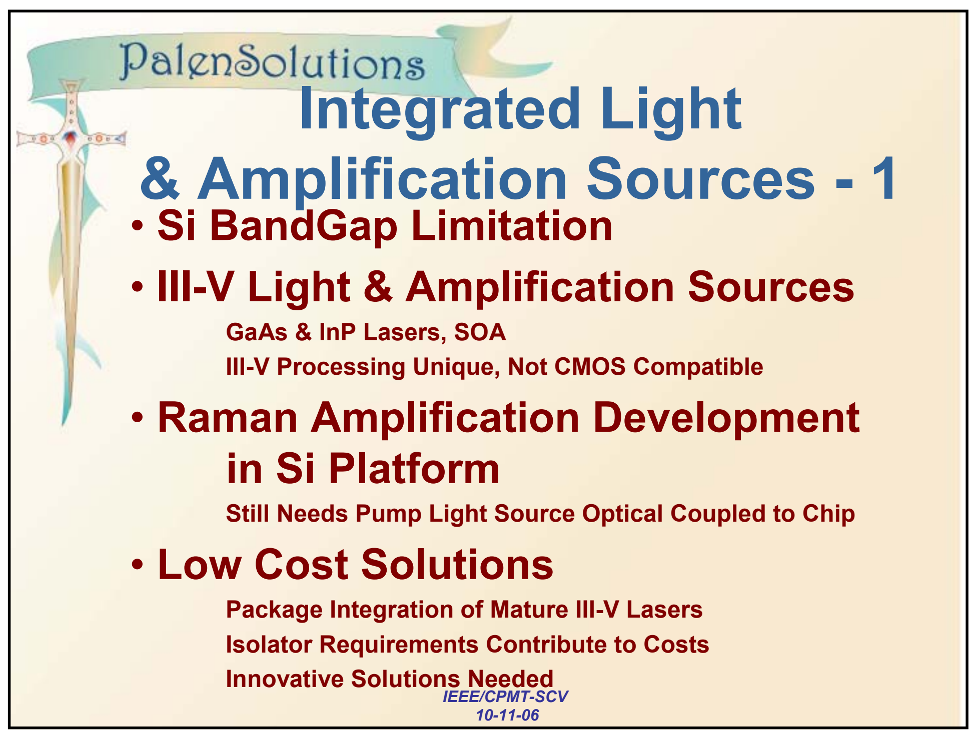
PalenSolutions
Integrated Light
& Amplification Sources - 1
• Si BandGap Limitation
• III-V Light & Amplification Sources
GaAs & InP Lasers, SOA
III-V Processing Unique, Not CMOS Compatible
• Raman Amplification Development
in Si Platform
Still Needs Pump Light Source Optical Coupled to Chip
• Low Cost Solutions
Package Integration of Mature III-V Lasers
Isolator Requirements Contribute to Costs
Innovative Solutions Needed
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PalenSolutions
Integrated Light
& Amplification Sources - 2
• Hybrid Silicon Laser - Intel/UCSB
InP Light Source at Wafer or Die Level "Glass-Glued" Heat Bonded
to Pre-Patterned Si Wafer
Using Low Temperature Oxygen Plasma
to Grow 25 Atom Thick Oxide Layer for Bonding
Claim "No Bonding Alignment" Required
Evanescent Optical Coupling through Oxide to Waveguide on Si
Waveguide External Cavity Define Wavelength
Scaleable Solution Potential with High Density & Small Footprint
Note: No Laser Performance Data Released
InP
