Technological Research and High Power Lasers for Semiconductor Processing

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US Technology Development Center

Outline

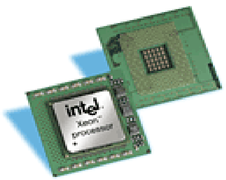
- Introduction
  - Semi Industry – Tokyo Electron (TEL) Business portfolio
- TEL Technological Development Strategy
- High Power Laser for Semi devices processing - Apps
  - CO_2 10.6 μm – Laser Spike Anneal
  - CO_2 9.4 μm – Dielectric Curing
- Summary

Electronic Business Food Chain

CY2009 World Market

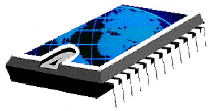
Electronic Applications

US$ 1,200 B (2008 – $1,400 B)



Semiconductor

US$ 230 B (2008-$260B)



Semiconductor Production Equipment

US$ 17 B (2008 - $31B)

The Market TEL Participates in

Source: Gartner Dataquest

Tokyo Electron Corporate Profile

- **Established : November 11,1963**
- **Employees : 10,204 (as of April 1, 2010)**

Business Sectors

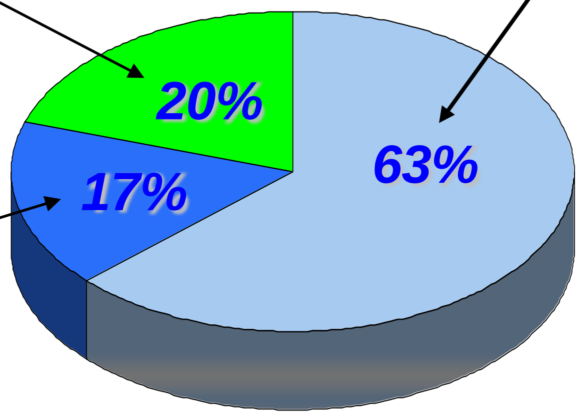
Electronic Components/ Computer Networks

Semiconductor Products
Computer Networks
Software
Boards and General Electronic Components

Semiconductor Production Equipment

Coater/Developer
Thermal Processing System
Cleaning System
Imported Product
MEMS

Plasma Etch System
Single Wafer Deposition System
Wafer Prober
GCIB System



FPD/PV Production Equipment

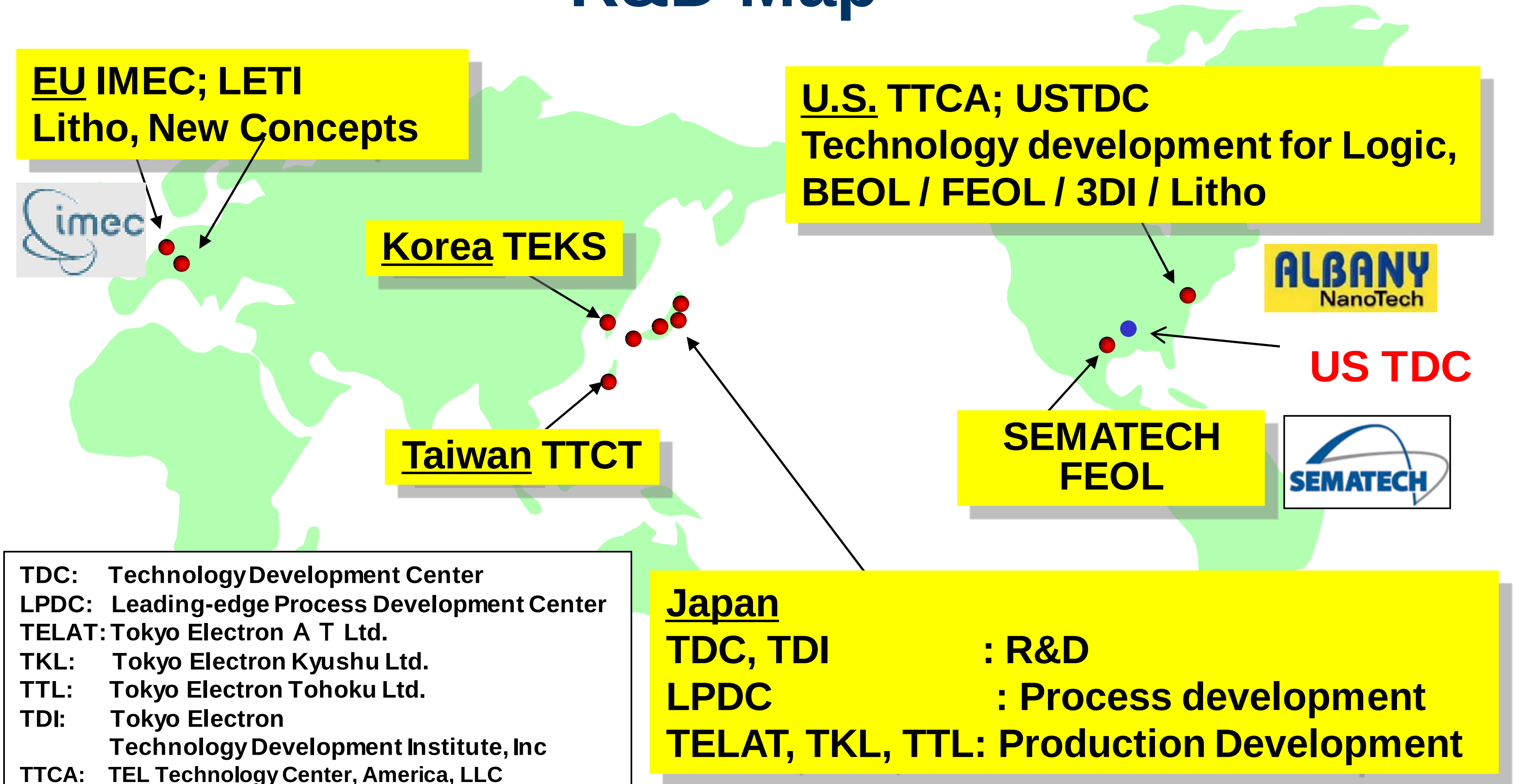
FPD Coater/Developer
FPD Plasma Etch/Ash System
Photovoltaic Cell Production Equipment

FY2010 Consolidated Net Sales: US $4,186 Million

Conversion rate of 100yen/US$ is used all through the presentation.

