Ultratech
WINNING SOLUTIONS

Laser Spike Annealing for sub-28nm Non-Junction Activation Applications

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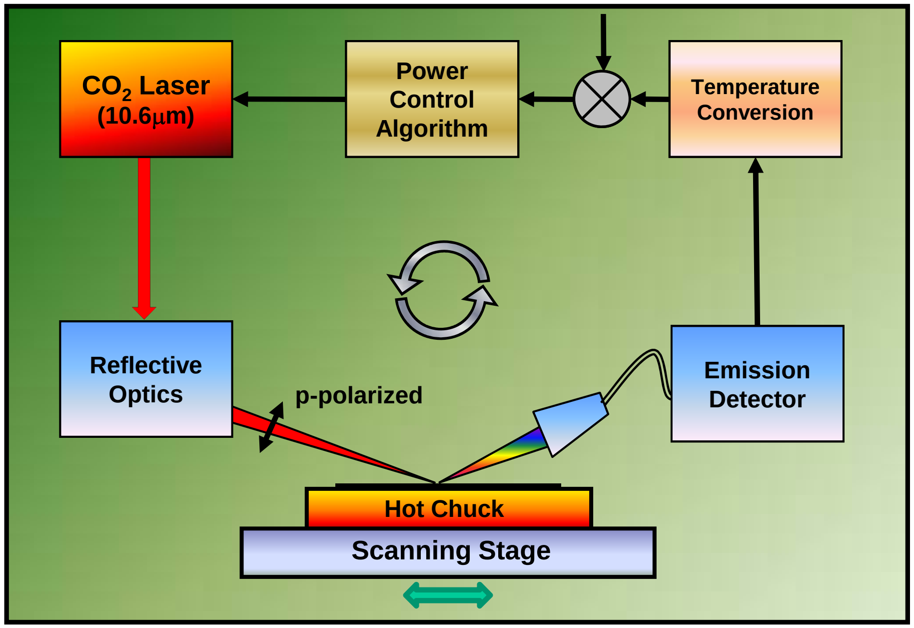
Outline

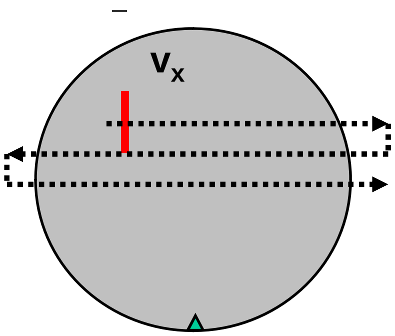
- Introduction
- Non-Ultrashallow Junction Applications
  - Front end of line
  - Middle of line
  - Back end of line
- Scaling to 450mm

Introduction

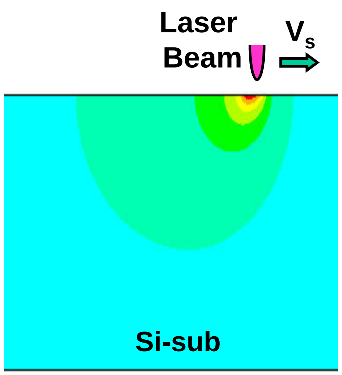
LSA101 Basic Platform (Single Beam)

LSA Block Diagram





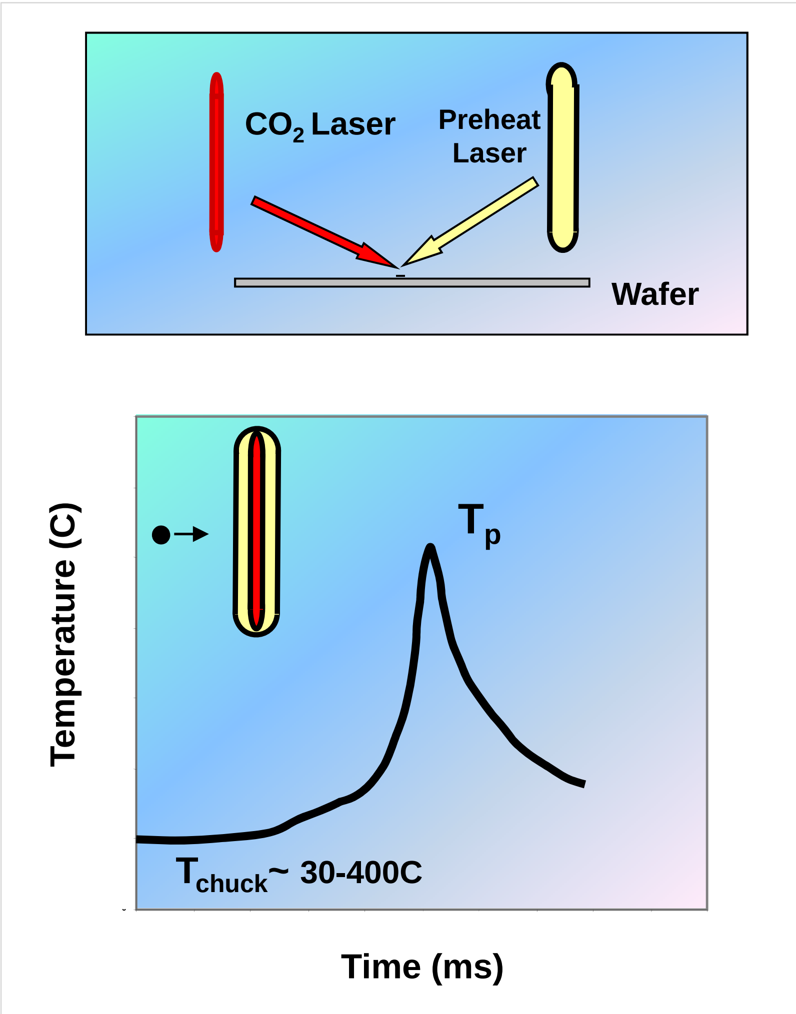
Top view of laser rastoring across wafer



2D thermal simulation

- Long wavelength, Brewster angle, p-polarized → Within-die Uniformity
- Full-wafer temperature feedback control → Die-to-die, WtW Repeatability
- Localized stress field → Low stress

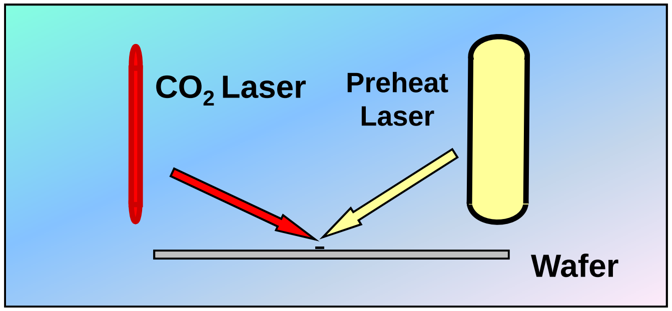
Dual-Beam LSA for Low Temperature Applications