wave-guide
Silicon
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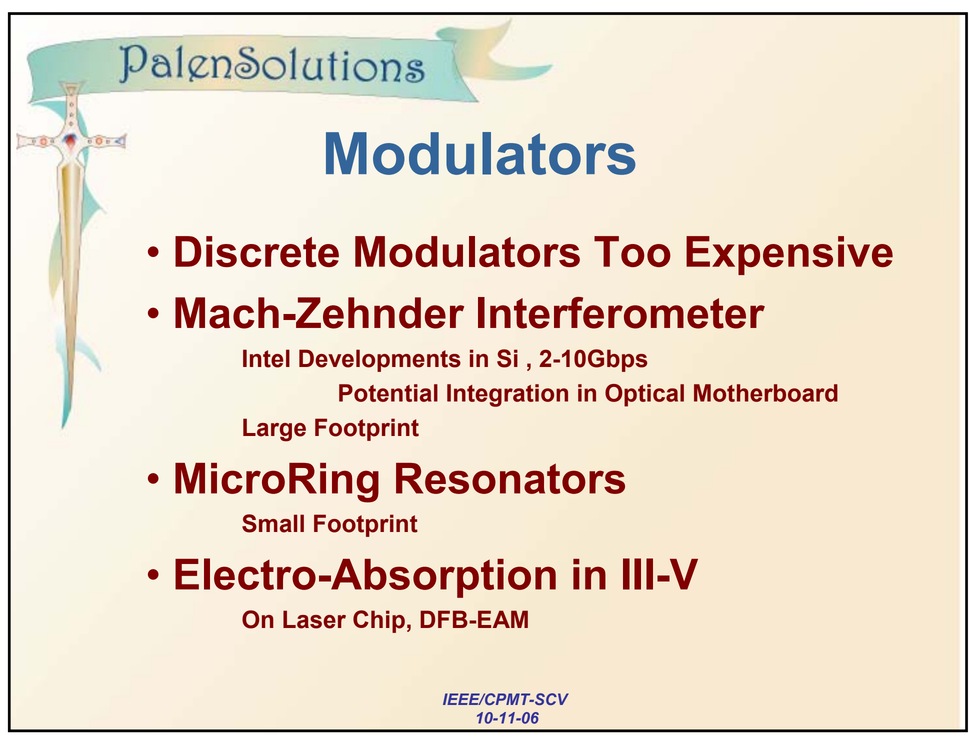
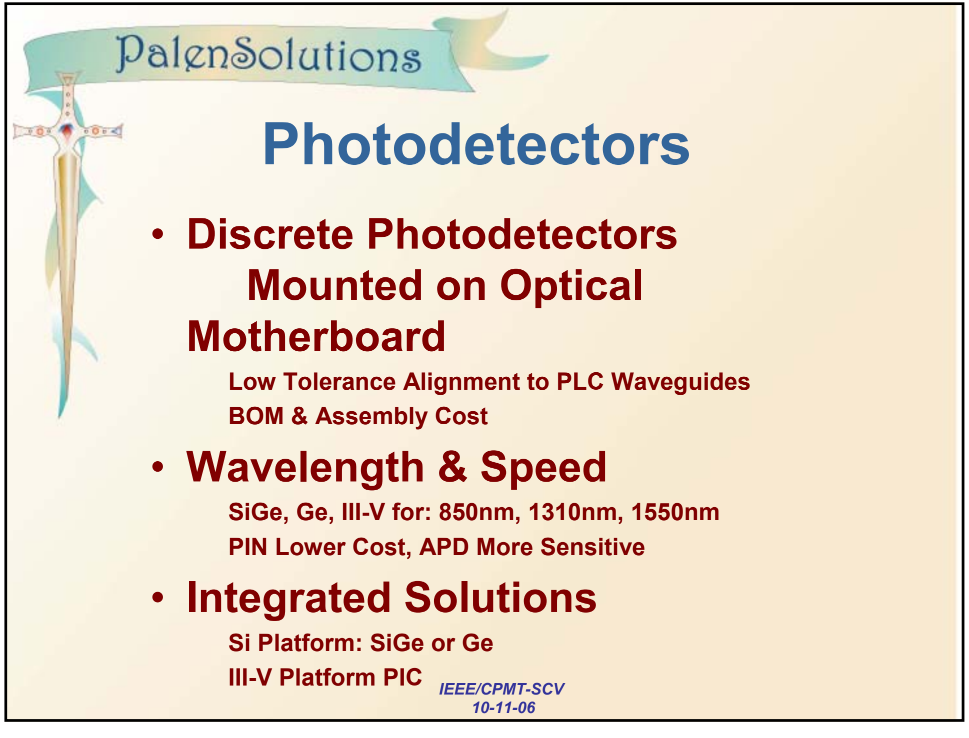

PalenSolutions
Modulators
• Discrete Modulators Too Expensive
• Mach-Zehnder Interferometer
Intel Developments in Si , 2-10Gbps
Potential Integration in Optical Motherboard
Large Footprint
• MicroRing Resonators
Small Footprint
• Electro-Absorption in III-V
On Laser Chip, DFB-EAM
IEEE/CPMT-SCV
10-11-06


PalenSolutions
Photodetectors
• Discrete Photodetectors Mounted on Optical Motherboard
Low Tolerance Alignment to PLC Waveguides
BOM & Assembly Cost
• Wavelength & Speed
SiGe, Ge, III-V for: 850nm, 1310nm, 1550nm
PIN Lower Cost, APD More Sensitive
• Integrated Solutions
Si Platform: SiGe or Ge
III-V Platform PIC
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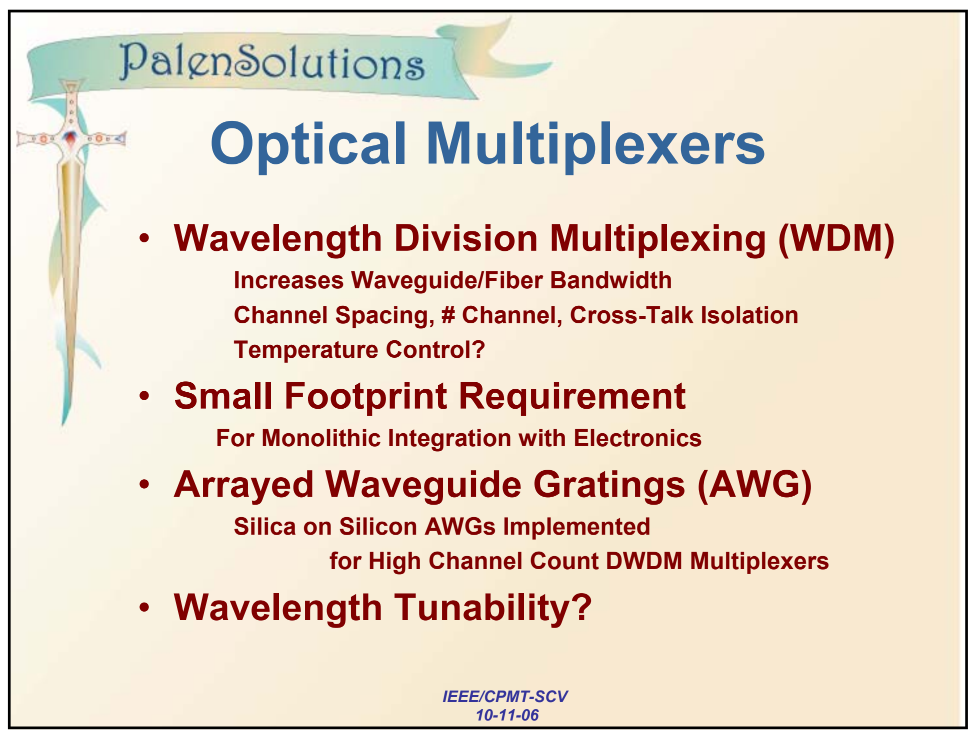
PalenSolutions
Optical Multiplexers
• Wavelength Division Multiplexing (WDM)
Increases Waveguide/Fiber Bandwidth
Channel Spacing, # Channel, Cross-Talk Isolation
Temperature Control?