TEL
Technological Development / Strategy

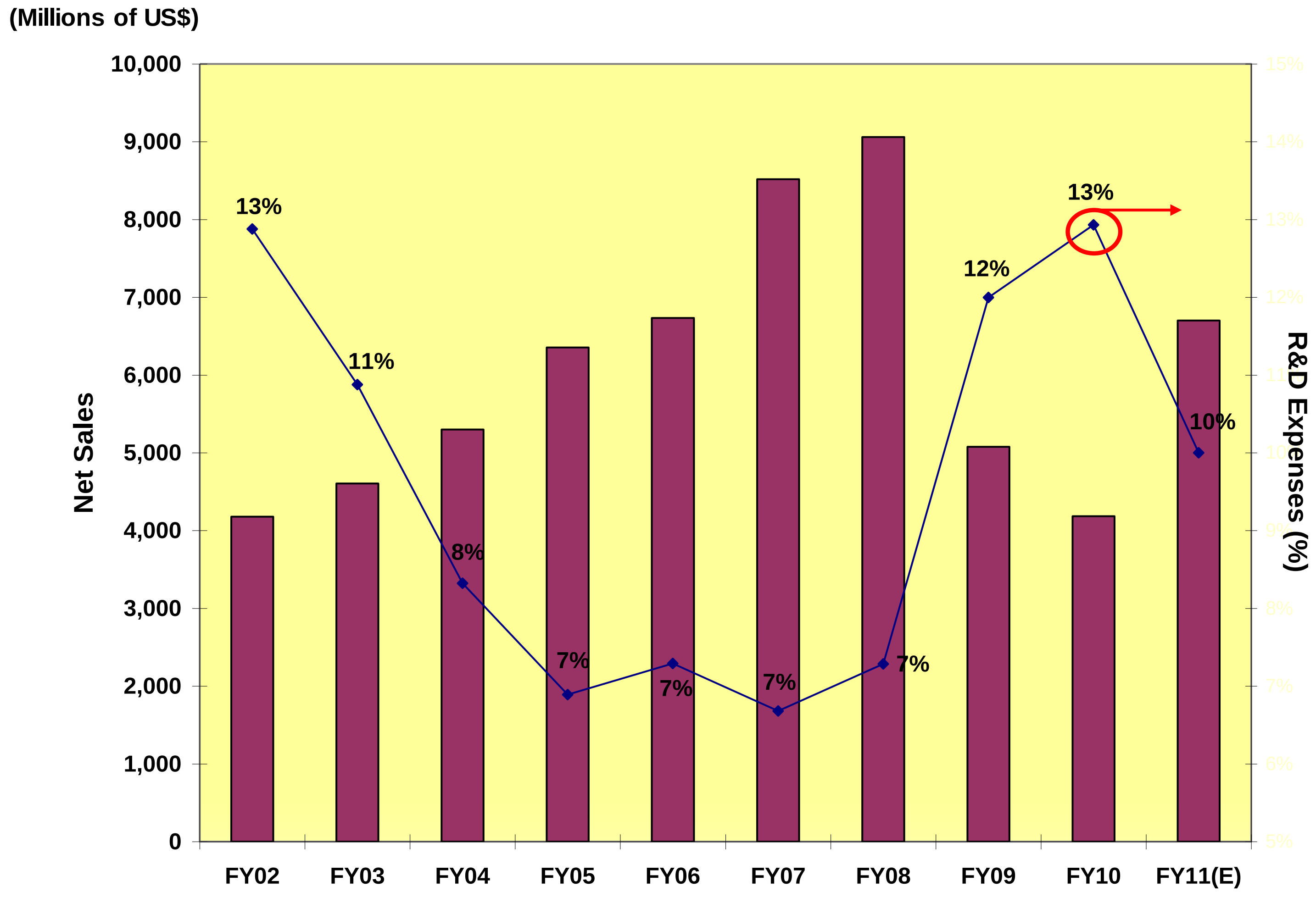
R&D Map



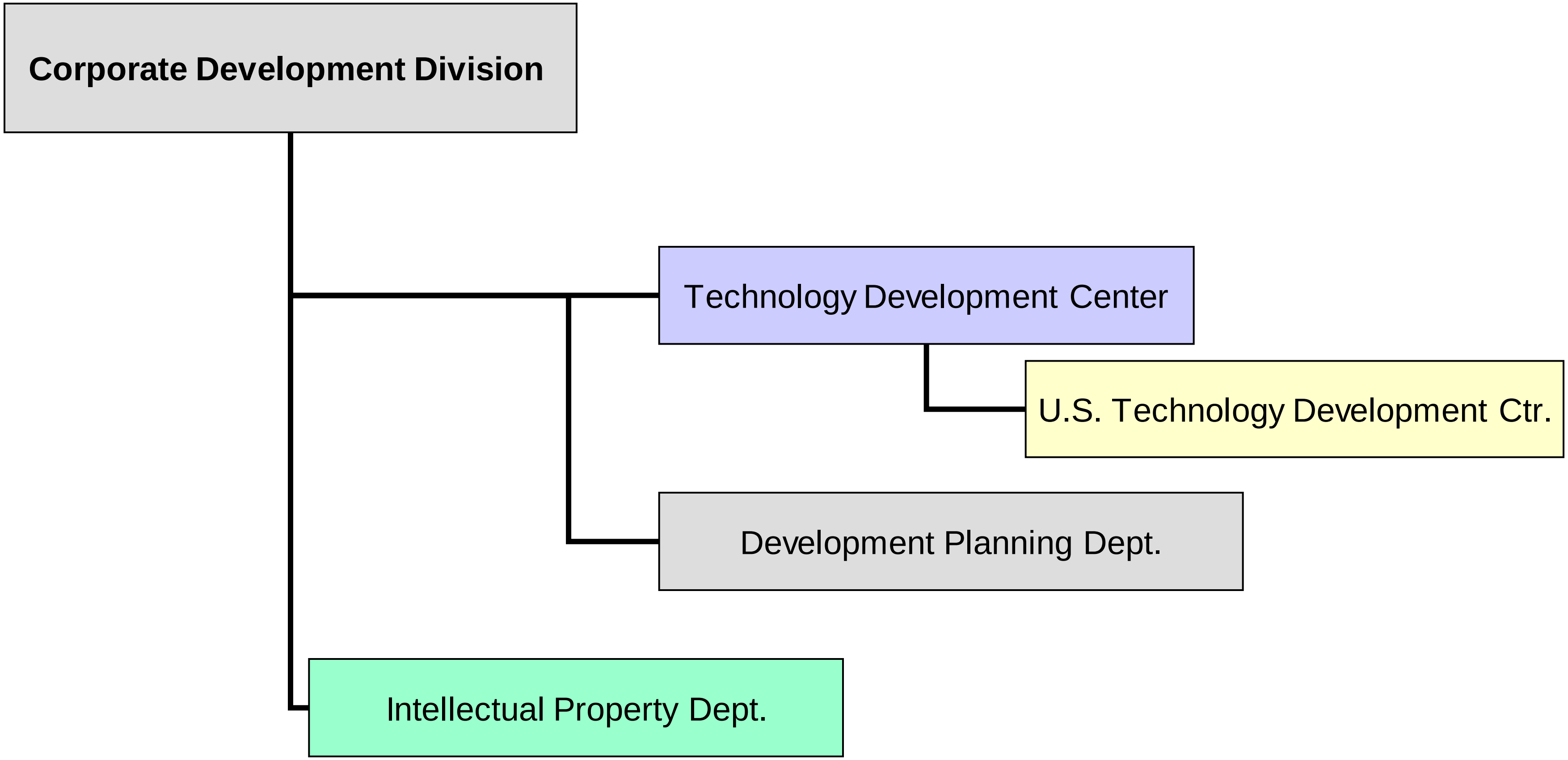
TDC: Technology Development Center
LPDC: Leading-edge Process Development Center
TELAT: Tokyo Electron A T Ltd.
TKL: Tokyo Electron Kyushu Ltd.
TTL: Tokyo Electron Tohoku Ltd.
TDI: Tokyo Electron Technology Development Institute, Inc
TTCA: TEL Technology Center, America, LLC
TEKS: Tokyo Electron Korea Solution Ltd.
TTCT: TEL Technology Center, Taiwan

Imec ; leti Consortium in EU
SEMATECH : Consortium in U.S.

R&D Expenses as a Percentage of Net Sales



Corporate R&D Organization



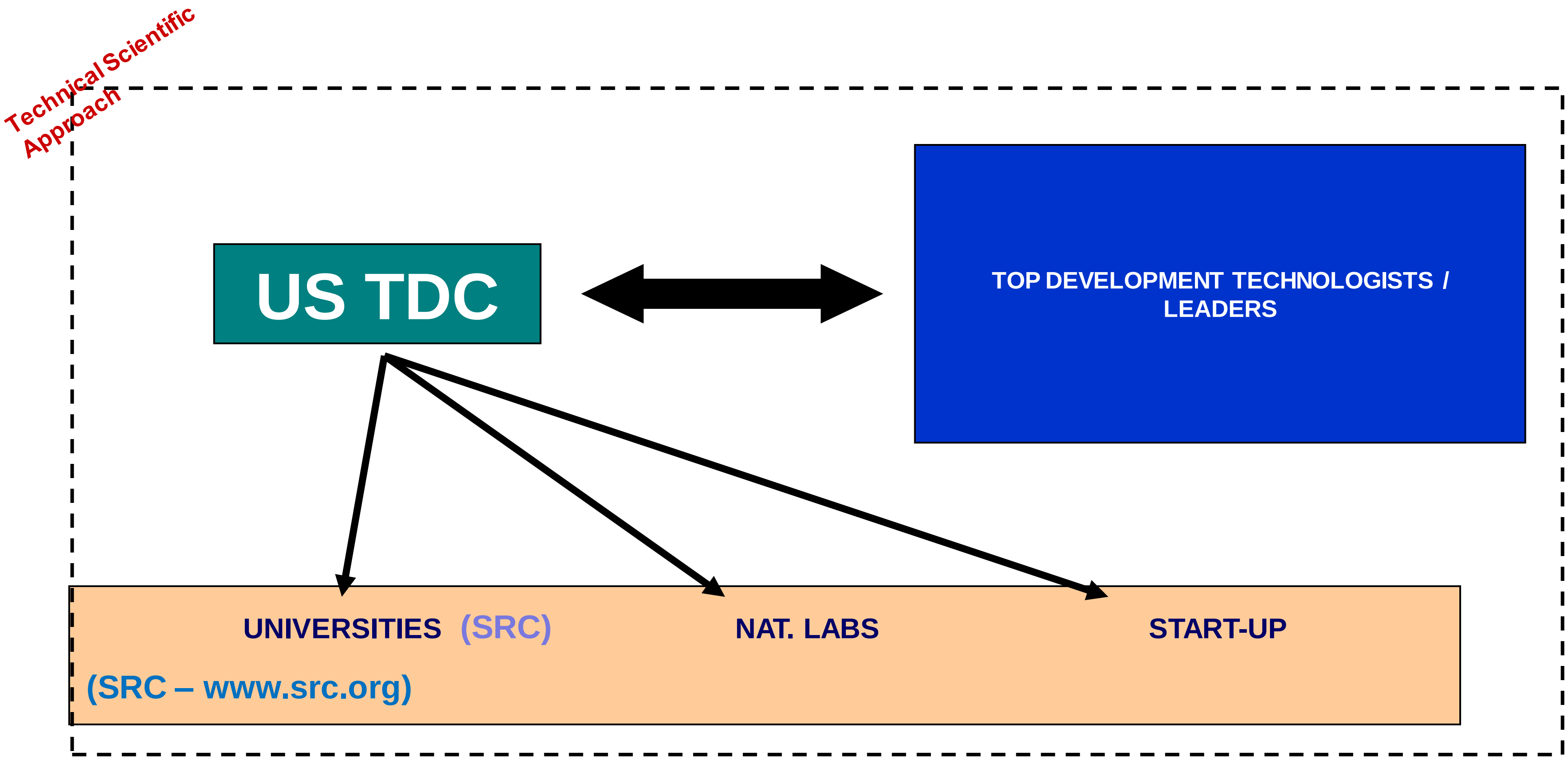
US TDC Missions / Approach

- **Identify US New Technologies in early stage**
- **Develop TEL New technologies initiated in US TEL entities**
- **Evaluate technical merit on F/S**
- **Transfer and assist P/D and Tool Development**

Key points for success:

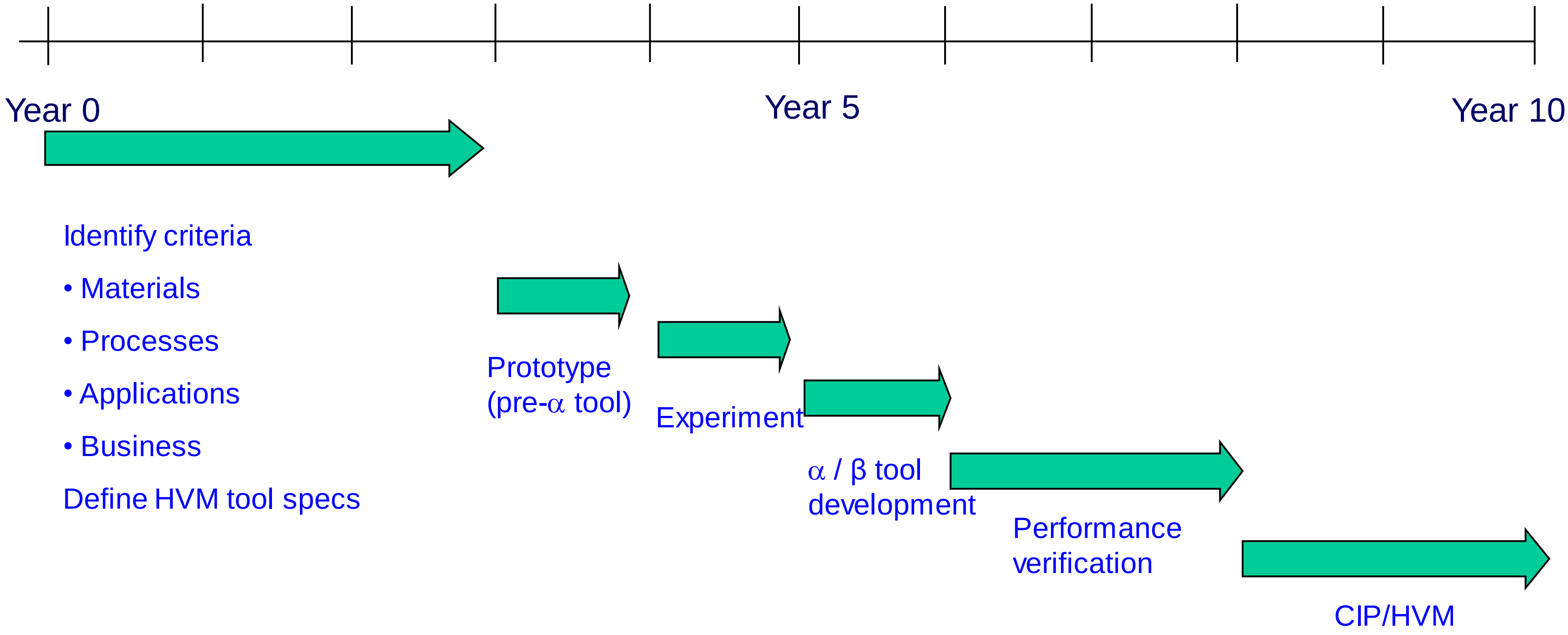
- F/S in appropriate places
- Process transfer gradually
- Infrastructure Place / Develop:
  - Close to the source
  - Careful personnel recruiting