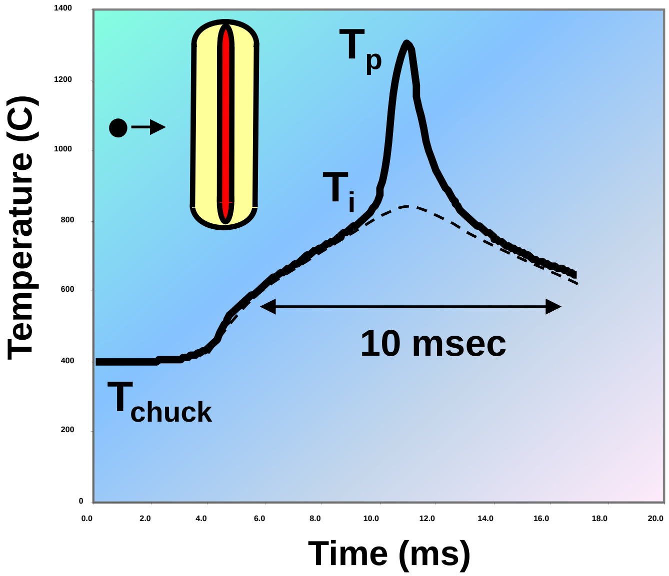


Key highlights

- Preheat laser beam used at low power to enable CO2 absorption at low chuck temperatures
- Temperature measurement and control system designed for lower temperature range
- Used for middle of line processes such as:
    - Nickel silicide formation
    - Silicide contact resistance reduction

Dual Beam LSA for Long Dwell Applications

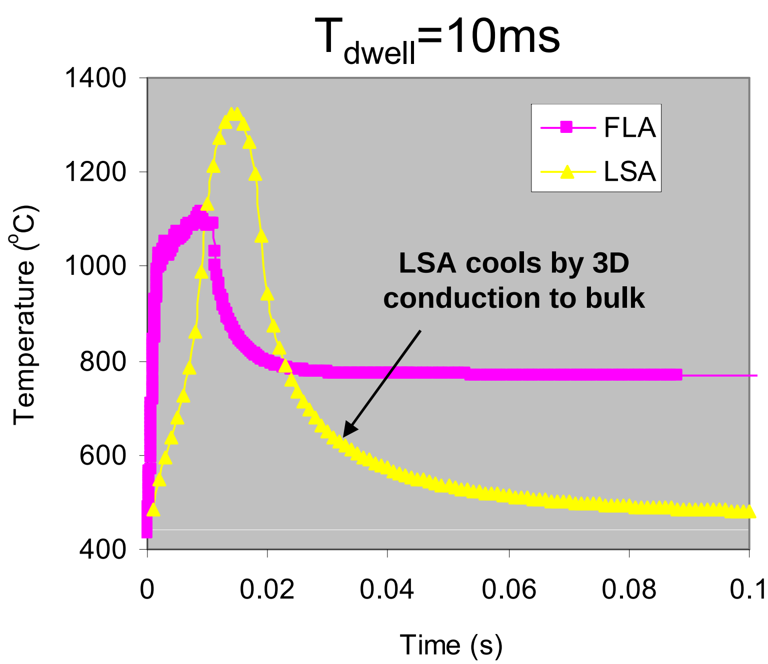


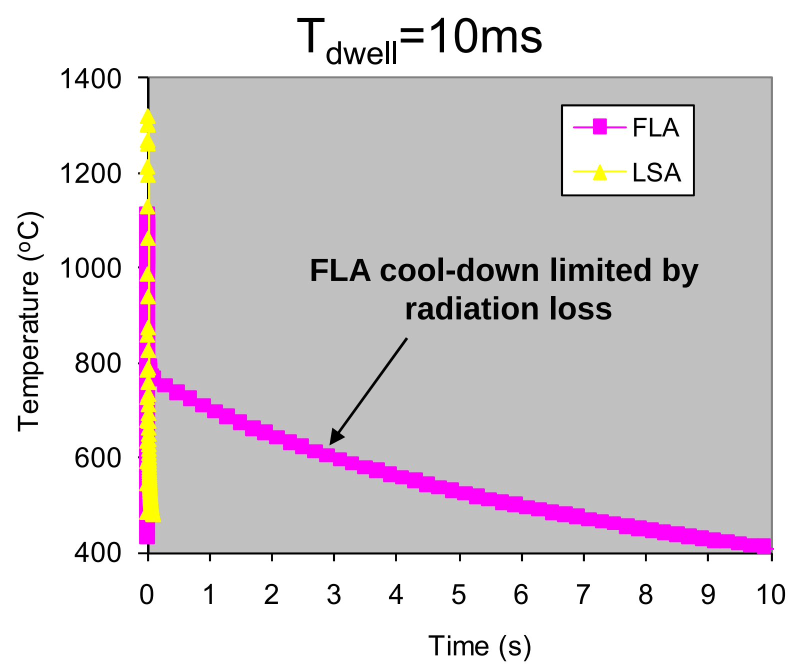


Key highlights

- Preheat laser beam enables a long dwell thermal profile (~10msec) to be superimposed on the CO_2 profile (100's μsec)
- Typically used for front end processes, e.g.,
  - Defect anneal
  - Solid phase epitaxy
  - Stress reduction

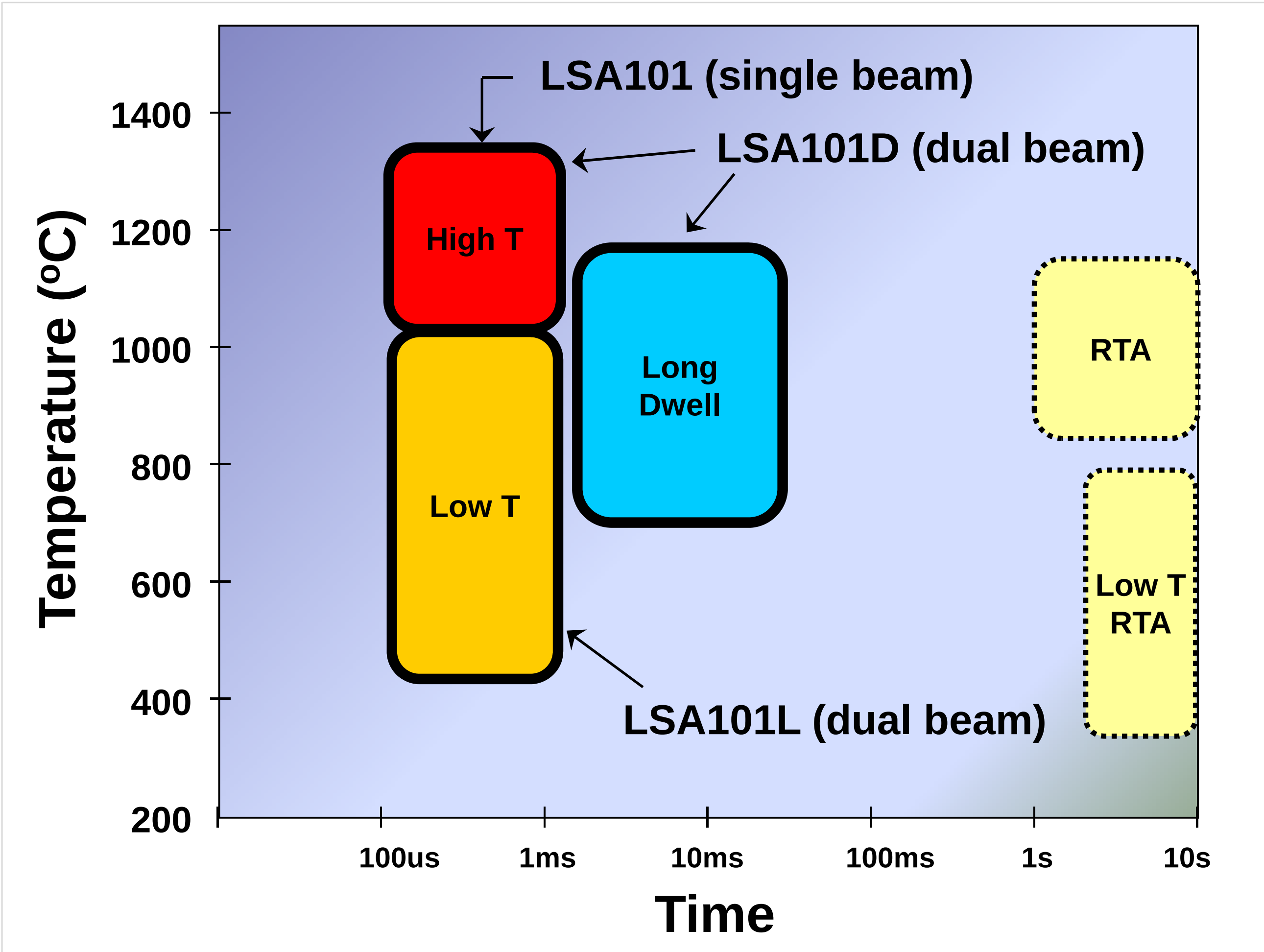
LSA vs FLA Long Dwell Cooling Comparison