• Small Footprint Requirement
For Monolithic Integration with Electronics
• Arrayed Waveguide Gratings (AWG)
Silica on Silicon AWGs Implemented
for High Channel Count DWDM Multiplexers
• Wavelength Tunability?
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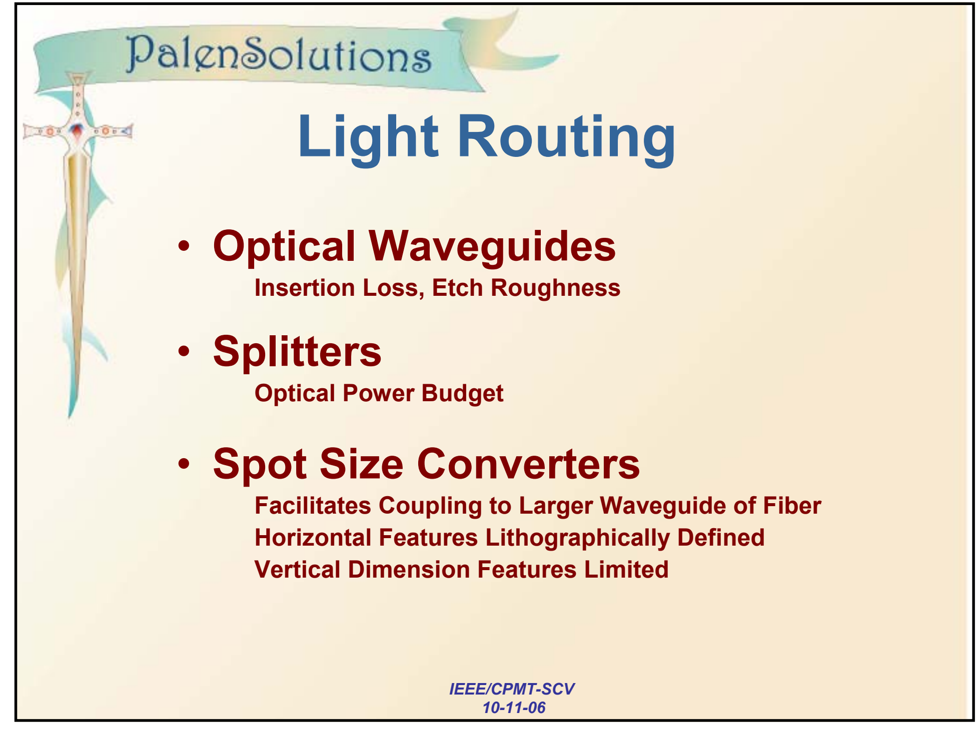
PalenSolutions
Light Routing
• Optical Waveguides
Insertion Loss, Etch Roughness
• Splitters
Optical Power Budget
• Spot Size Converters
Facilitates Coupling to Larger Waveguide of Fiber
Horizontal Features Lithographically Defined
Vertical Dimension Features Limited
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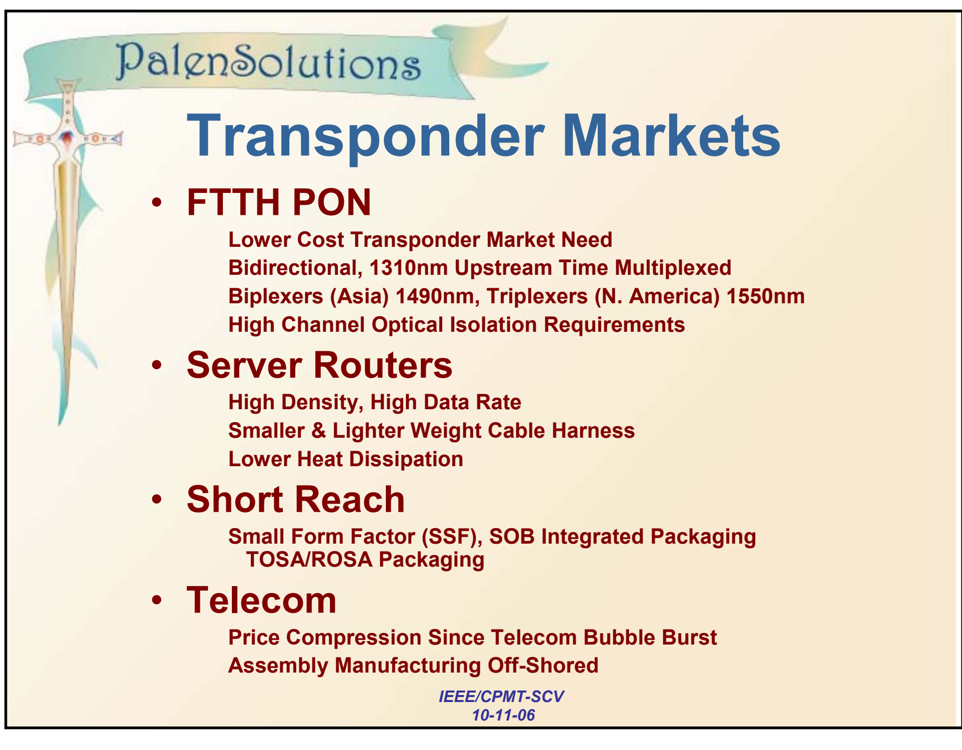