US TDC Technology “Seeds”



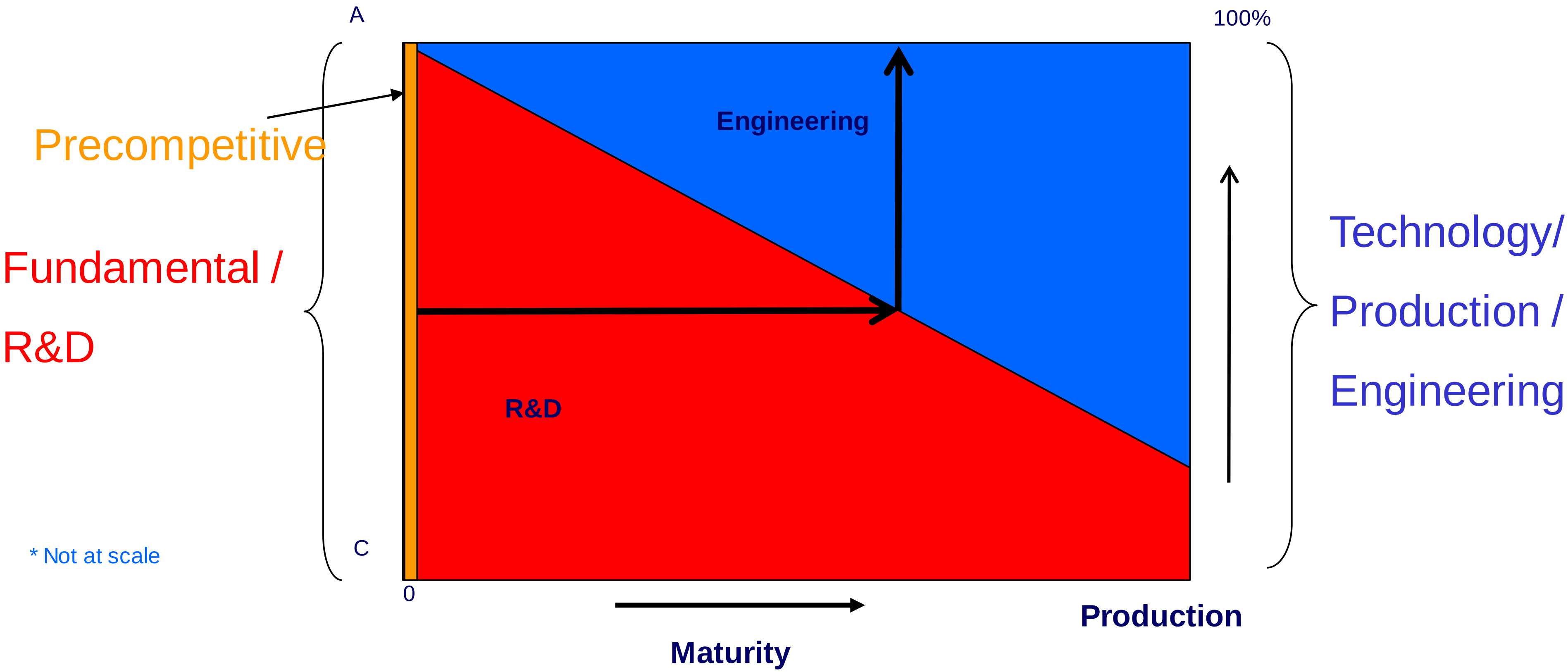
New internal projects

Time-to-market for HVM Solutions (New Technology & New Tool)



Great efforts are needed to make 2020 HVM even with possible skipped steps and learning from past development experience.

Square Of Success (SOS)*



- **Early technology engagement – less engineering effort**

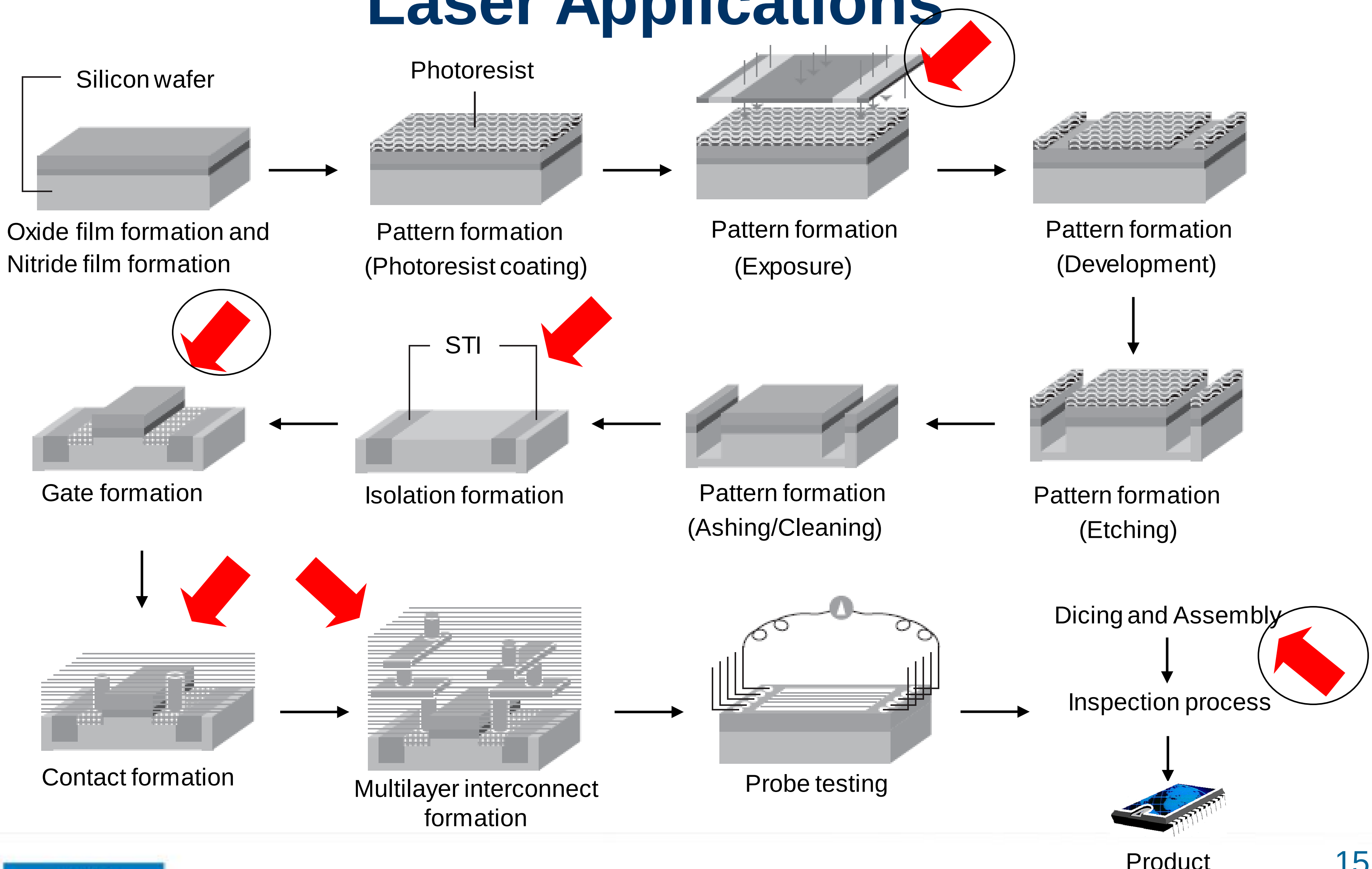
Semi Industry and R&D

- There is no real fundamental R&D in Semi Industry (except IBM and SAMSUNG)
- Most of development activities are started after F/S on large scale concept has been demonstrated.
- Industry is relying on Academia (in US -> SRC), Government Programs (Japan) or Development Consortia (SEMATECH; IMEC; LETI)

