CHE323/CHE384
Chemical Processes for Micro- and Nanofabrication
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Lecture 19
Rapid Thermal Processing

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Reading:
Chapter 6, *Fabrication Engineering at the Micro- and Nanoscale*, 4th edition, Campbell

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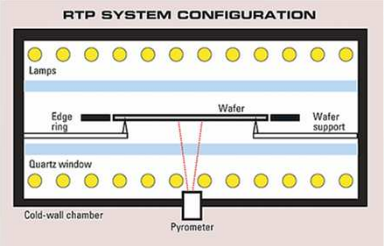
The Shallow Junction Challenge

- The need for shallow junctions (20 – 50 nm today) means that diffusion lengths must be:
  - Small
  - Well controlled
- Annealing at high temperatures is required for dopant activation and low defect density
- To achieve short diffusion length, we need:
  - Fast ramp to temperature
  - Well controlled Temperature(time)
  - Short bake time

Rapid Thermal Processing (RTP)

- A bank of lamps rapidly heats a single wafer suspended on low thermal-mass pins

Images from Mattson Technology



Rapid Thermal Processing (RTP)

- Radiative heating (optical energy)
  - Front-side and/or backside
- Temperature range of 150^{0}C - 1300^{0}C
- Ramp rates of 200^{0}C/s or more
- Sub-second anneals are possible
  - Wide range of time/temperature options used to choose between competing reactions with different activation energies
- Fast cooling also required
- Non-equilibrium processes!

Rapid Thermal Processing (RTP)

- Temperature uniformity is difficult to achieve
  - Radial heating lamps used, chamber reflects light
  - Edges radiate more heat out – use an edge ring
  - Wafer can be rotated (~200 rpm) to improve uniformity
  - Pattern Loading Effect – emissivity variation across die
  - About 3ºC across die variation possible, but hard to achieve
- Optical pyrometry used to measure wafer temp.
  - measures the intensity of light within a certain bandwidth emitted from a wafer
  - Emissivity variations of wafer make calibration difficult (absolute temperatures are almost never known)

Thermal Transfer Mechanisms

- Radiative: Stefan-Boltzmann equation

$$Heat\ Flow = \dot{q} = \varepsilon\sigma T^4$$

ε = emissivity of emitting body (ε = 1 for black body)
σ = Stefan-Boltzmann Constant = 5.6697 x 10^{-8} W/m^2-K^4

- Conduction: $\dot{q} = k\nabla T$
- Convection: $\dot{q} = h(T - T_\infty)$

Radiative Heating

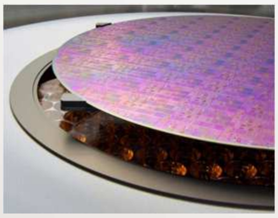
- At high temperatures, radiative power transfer dominates
- Absorption by the wafer

$$\varepsilon(\lambda) = 1 - R(\lambda) - T(\lambda)$$

absorption reflection transmission

$$\varepsilon_{Si} \approx 0.7, \qquad T_{Si} \approx 0$$

Heating Options



Backside Heating

Frontside Heating

Source: Applied Materials, Vantage RTP

Uses of RTP

- Rapid Thermal Annealing (RTA)
  - Shallow junctions
- Rapid Thermal Oxidation (RTO)
  - Dry O_2 for thin oxides
- Rapid Thermal Nitridation (RTN)
- Silicide/Salicide (self-aligned silicide)
  - $TiSi_2$, NiSi, $CoSi_2$, etc.
- High-k gate dielectric densification

RTA Process Matrix

	Pros	Cons
"soak" RTP Ramp < 100°C/s Time > 5 s	• Reasonable thermal control • Low stress • Simple Equipment	• Larger thermal budget (Dt)
"spike" RTP Ramp > 100°C/s Time < 2 s	• Reduced TED • Reduced thermal budget (Dt)	• Higher peak temperature hard to measure and control • More expensive

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Lecture 19: What have we learned?

- Why are shallow junctions needed today, and why are they hard to make?
- Describe the basic components of an RTP system
- How is heating accomplished in an RTP system?
- How is temperature measured in an RTP system?
- What is RTP used for?