PalenSolutions
Transponder Markets
• FTTH PON
Lower Cost Transponder Market Need
Bidirectional, 1310nm Upstream Time Multiplexed
Biplexers (Asia) 1490nm, Triplexers (N. America) 1550nm
High Channel Optical Isolation Requirements
• Server Routers
High Density, High Data Rate
Smaller & Lighter Weight Cable Harness
Lower Heat Dissipation
• Short Reach
Small Form Factor (SSF), SOB Integrated Packaging
TOSA/ROSA Packaging
• Telecom
Price Compression Since Telecom Bubble Burst
Assembly Manufacturing Off-Shored
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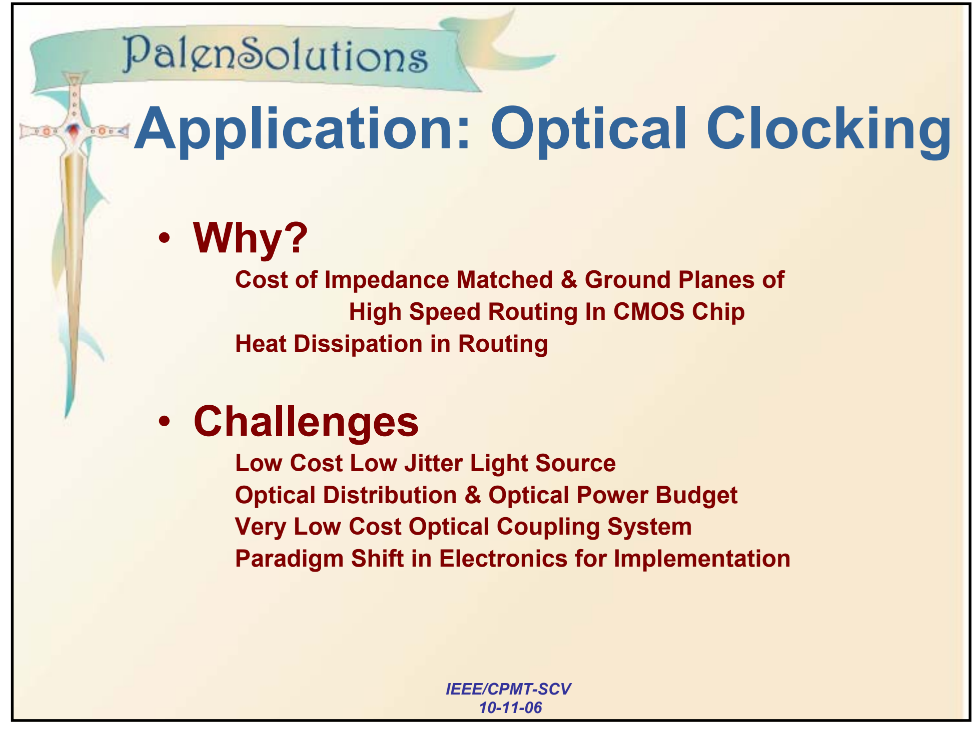
PalenSolutions
Application: Optical Clocking
• Why?