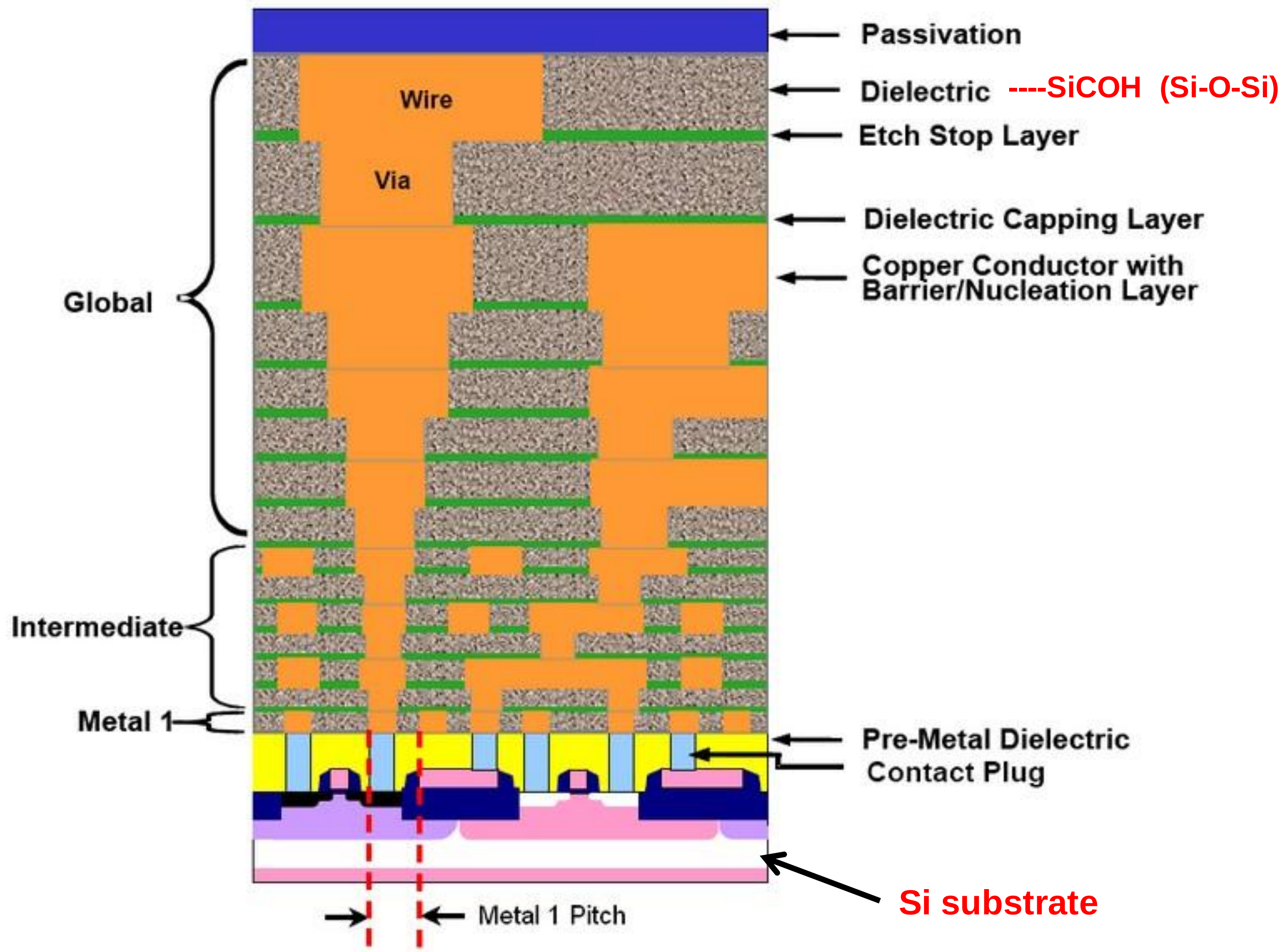
  NOTE – Most of Consortia does not have fundamental R&D either

High Power Laser Applications in CMOS Fabrication

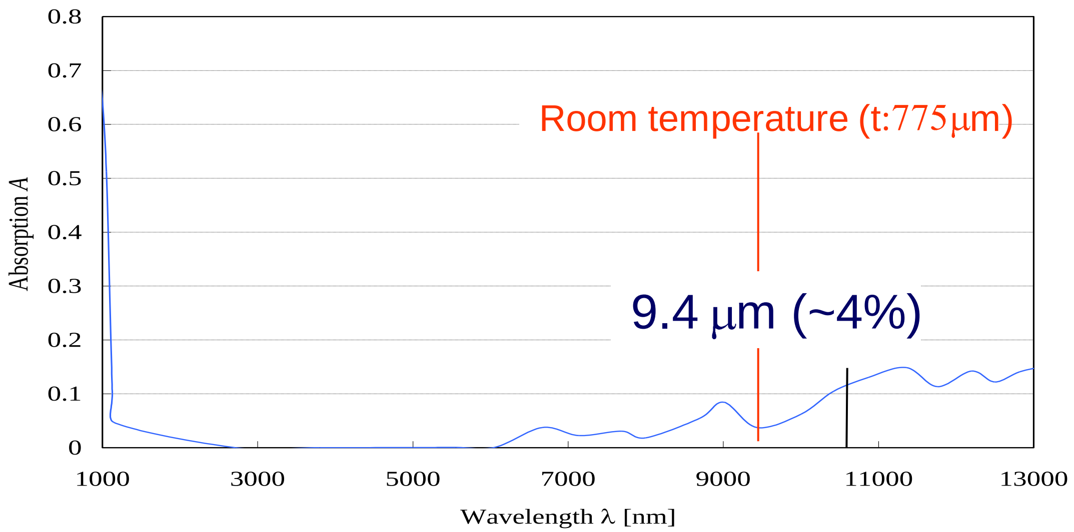
CMOS Process Steps / Potential Laser Applications



