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Laser Processing of 2-D and 3-D Structures for Tunable Embedded Capacitors

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Presentation given by: Rabindra Das, R&D Scientist

Outline

- Motivations
- Objectives
- Approach
- Systems studied
  - Vertical Multi-layer Capacitors
  - Capacitor library
  - 3-D structures
- Results
- Summary

Future Demands

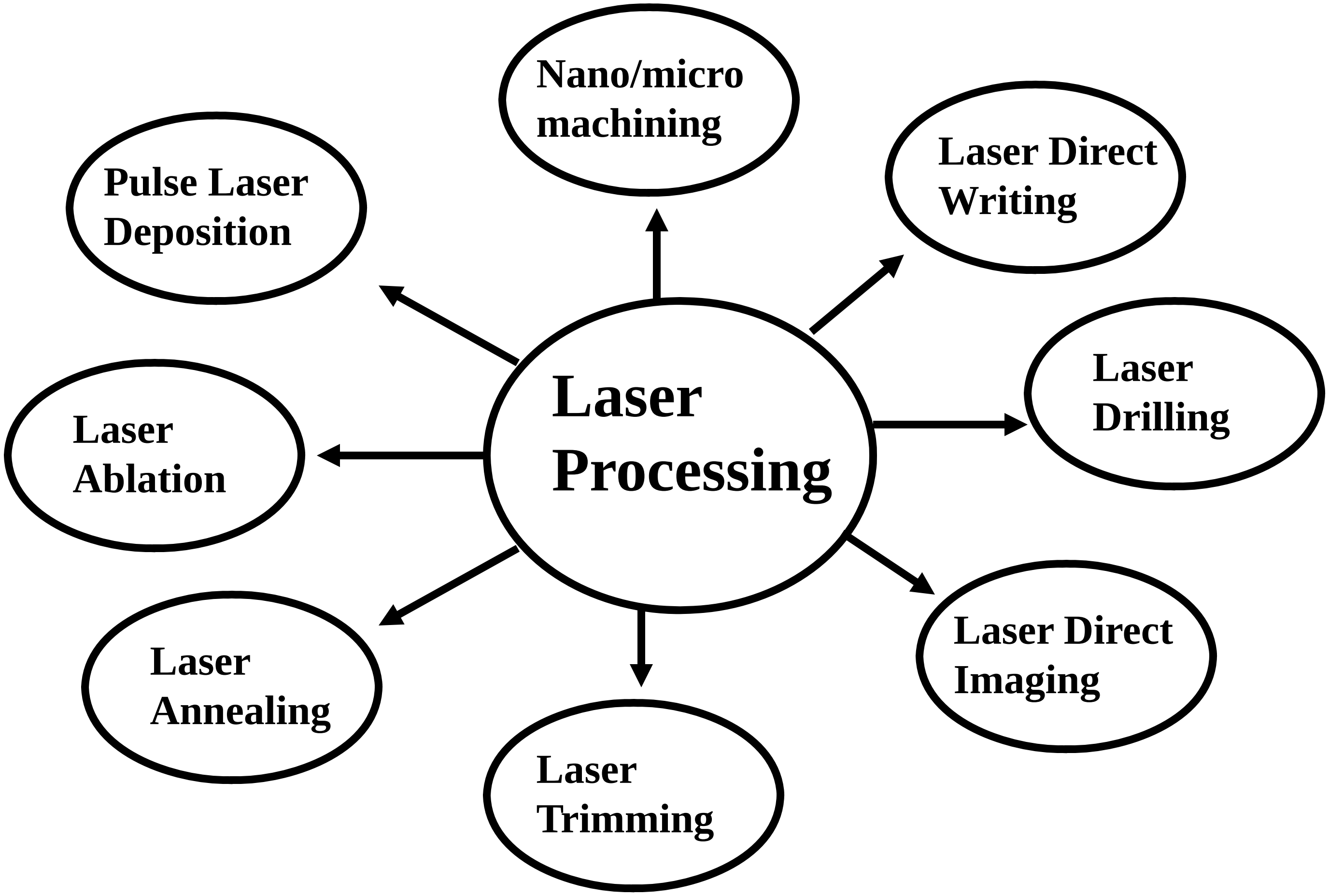
- Increased unit volume complexity
  - Size reduction
- Materials flexibility
  - Compatible with multiple packages/ materials set
- Process simplicity
- Multi-functionality
  - Materials with multiple properties

→ **Laser Processing**

Why Laser Annealing/Processing?