Cost of Impedance Matched & Ground Planes of
High Speed Routing In CMOS Chip
Heat Dissipation in Routing
• Challenges
Low Cost Low Jitter Light Source
Optical Distribution & Optical Power Budget
Very Low Cost Optical Coupling System
Paradigm Shift in Electronics for Implementation
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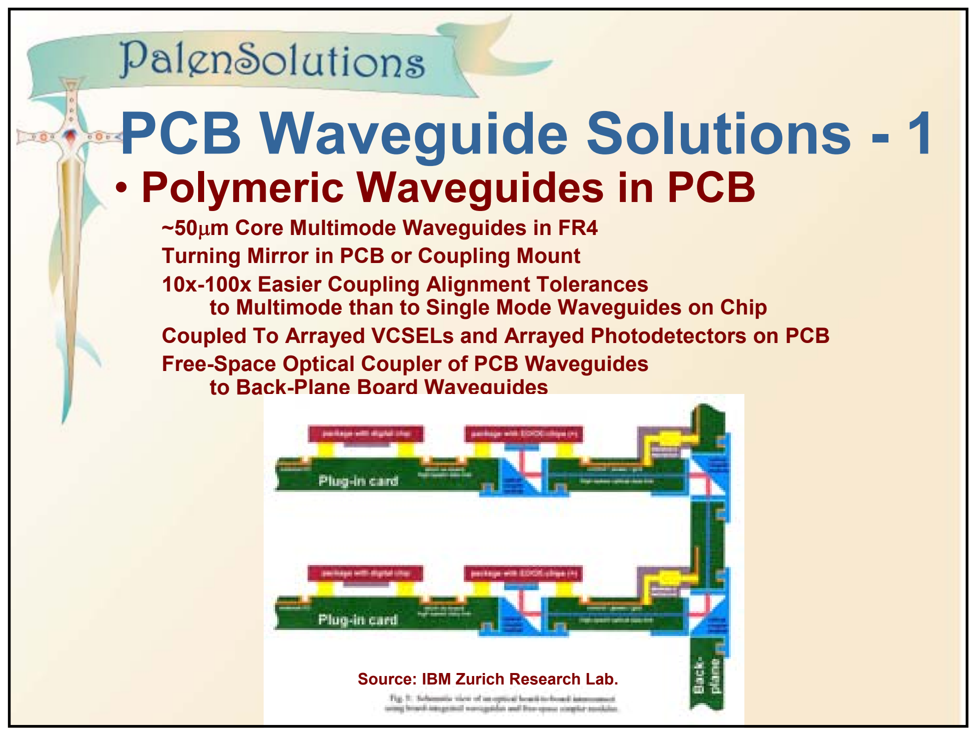
PalenSolutions
PCB Waveguide Solutions - 1
• Polymeric Waveguides in PCB
~50μm Core Multimode Waveguides in FR4
Turning Mirror in PCB or Coupling Mount
10x-100x Easier Coupling Alignment Tolerances
to Multimode than to Single Mode Waveguides on Chip
Coupled To Arrayed VCSELs and Arrayed Photodetectors on PCB
Free-Space Optical Coupler of PCB Waveguides
to Back-Plane Board Waveguides
Plug-in card
Plug-in card
Back-plane
Source: IBM Zurich Research Lab.

PalenSolutions
PCB Waveguide Solutions - 2
• Challenges:
Low Cost Optical Coupler Solutions
with Passive Alignment Connectors
Fabrication Process Integration of Waveguides in PCB
Routing of Thicker Waveguide & Cladding Layers in PCB