Typical MPU Cross-section



Absorption of Si : Temperature Dependence

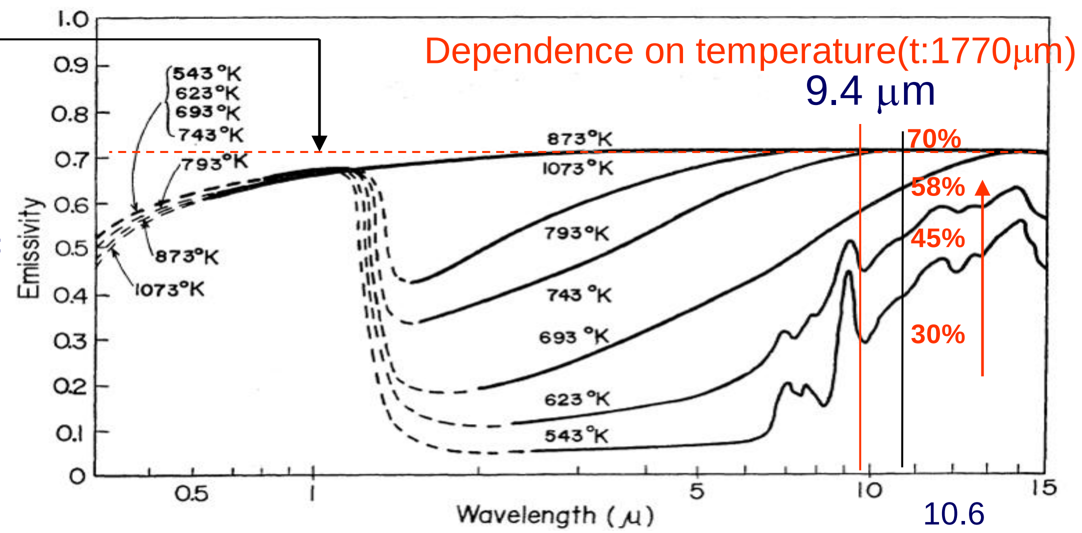


1) Handbook of optical constants of solids E.D. Palik

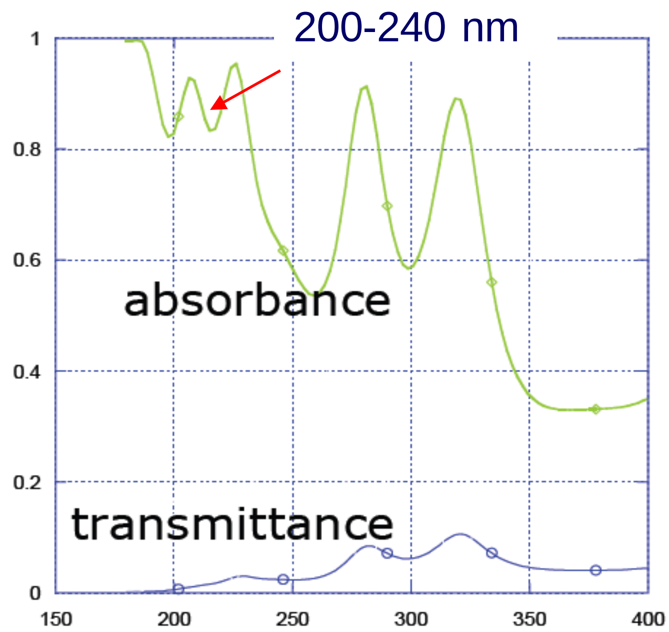
2) JJAP 6,3,1967 T. Sato

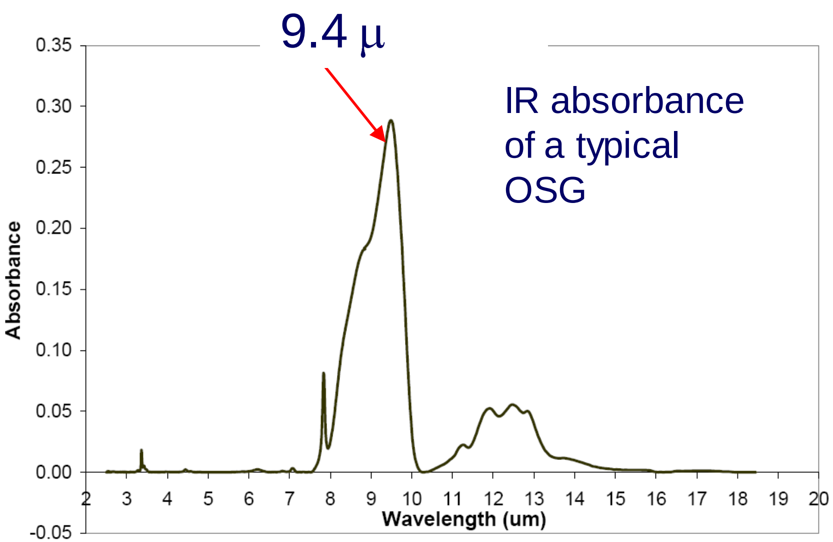
MAX absorption except reflection

Absorption=



ULK UV and IR Absorbance





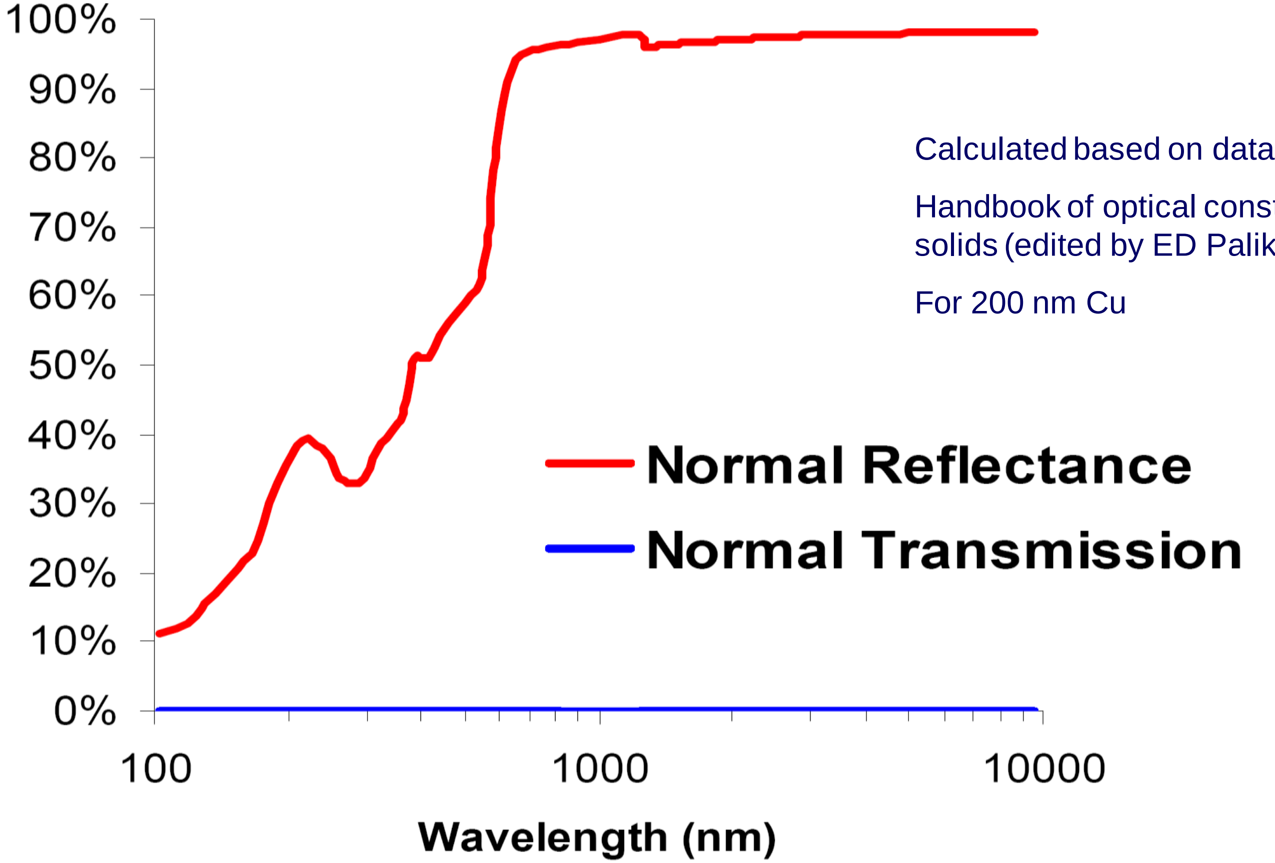
UV absorption bands:

- 200 ~ 240nm: Si-O in not fully crosslinked environment
- 260 ~ 300nm: Si-Me
- > 300 nm: C-C and VDW
- < 190nm: aggressive crosslinking may lead to skin layer effect

IR absorption bands:

Si-O-Si and Si-O-C stretching modes

Cu: Normal Reflectance and Transmission



Calculated based on data from

Handbook of optical constants of solids (edited by ED Palik, 1985)

For 200 nm Cu

- No transmission at any wavelength.
- Strong absorption at UV range.

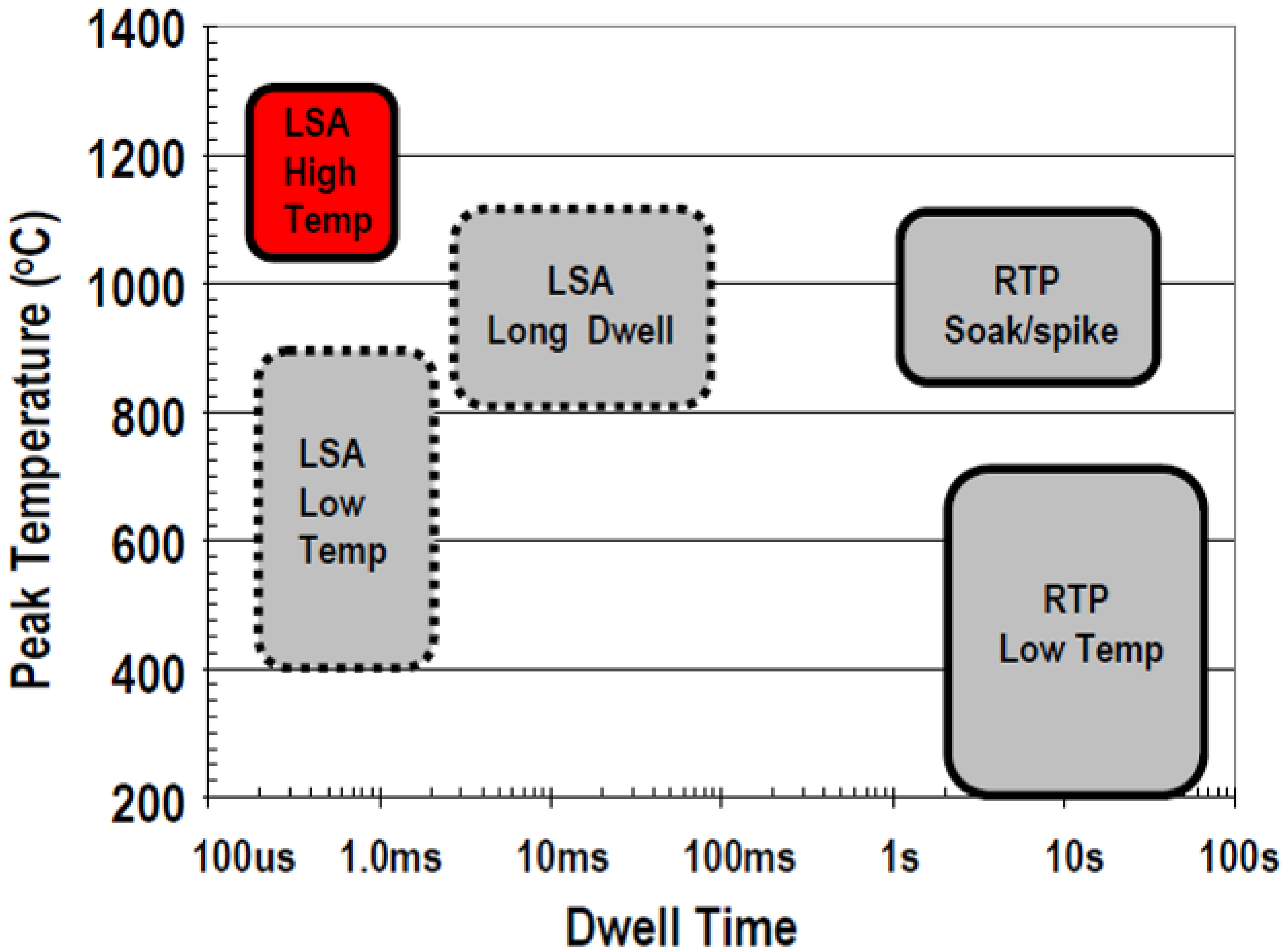
Laser Spike Annealing (LSA) Using 10.6 μm CO_2 Laser

Using thermal effect of radiation absorbed in doped Si substrate

Applications

- Dopant activation
- NiSi Formation
- High-K/ Metal Gate
- Non-planar gate structure

LSA Thermal Processing Regimes

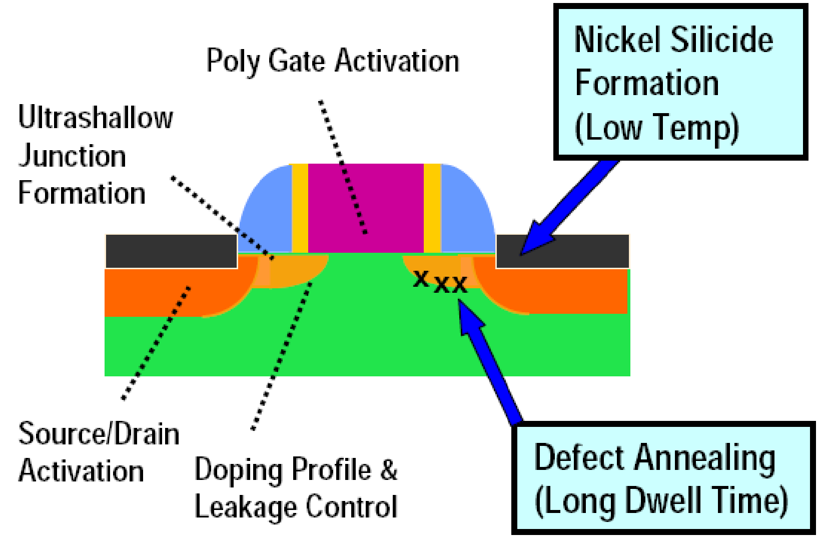


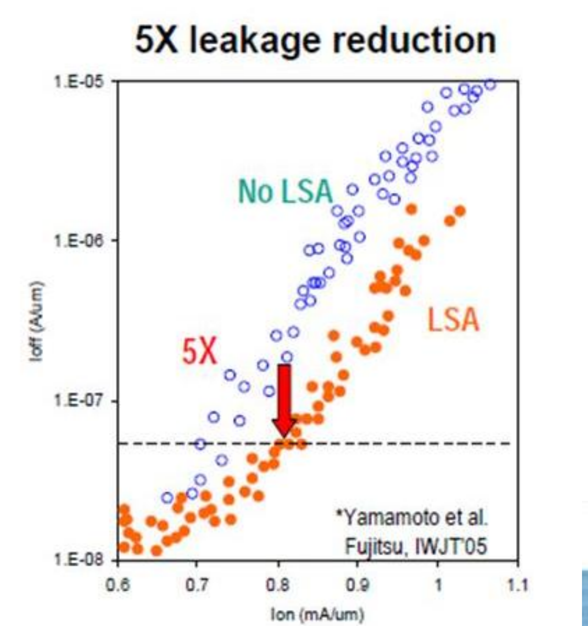
Potential FEOL Applications

LSA Insertion Points:

Device Flow

- Isolation
- Gate Ox
- Gate Formation
- S/D Extension & Halo
- ① →
- SW Spacer Formation
- ② →
- SMT Process
- Deep S/D Implantation
- ③ →
- S/D spike RTA
- ④ →
- Ni Silicidation
- ⑤ →
- BEOL Process