- **Ultra-high power density (up to 30 MW/cm^2 in just 30 ns)**
  - ❖ **High *volume* power density near surface**
  - ❖ **Minimal heating beneath absorptive films due to low total energy deposition**
  - ❖ **Extremely high cooling rate (>10^9 °C/s)**
  - ❖ **Sharp temperature gradients**
- ❖ **Temperature gradients and quench rates tunable by choice of wavelength and pulse duration**

Possible Laser Processing



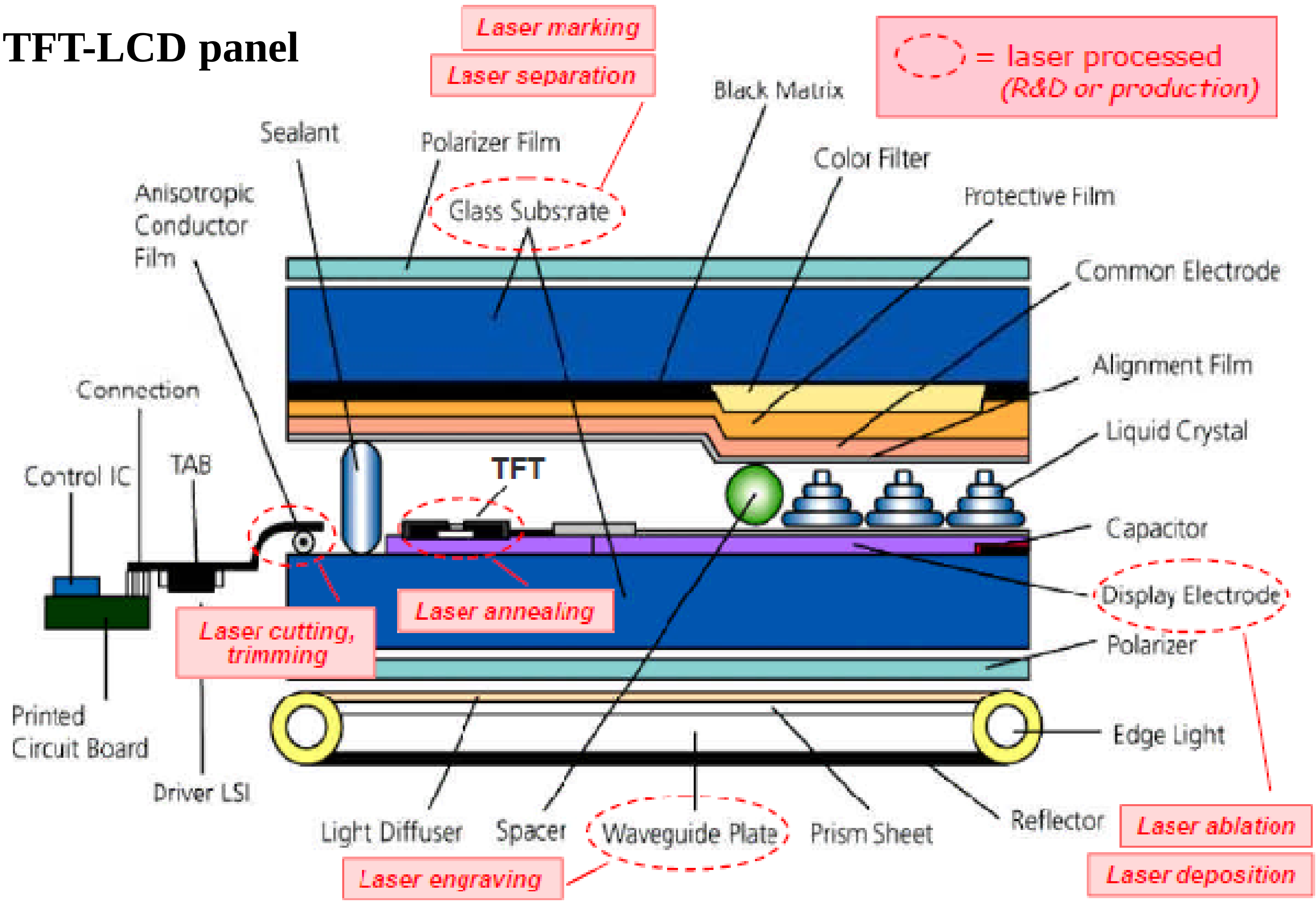
Computer Controlled & Spot-by-Spot

Example : Laser Micromachining

- 2D & 3D medical device
- Packaging
- Micro-fluidics
- PCB microvias
- Semiconductors industry
- Fuel injector hole micromachining
- Probe card micro drilling
- Ink jet nozzle micro drilling
- Wire stripping

Laser Material Processing in Microelectronics…

TFT-LCD panel



Source : Corey Dunsky, Coherent, Inc.