PCB Reliability Issues Related to Polymeric Waveguide Layers
• Market Space Need?
Need For PCB Photonic Routing Solution
vs. Electronic PCB Routing?
Will Developments in PIC Transponders
Fill The Need of Photonic PCB Solution?
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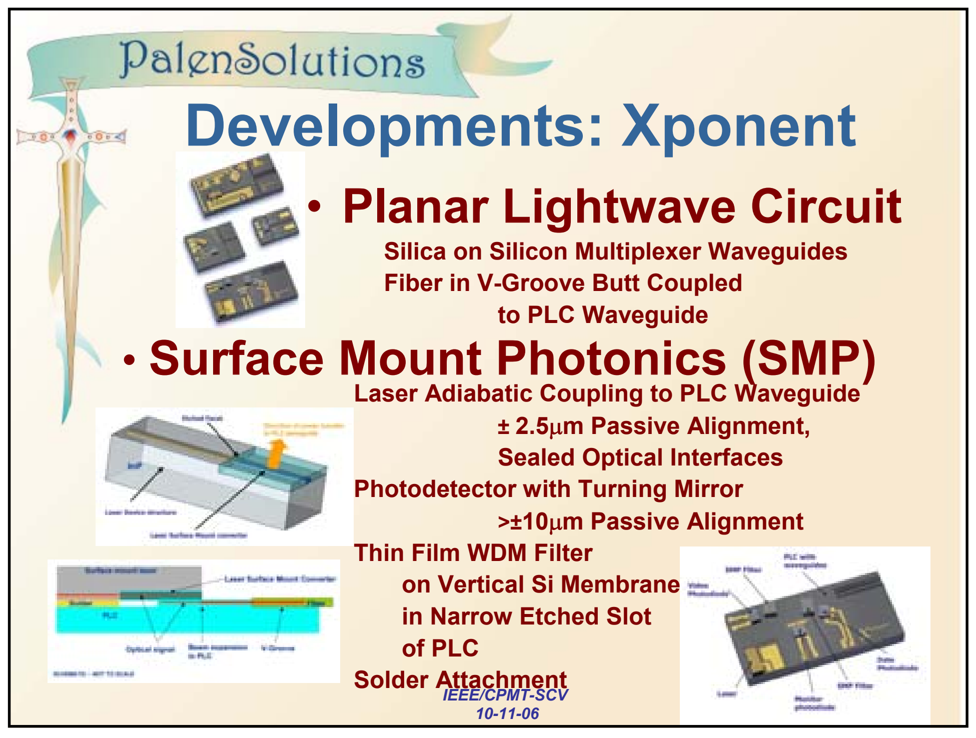
PalenSolutions
Developments: Xponent
• Planar Lightwave Circuit
Silica on Silicon Multiplexer Waveguides
Fiber in V-Groove Butt Coupled
to PLC Waveguide
• Surface Mount Photonics (SMP)
Laser Adiabatic Coupling to PLC Waveguide
± 2.5μm Passive Alignment,
Sealed Optical Interfaces
Photodetector with Turning Mirror
>±10μm Passive Alignment
Thin Film WDM Filter
on Vertical Si Membrane
in Narrow Etched Slot
of PLC
Solder Attachment
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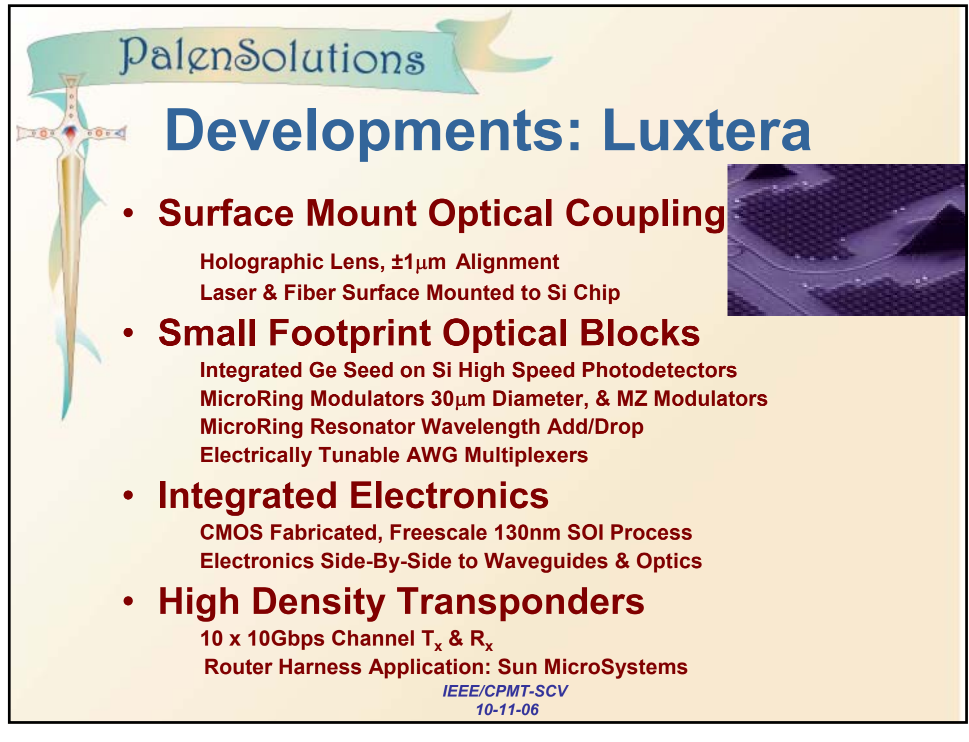
PalenSolutions
Developments: Luxtera
• Surface Mount Optical Coupling
Holographic Lens, ±1μm Alignment
Laser & Fiber Surface Mounted to Si Chip
• Small Footprint Optical Blocks
Integrated Ge Seed on Si High Speed Photodetectors