- **LSA relaxes to chuck temperature within 100msec, cooling by 3D conduction to the bulk Si (localized heating)**
- **FLA cools slowly from 800C (5-10sec), limited by radiation loss due to global heating (1D cooling)**
- **For FLA, this allows time for possible de-activation and diffusion**

Laser Spike Annealing Process Space

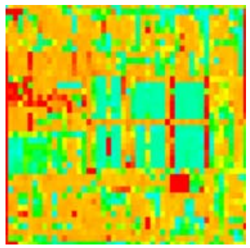


- **Dual-beam LSA enables a wide range of applications on a single platform**

Pattern Effects for Different Annealing Technologies

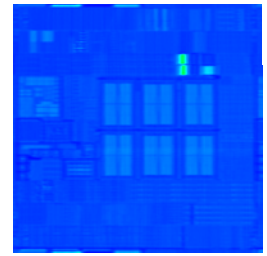
FLA & DL

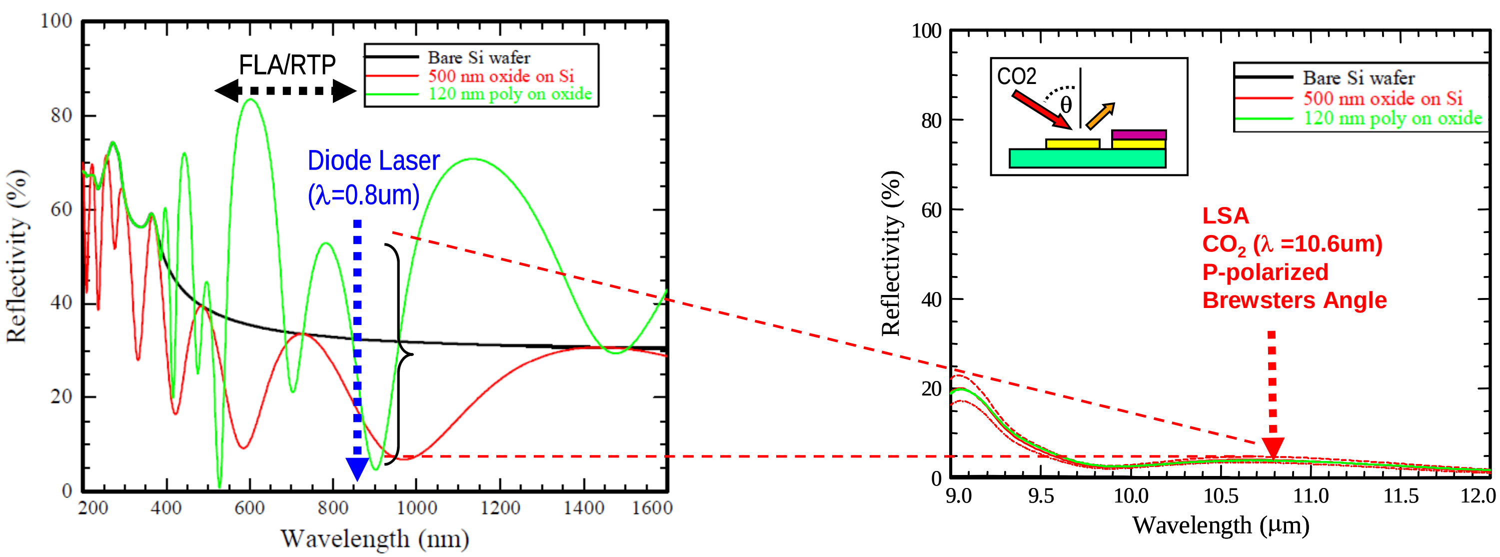
- Short λ
- Normal incidence



LSA

- Long λ
- Brewster angle
- p-polarization

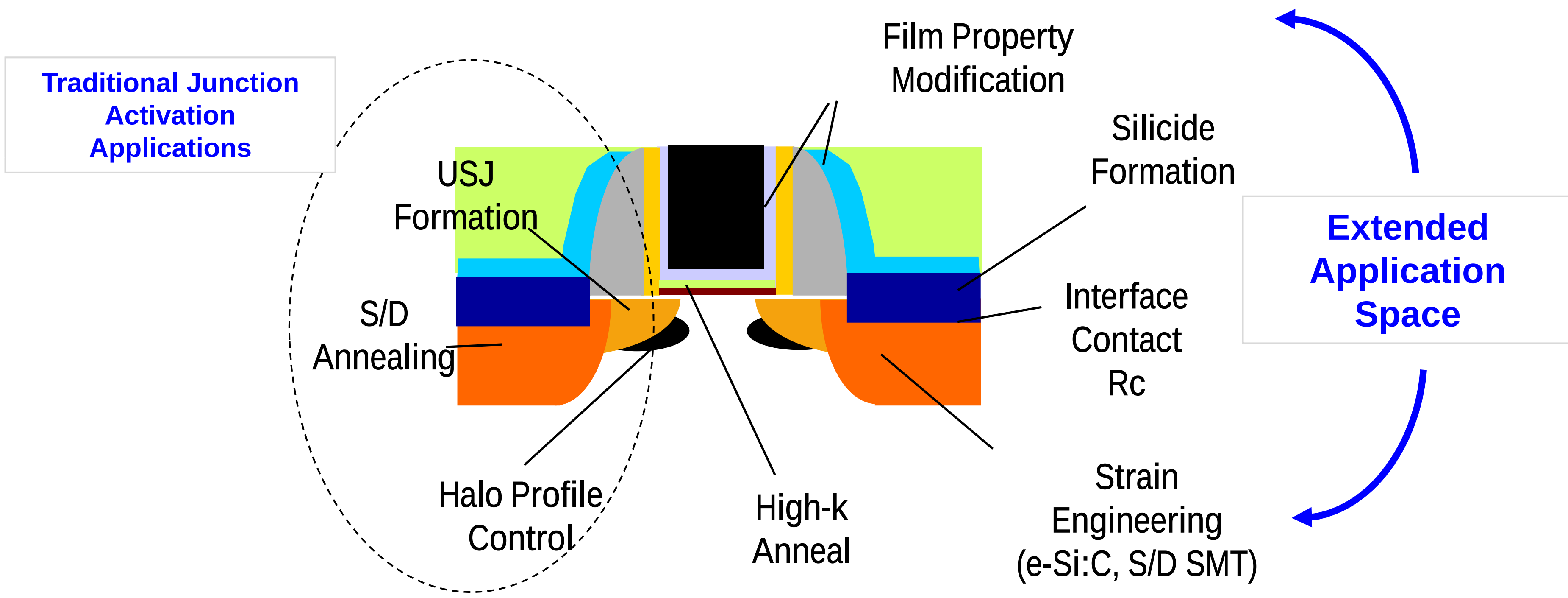




- Pattern effects caused by thin film interference variations → severe at short λ
- Long λ insensitive to device film variations