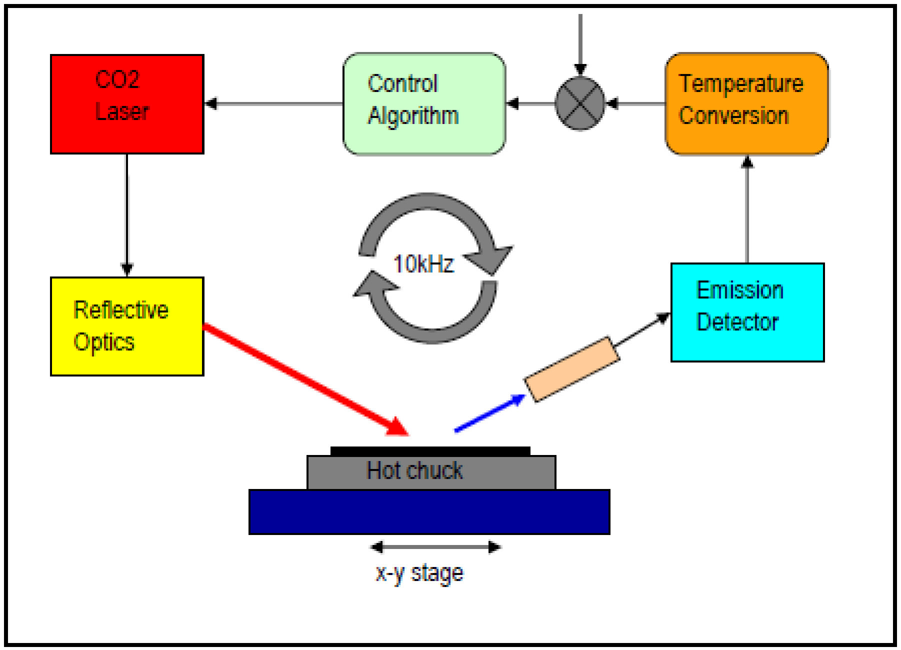


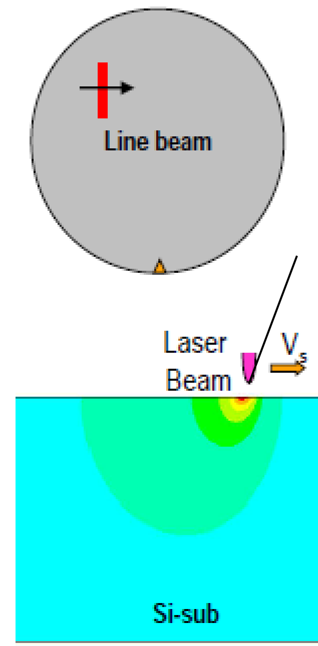


LSA System Architecture (1)

Single beam operation

Commercial:5kW, 100μm x 1.25~4.4 cm





0.64-1.5 kW/mm^2

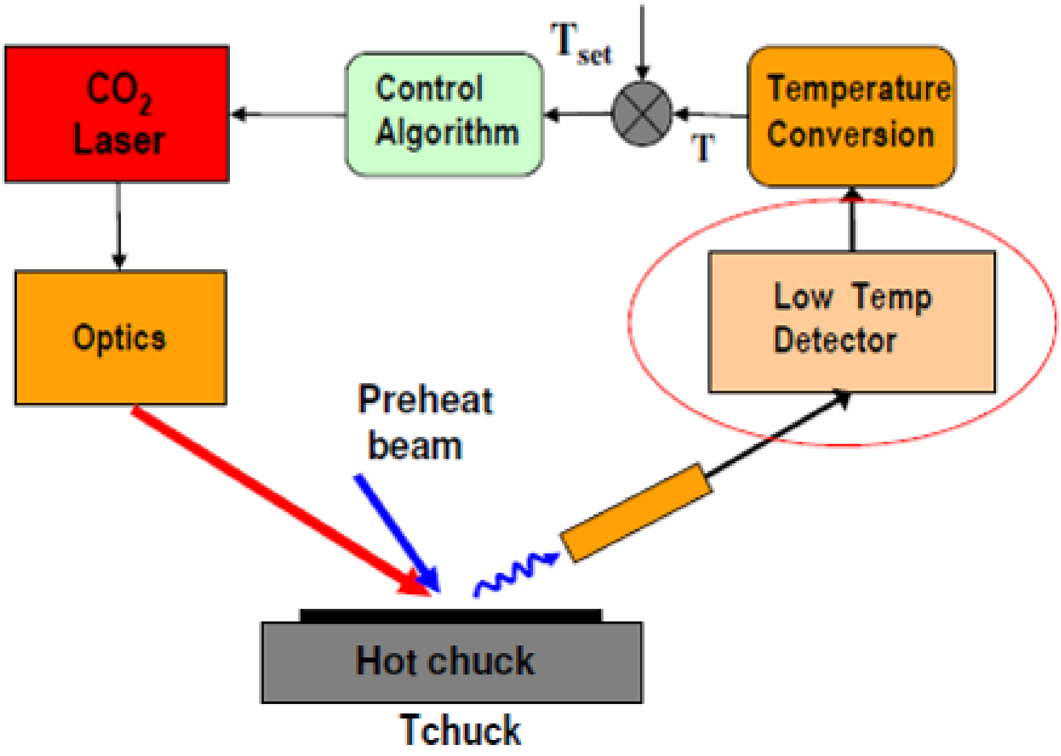
5-50 J/cm^2@

200us dwell time

- Long wavelength, p-polarized "line beam" incident on wafer at Brewster's angle to minimize pattern effects
- Wafer scanned under the beam, stage speed determines dwell time ← Scan speed:10~100 cm/sec
- Real-time peak temperature measurement in feedback loop to laser.

LSA System Architecture (2)

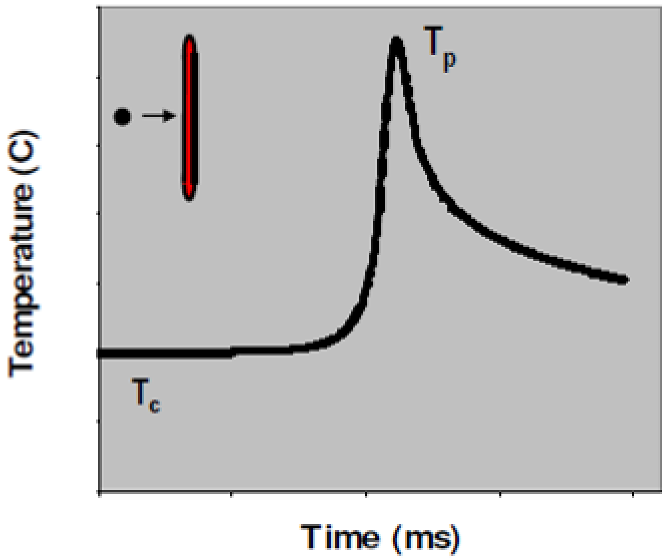
Dual beam operation



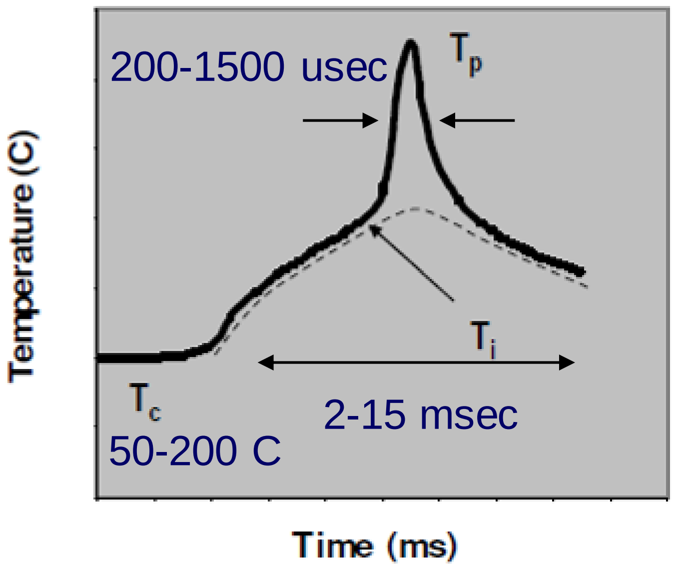
- Preheat beam heats wafer just enough for CO2 beam to couple into wafer, allowing low chuck temperature.
- Low temperature pyrometer allows closed loop temperature control to ~400ºC.