MicroRing Modulators 30μm Diameter, & MZ Modulators
MicroRing Resonator Wavelength Add/Drop
Electrically Tunable AWG Multiplexers
• Integrated Electronics
CMOS Fabricated, Freescale 130nm SOI Process
Electronics Side-By-Side to Waveguides & Optics
• High Density Transponders
10 x 10Gbps Channel T_x & R_x
Router Harness Application: Sun MicroSystems
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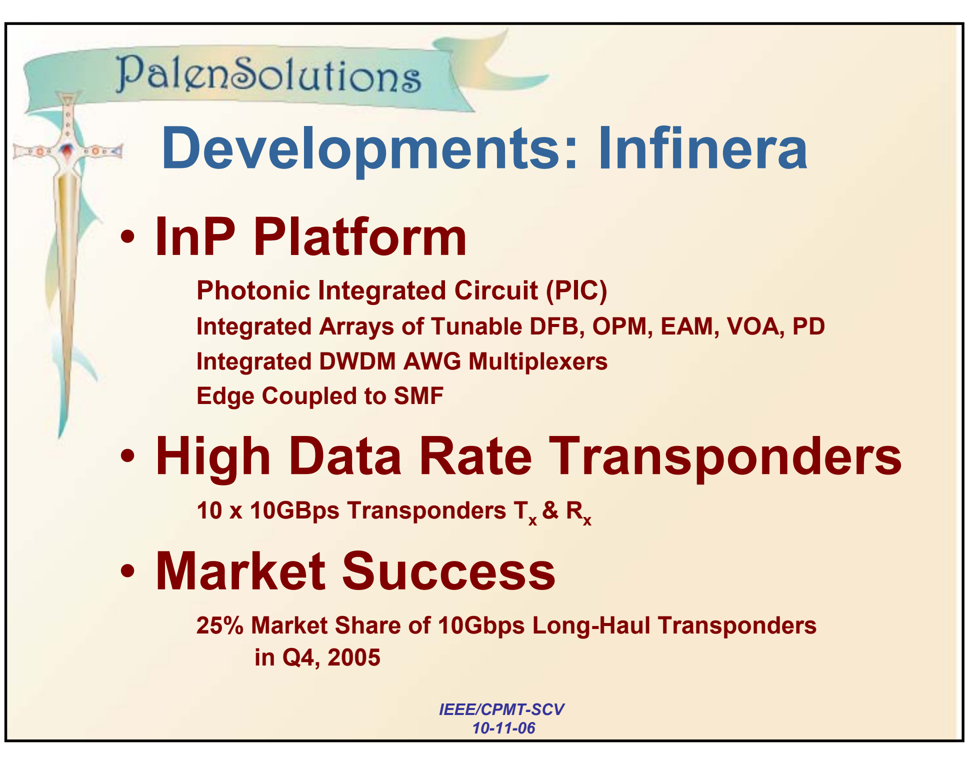
PalenSolutions
Developments: Infinera
• InP Platform
Photonic Integrated Circuit (PIC)
Integrated Arrays of Tunable DFB, OPM, EAM, VOA, PD
Integrated DWDM AWG Multiplexers
Edge Coupled to SMF
• High Data Rate Transponders
10 x 10GBps Transponders T_x & R_x
• Market Success
25% Market Share of 10Gbps Long-Haul Transponders in Q4, 2005
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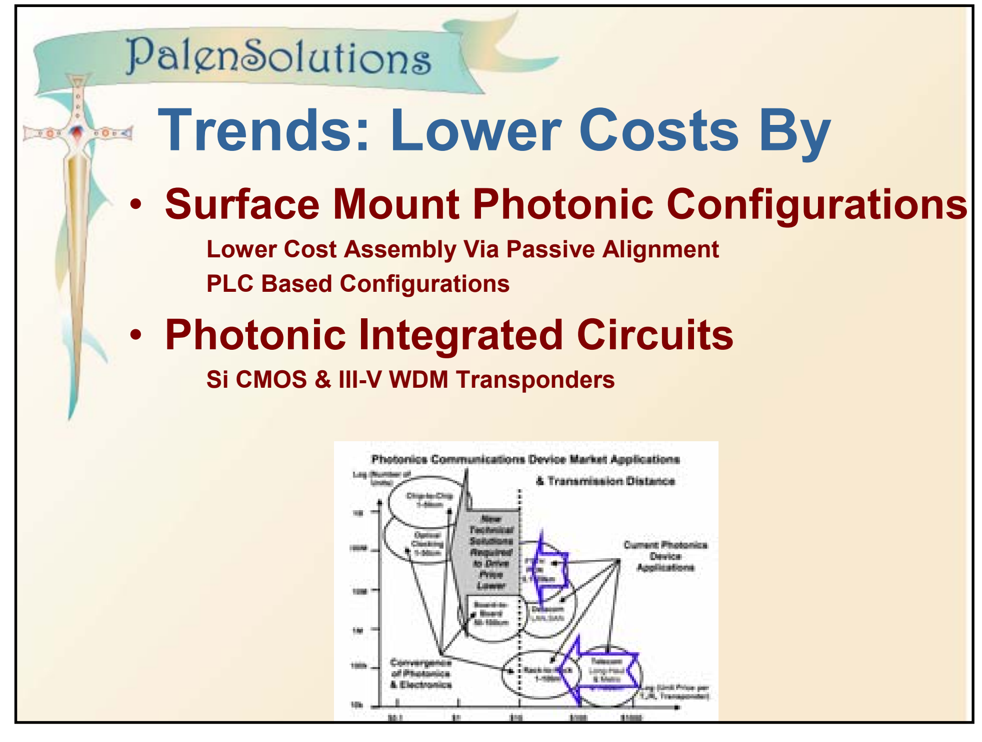
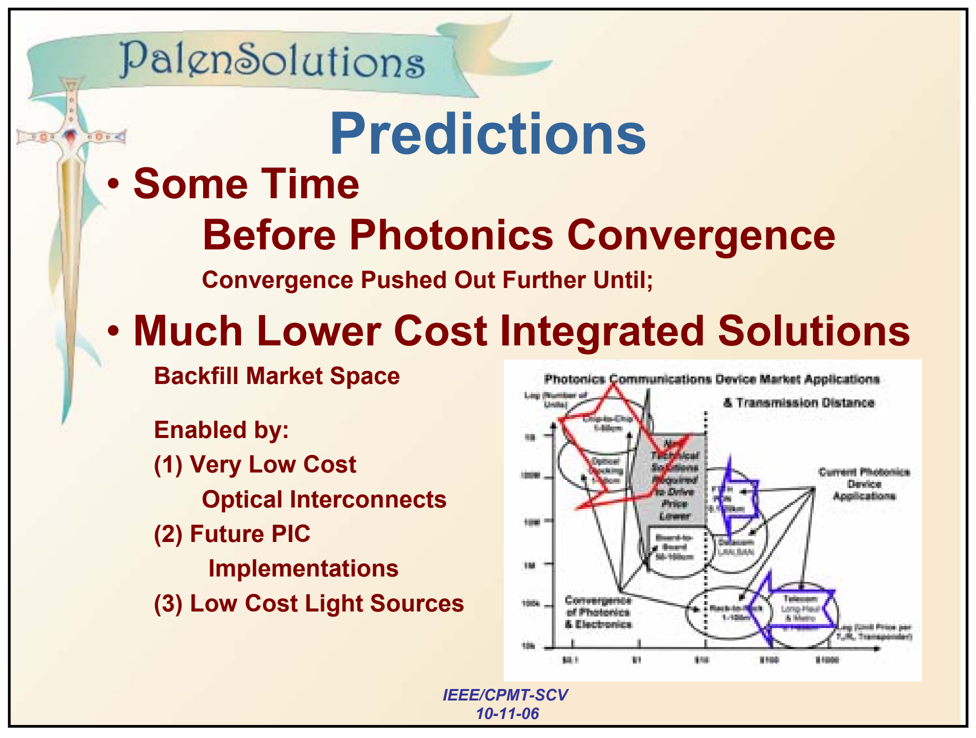
10-11-06


PalenSolutions
Trends: Lower Costs By
• Surface Mount Photonic Configurations
Lower Cost Assembly Via Passive Alignment