Non-USJ Applications

LSA Applications in Advanced Logic



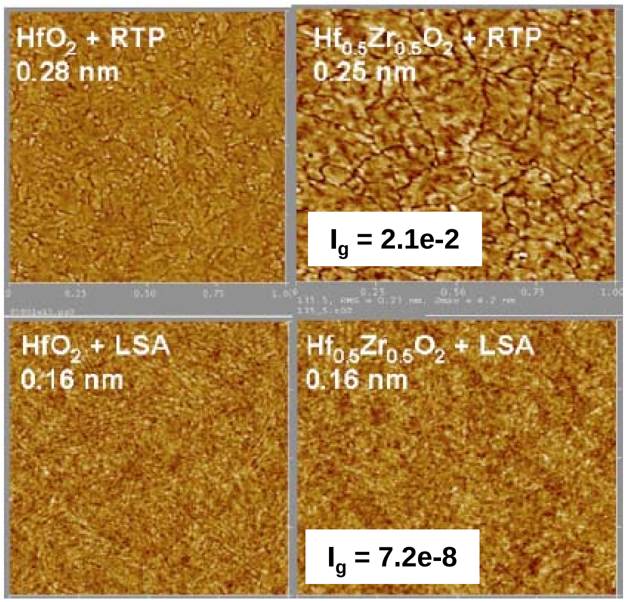
- **Expand to non-junction related applications: strain engineering, interface engineering, silicide formation, film property modifications.**

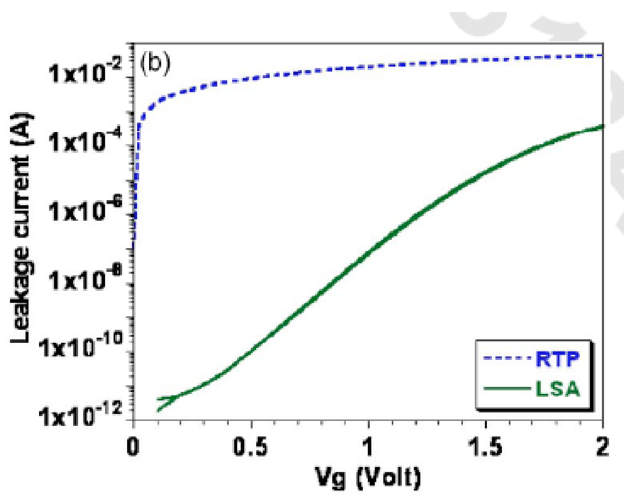
LSA For High-k Post-Depostion Anneal

HfO_2 $Hf_{0.5}Zr_{0.5}O_2$

RTP

LSA



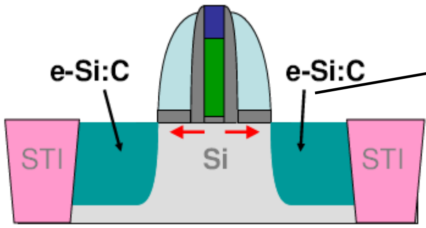


<u>Advantages of LSA for HK Anneal</u>

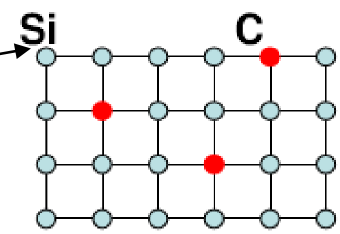
- **Lower gate leakage**
- **Smoother, void free film**
- **Higher k value due to more favorable phase mixing**
- **Can lead to lower EOT due to thinner interfacial layer (lower thermal budget)**

*Sources: Triyoso et al., Appl. Phys. Letters (2008)
Gilmer et al., ESSDERC (2006)

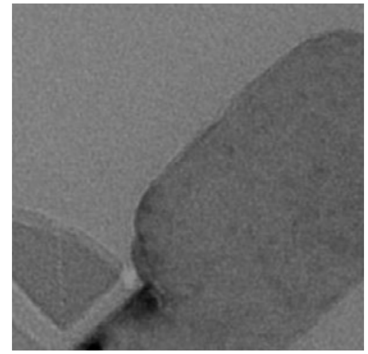
LSA For embedded SiC (NMOS Strain)