Single Beam VS Dual Beam

Single beam operation

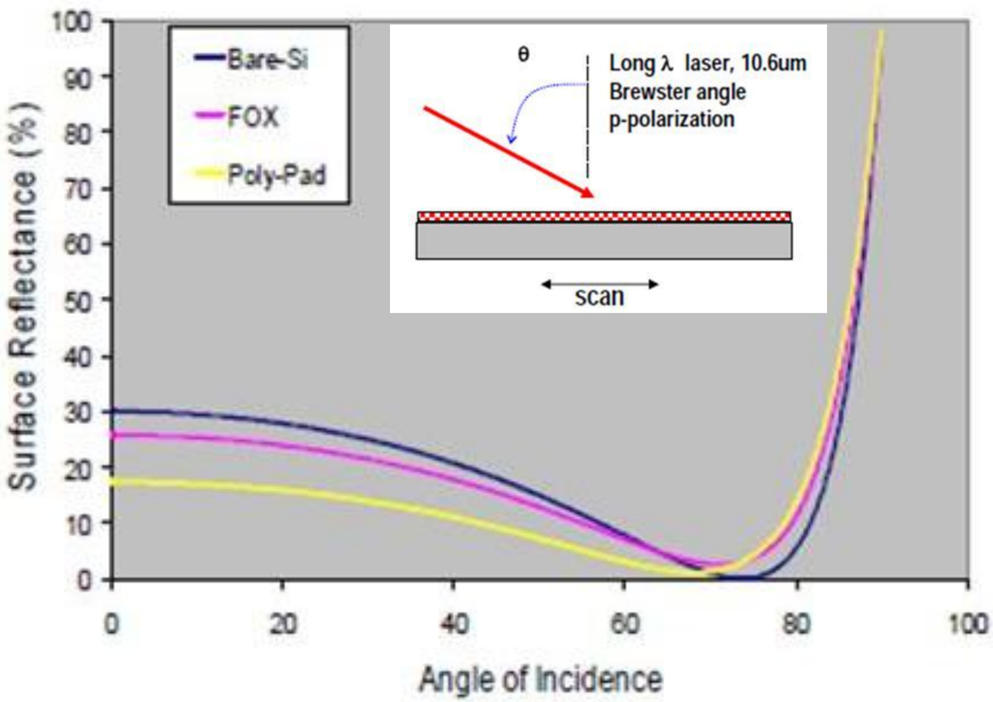


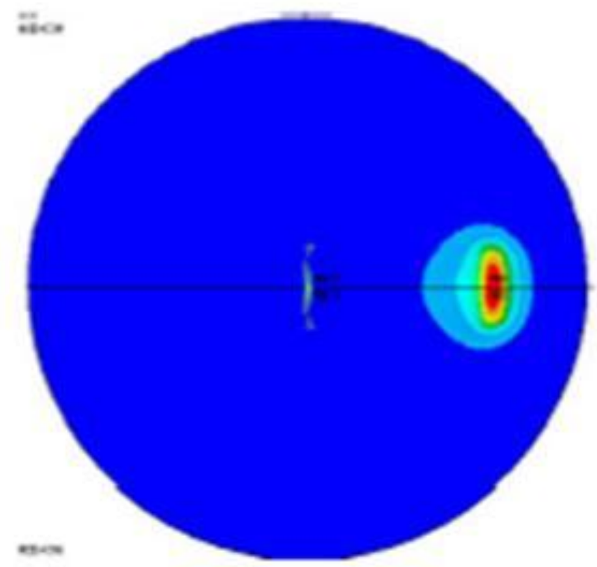
Dual beam operation



- **Single beam configuration covers the high temperature (Short dwell time) regime.**
- **Dual beam configuration covers the long dwell time and low temperature regimes**

Merits of Brewster Angle Irradiation





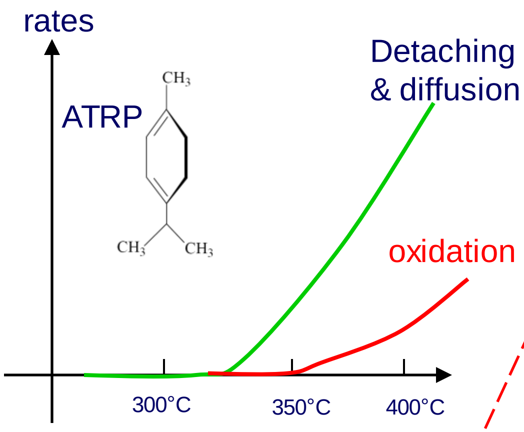
- Long wavelength: >>length scale of devices and film thickness
- P-polarization and Brewster angle make cross-die absorptivity non-uniformity to ~ 1%.
- Temperature gradients: Minimal Pattern effects give uniform thermal stress
- Stress dissipation: Minimized thermal shock as a result of fast scanning
- Dwell time: Dwell time flexibility allows low wafer warpage for critical process steps

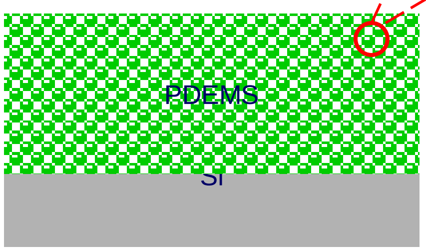
Advanced Dielectric Treatment Using 9.4 μm CO2 Laser

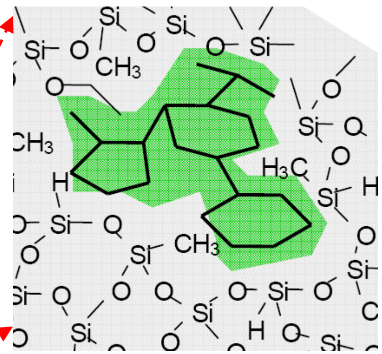
- Energy is delivered specifically to SiCOH film without damaging the underlayers and substrate.
  - A laser sonication process where CO_2 laser-excited vibration in Si-O-Si backbone structure

- Major applications in Interconnect :
  - Dielectric curing
  - Dry cleanning

Dielectric Curing Porogen Removal Mechanism

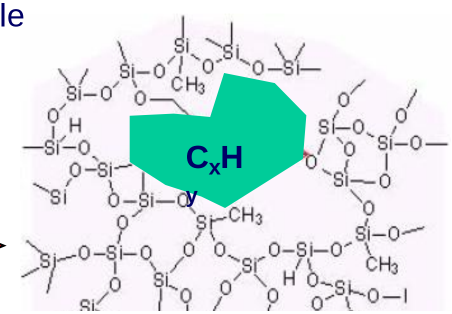






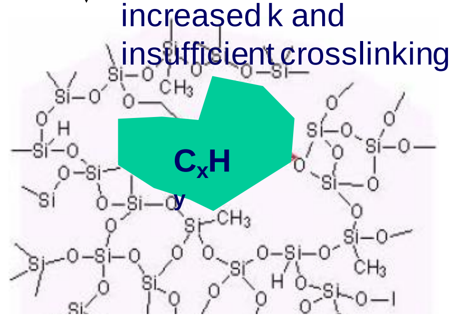
- Bottom up heating profile
- Residues at the bottom start to oxidize before outdiffusion.
- Insufficient crosslinking

Thermal



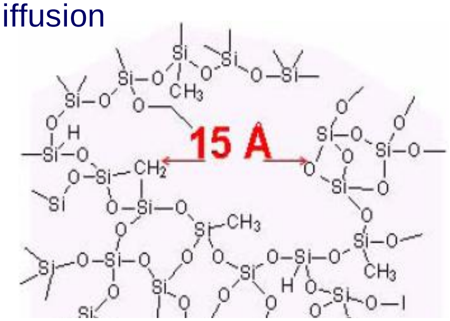
UV

- UV induced crosslinking may occur before complete porogen removal
- Trapped residues may oxidize, causing increased k and insufficient crosslinking

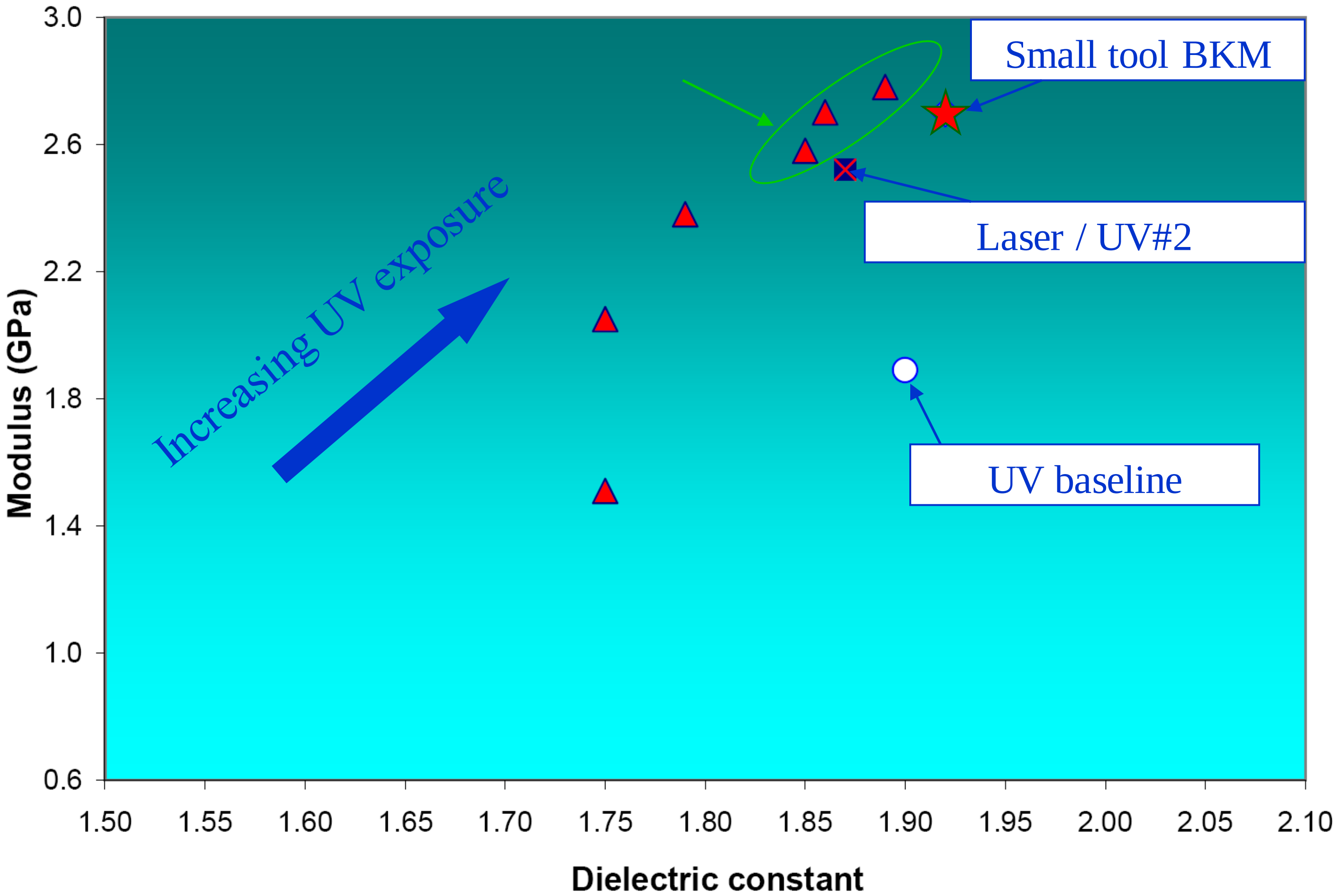


IR / (UV)