PLC Based Configurations
• Photonic Integrated Circuits
Si CMOS & III-V WDM Transponders
Photonics Communications Device Market Applications
& Transmission Distance
New Technical Solutions Required to Drive Price Lower
Current Photonics Device Applications
Convergence of Photonics & Electronics


PalenSolutions
Predictions
• Some Time
Before Photonics Convergence
Convergence Pushed Out Further Until;
• Much Lower Cost Integrated Solutions
Backfill Market Space
Enabled by:
(1) Very Low Cost
Optical Interconnects
(2) Future PIC
Implementations
(3) Low Cost Light Sources
Photonics Communications Device Market Applications
& Transmission Distance
Current Photonics
Device
Applications
Convergence
of Photonics
& Electronics
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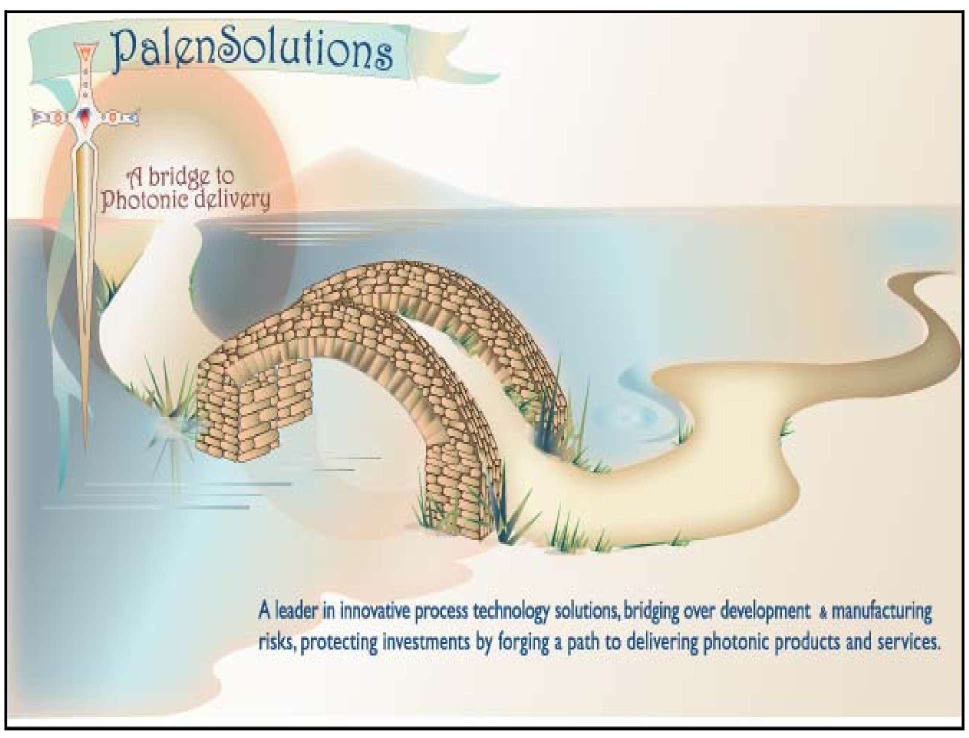
PalenSolutions
A bridge to
Photonic delivery
A leader in innovative process technology solutions, bridging over development & manufacturing
risks, protecting investments by forging a path to delivering photonic products and services.