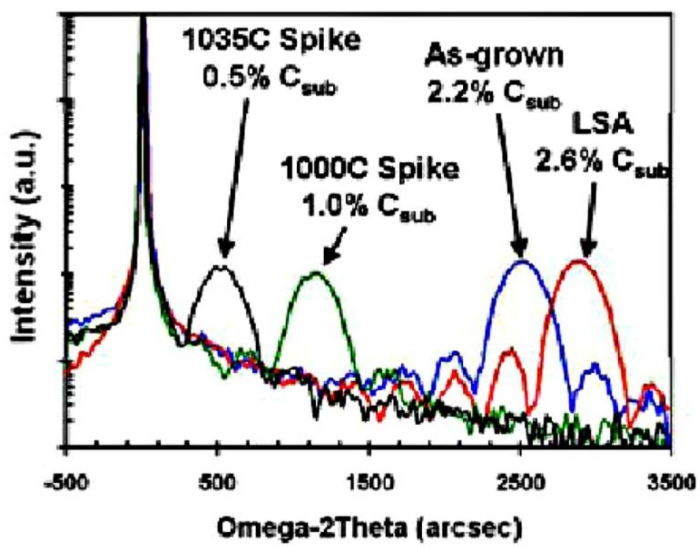
NMOS with e-SiC

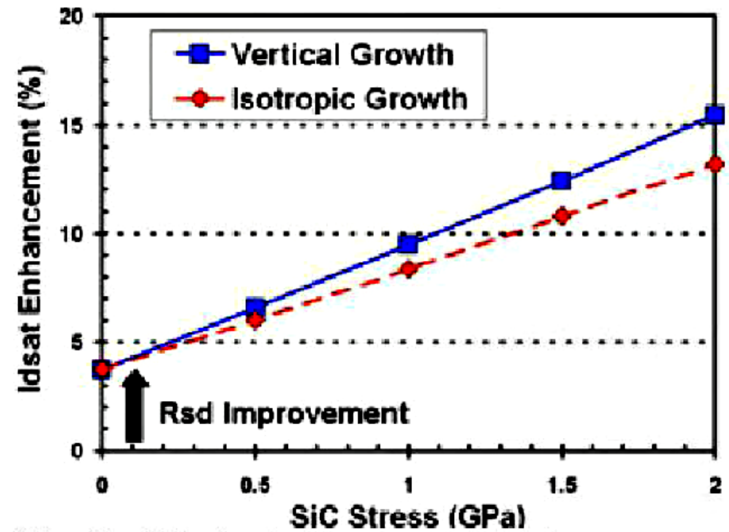


Want max. substitutional C



High Res TEM of defect-free SiC:P



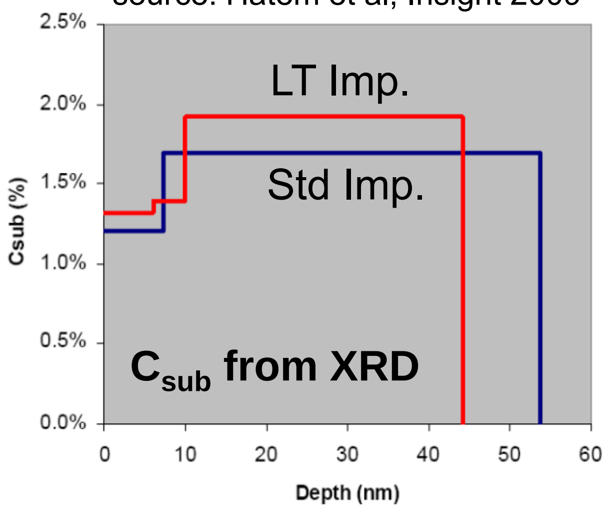


*Source: P. Grudowski et. al.,SOI'07

- **Embedded SiC can be formed by epi-SiC**
- **LSA enables conversion of C_{int} to C_{sub} → better device performance**

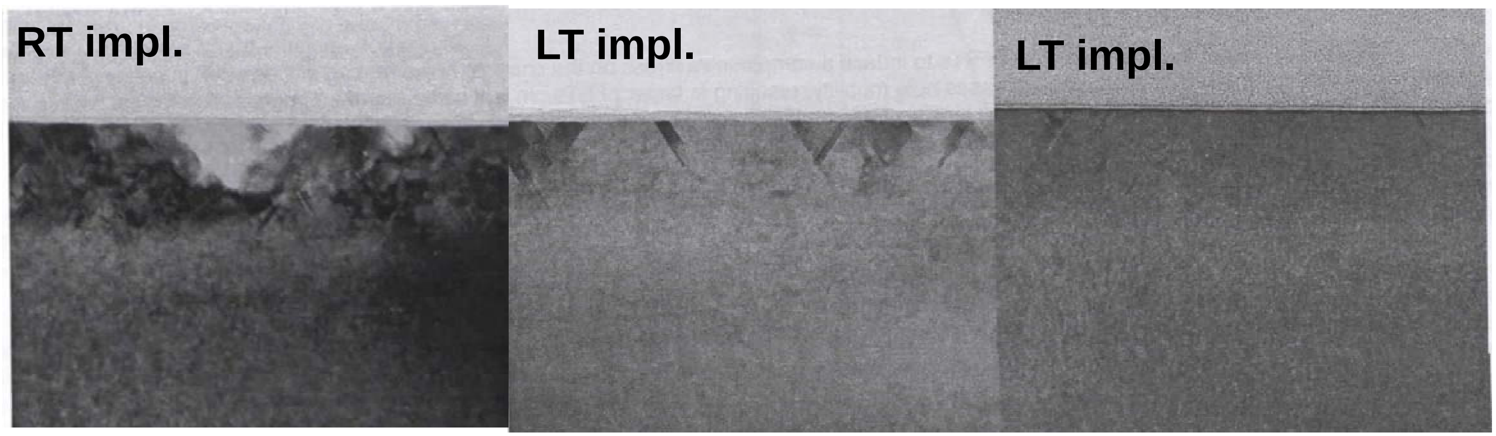
Embedded SiC Using Cryogenic Implant + LSA

*source: Hatem et al, Insight 2009



Almost 100% C subtitutionality using LT implant and optimized LSA

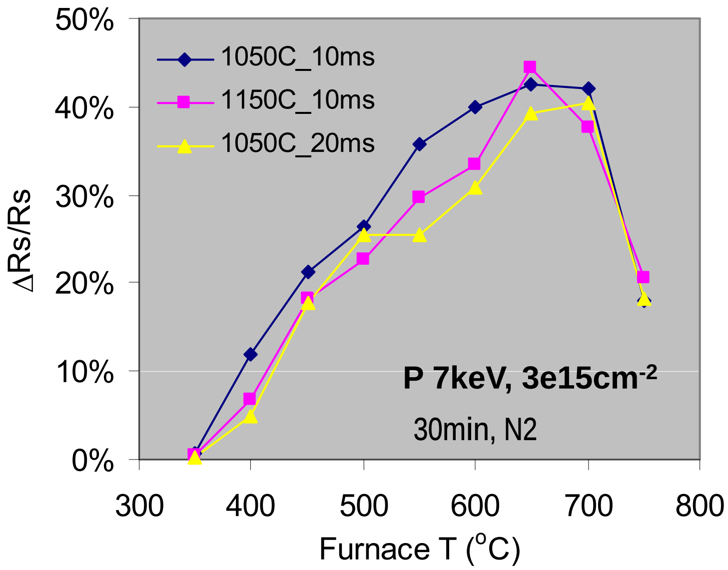
Implant conditions:
2% implanted C
C 4.6e15@11keV +
C 7.5e14@5.5keV +
P 3e15@7keV