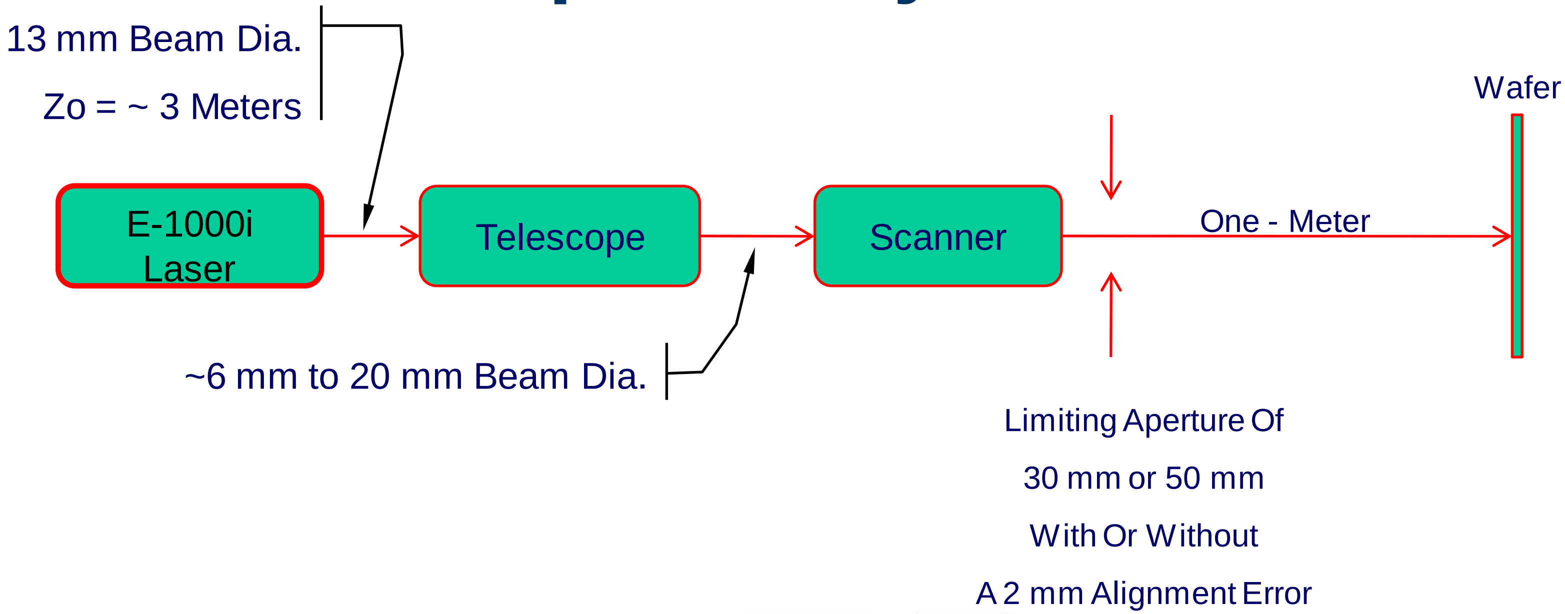
- Top down heating profile
- Vibration of skeleton structure helps detach porogen residue and its outdiffusion

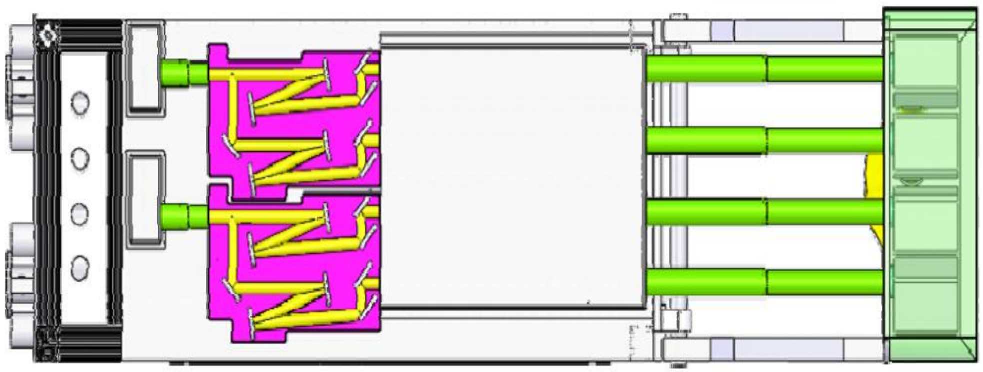


k2.0 PDEMS Curing Results



Optical Layout



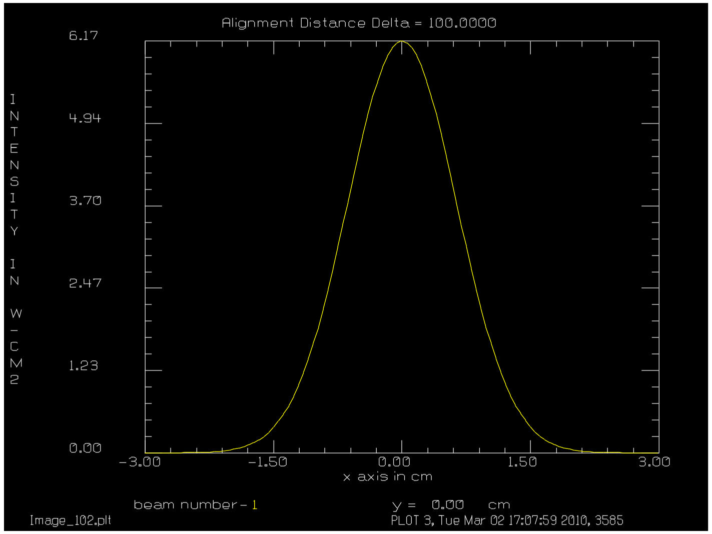


Beam Profile

Original Laser Beam

Mode Quality (M^2)	<1.2
Beam Diameter at $1/e^2$ (mm)	12 ±1.5
Full-Angle Beam Divergence (mrad)	<1.5

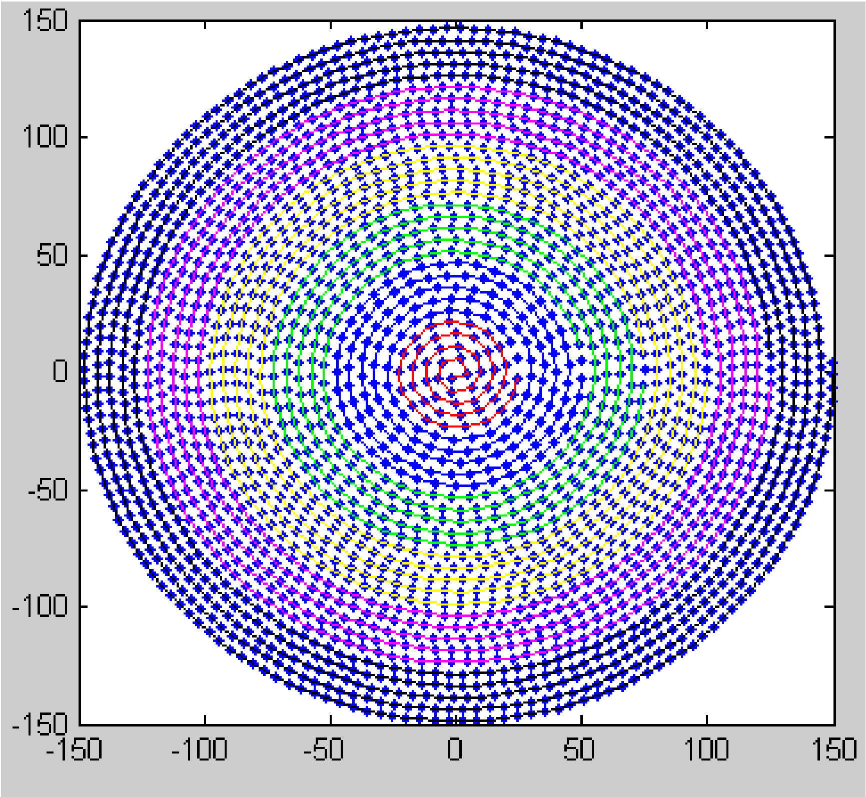
- Power intensity reduction: from ~2000 W/cm^2 at the laser head to <10 W/cm^2 at wafer plane.
- Multiple scanning beams are used for throughput improvement.

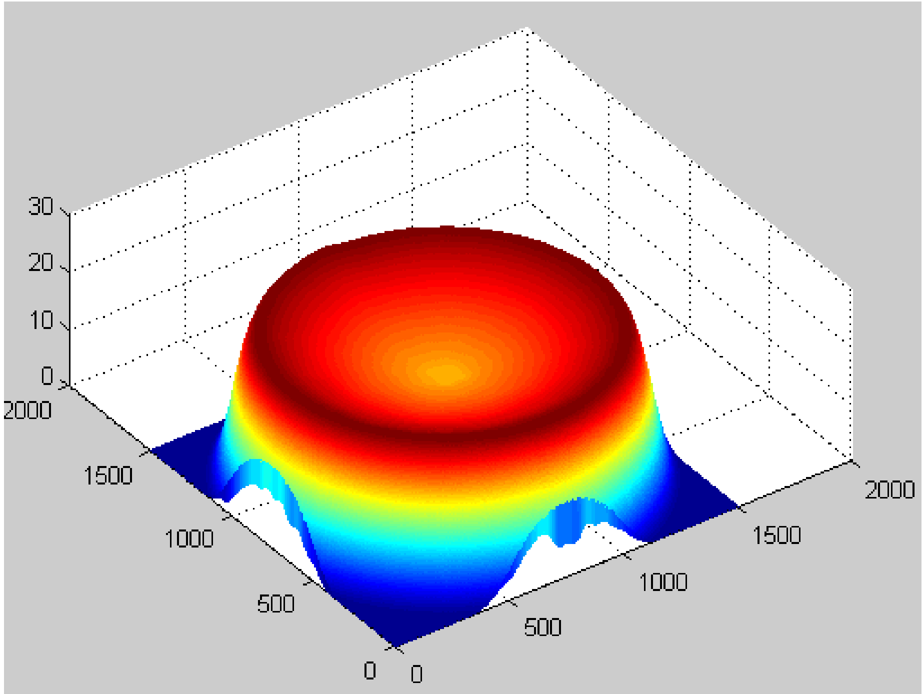


Beam At Wafer

E 1000i : - First pulsed fully sealed off CO_2 laser with 1,000 W average and > 2,5 kW peak power.

Multi-segment Stitching





To compensate for lateral heat dissipation, a center-low edge-high heating profile is generated by stitching 6 or more spiral segments.

Summary

- Lack of fundamental R&D in Semi industry will impact next generations device development
  - Academia and Top R&D Organizations will play a big role in keeping Moore's Law path on the right track
- High power lasers need in-depth evaluation before they can be adopted in CMOS applications
  - Coherent light can have significant advantages over other old technologies