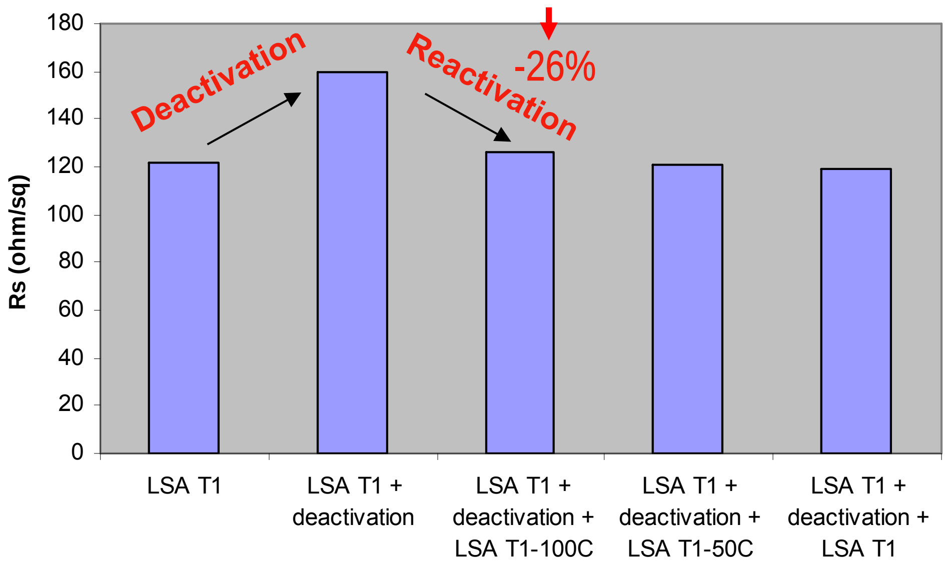
(a) Non-optimized **(b) Optimized implant** **(c) Optimized implant & LSA**

LSA for Dopant Re-activation: Phosphorous

P de-activation

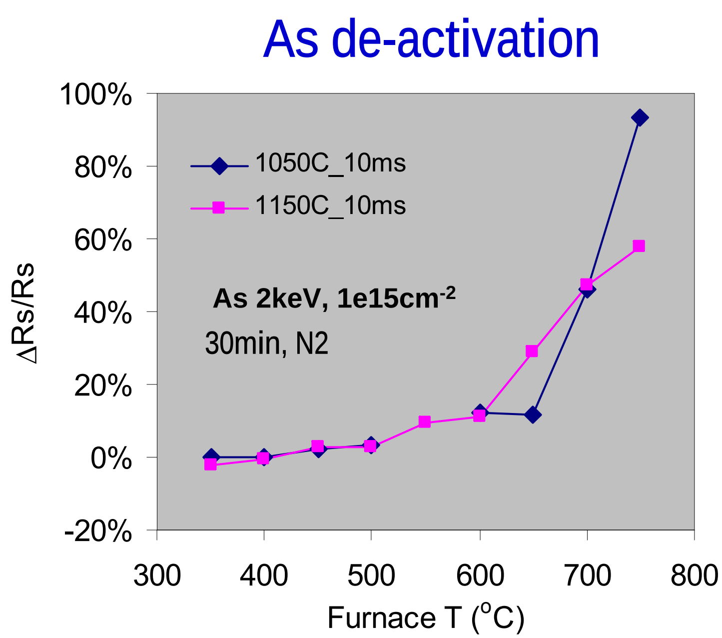


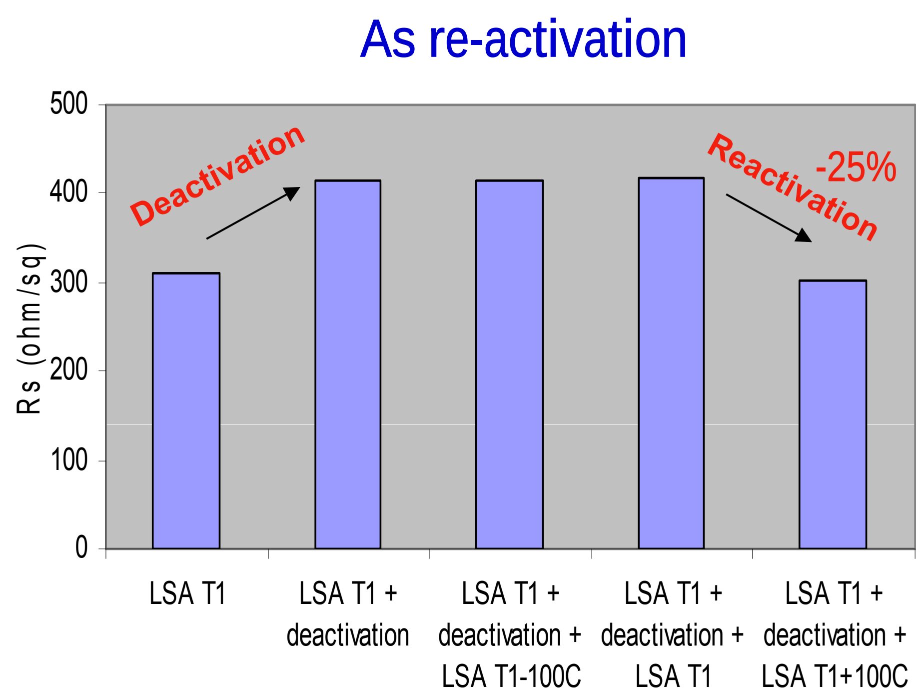
P re-activation



- **P deactivation occurs at very lower temperature**
- **However, deactivation can be fully recovered by a 2nd LSA anneal (even at lower T than 1st LSA)**

LSA for Dopant Re-activation: Arsenic



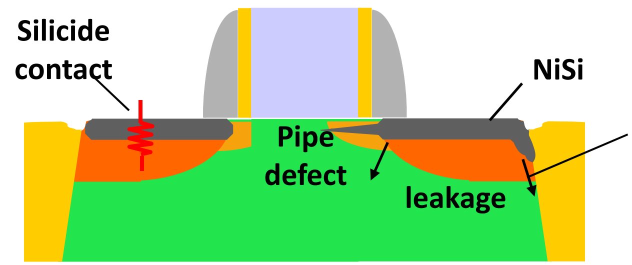


- **For As, deactivation is small < 600°C.**
- **Reactivation also requires higher annealing temperature**

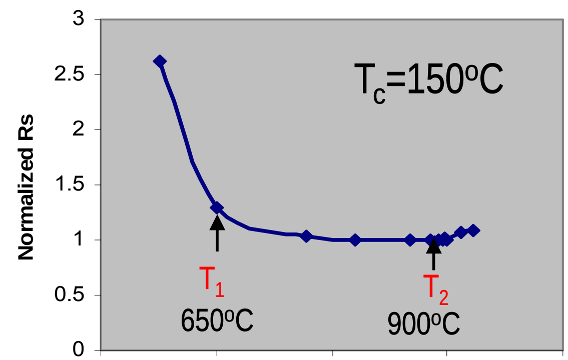
LSA For Ni Silicide Leakage Reduction

- USJ Formation
- Ni Dep
- RTP1 (Ni-rich silicide)
- Selective Etch
- RTP2 (NiSi formation)

Replace by DB-LSA



Leakage due to excess thermal budget from RTA

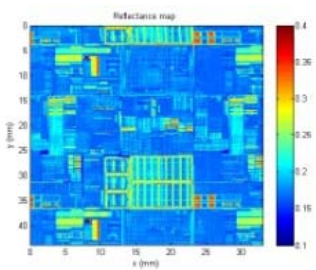


Transition curve "pushed" ~ 200C higher for LSA compared to RTP

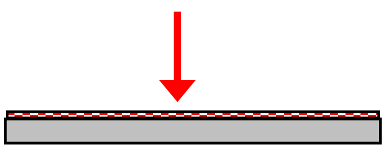
- Low thermal budget nature of LSA minimizes silicide diffusion & junction leakage.

Pattern Effects For Nickel Silicide Applications

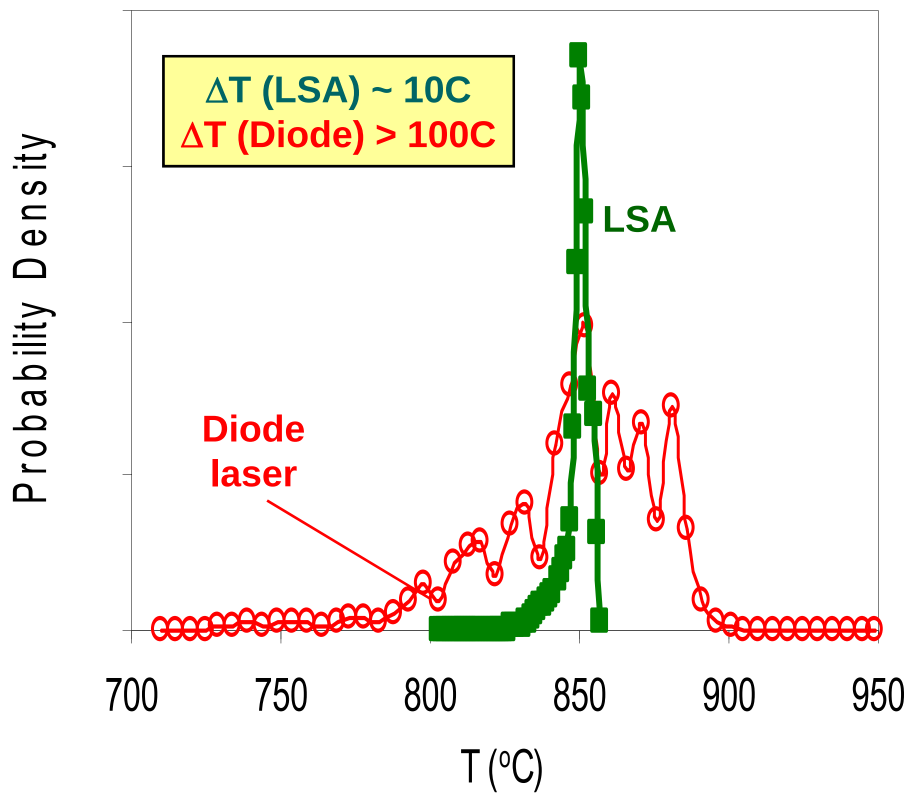
Measured reflectance: Diode Laser



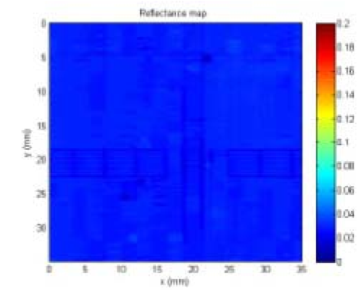
Short λ
Near normal



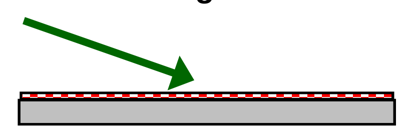
Within-die temperature distribution:
Simulated from measured reflectance maps



Measured reflectance: LSA

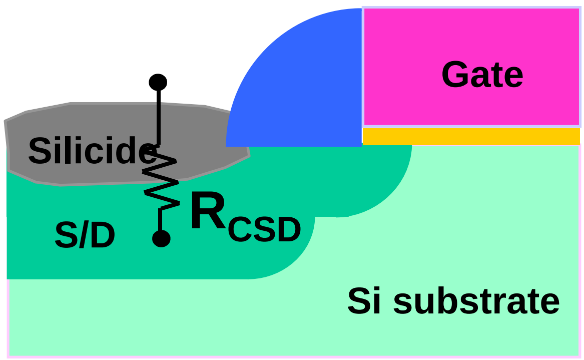


CO2 laser
Brewster angle



- **Severe pattern effects of diode laser can impact yield as process windows shrink**
- **Uniformity of LSA reduces risk of yield loss and allows higher process temperatures**

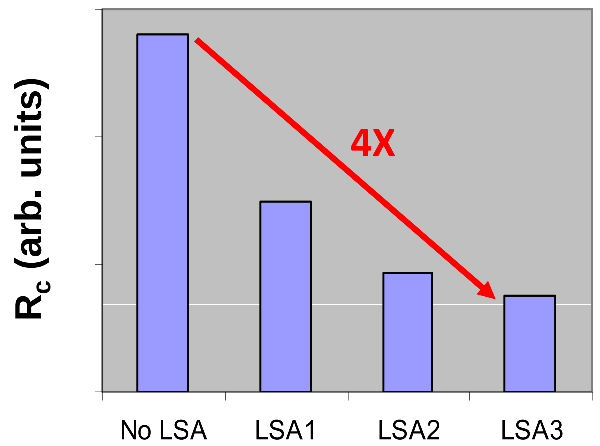
LSA for Silicide Contact Resistance Reduction



$$\rho_c \propto \exp\left[\frac{4\pi\sqrt{\varepsilon m^*}}{h}\frac{\phi_B}{\sqrt{N_D}}\right]$$

- Exponential Function of
  - Doping Density, N_D
  - Barrier Height, ϕ_B

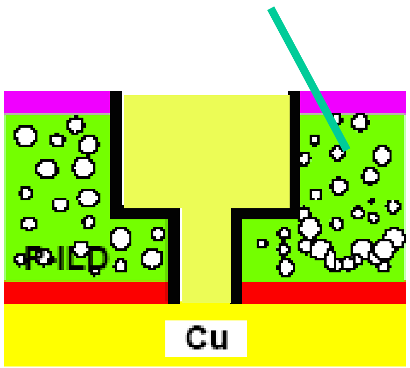
NiPt Contact Resistance Reduction by LSA (post silicide anneal)*



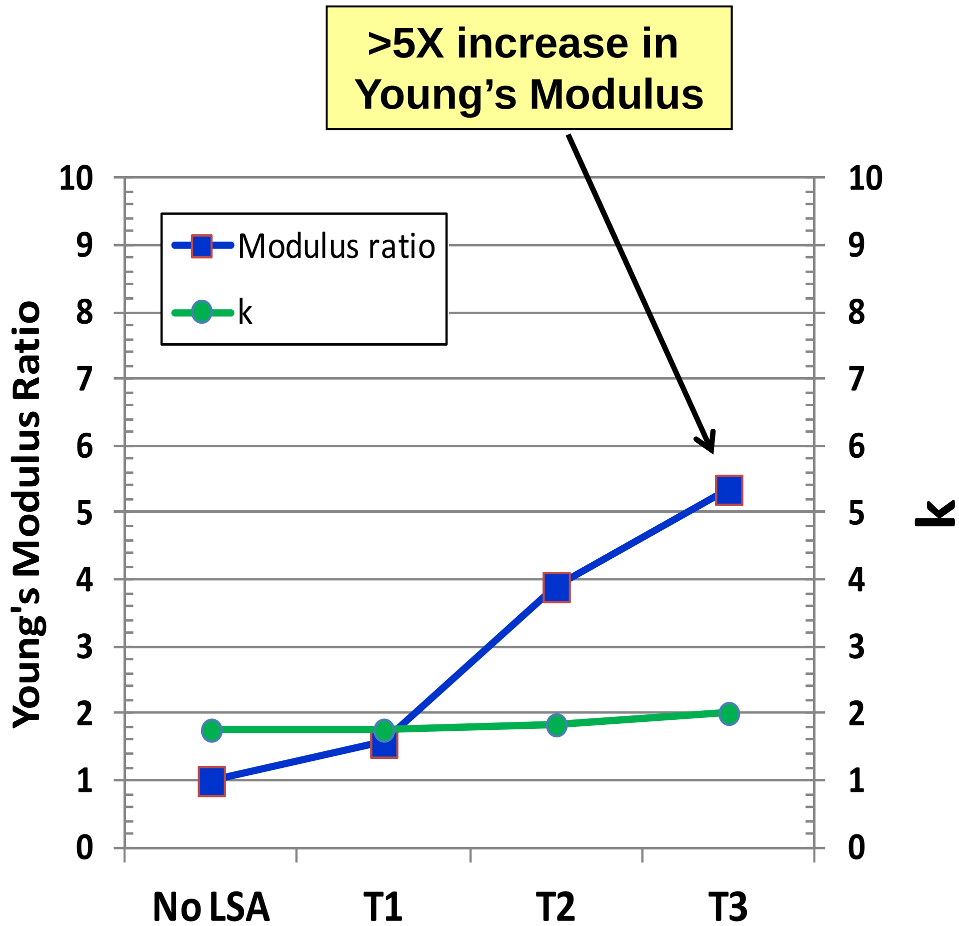
*** Unpublished data from IBM (2010)**

- **Silicide contact resistance becomes more significant as devices scale down**
- **LSA can reduce Rc by increasing active doping concentration and modulating barrier height.**

LSA For Low-k Curing



Low k film:
- Spin-on
- $Si_xO_yC_mH_n$
- 40% porosity

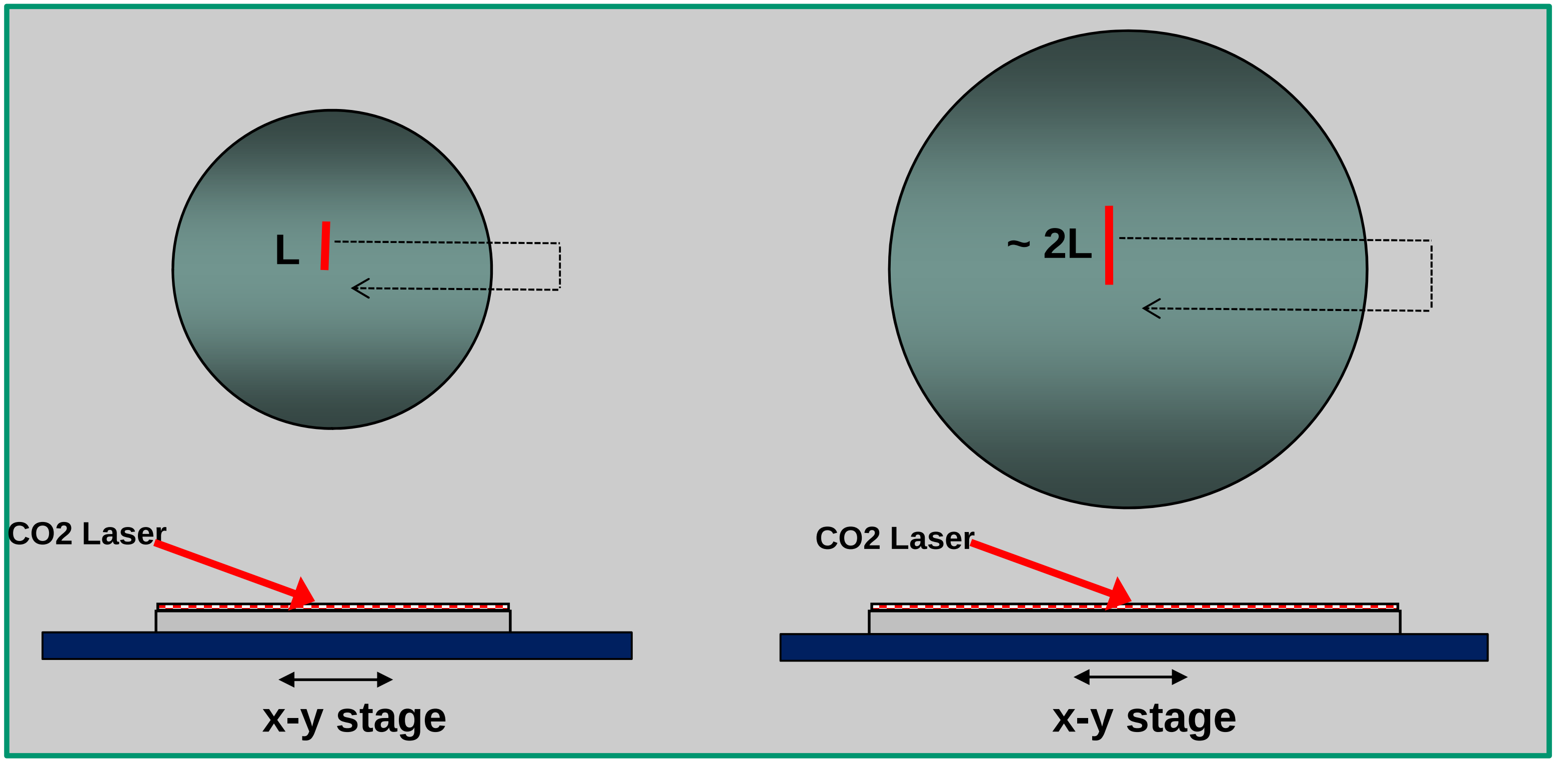


IBM, W. Volksen, et. al., IITC'06

- **LSA can significant enhance the mechanical strength of porous low-k films**

Scaling LSA to 450mm

Scaling LSA from 300mm to 450mm



- Scanning systems are inherently easier to scale to 450mm than "full wafer processing" systems
- Advantages: Within-die uniformity (low pattern effects), within wafer uniformity (full wafer temperature measurement and control), and low stress (localized heating)

Summary

- **As devices scale to sub-28nm, IC manufacturers are exploring and implementing LSA for more non-USJ steps (similar to history of RTP)**
- **We expect this trend to continue as devices move to 3D structures and new materials are introduced**
- **LSA (a scanning system) has fundamental advantages for scaling to 450mm, such as within-die uniformity, within-wafer uniformity, and low stress.**