Objectives

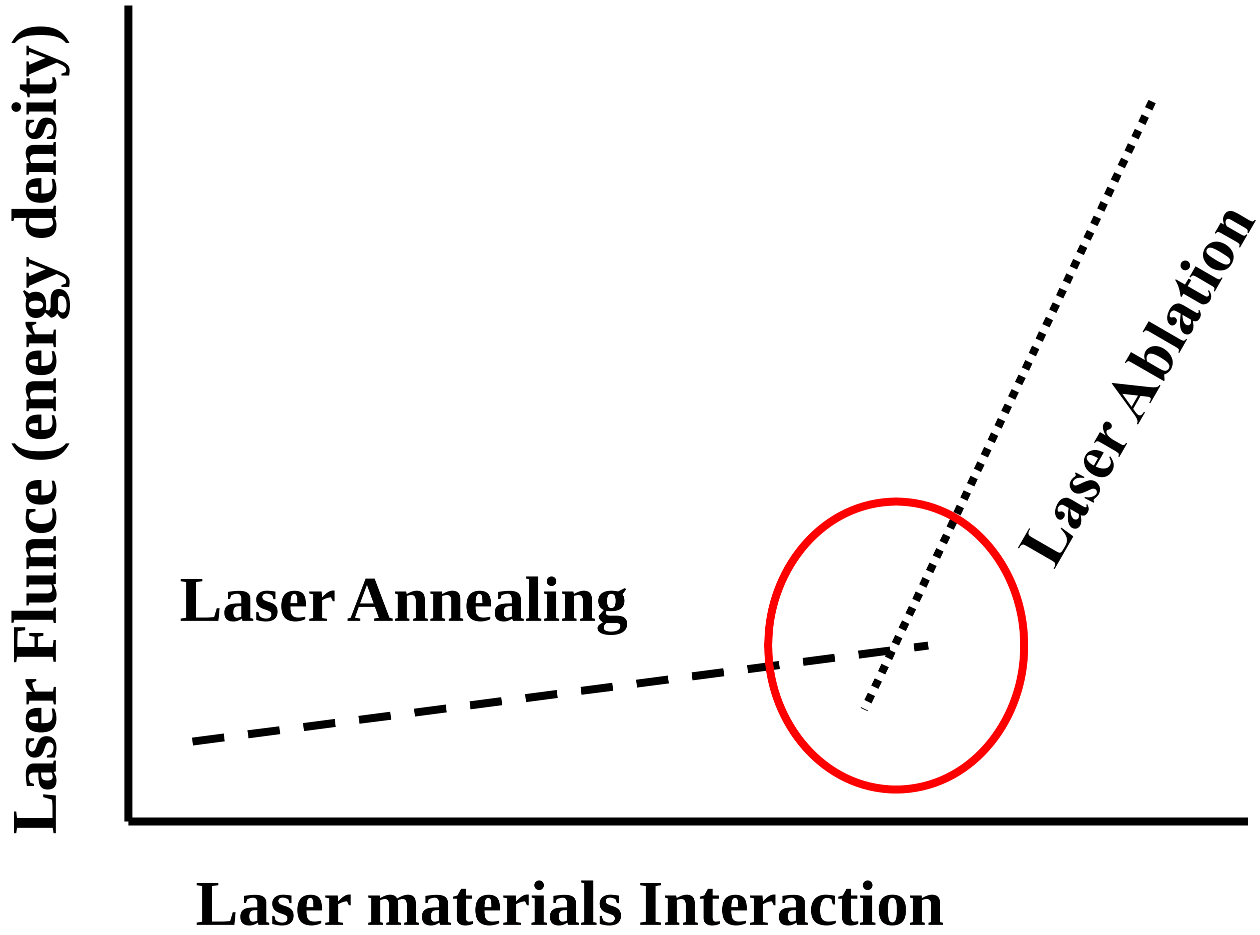
- **Develop laser processing of material that provides:**
  - **Tunable properties**
  - **New composition**
  - **New structure**

Substrate-Laser Interaction

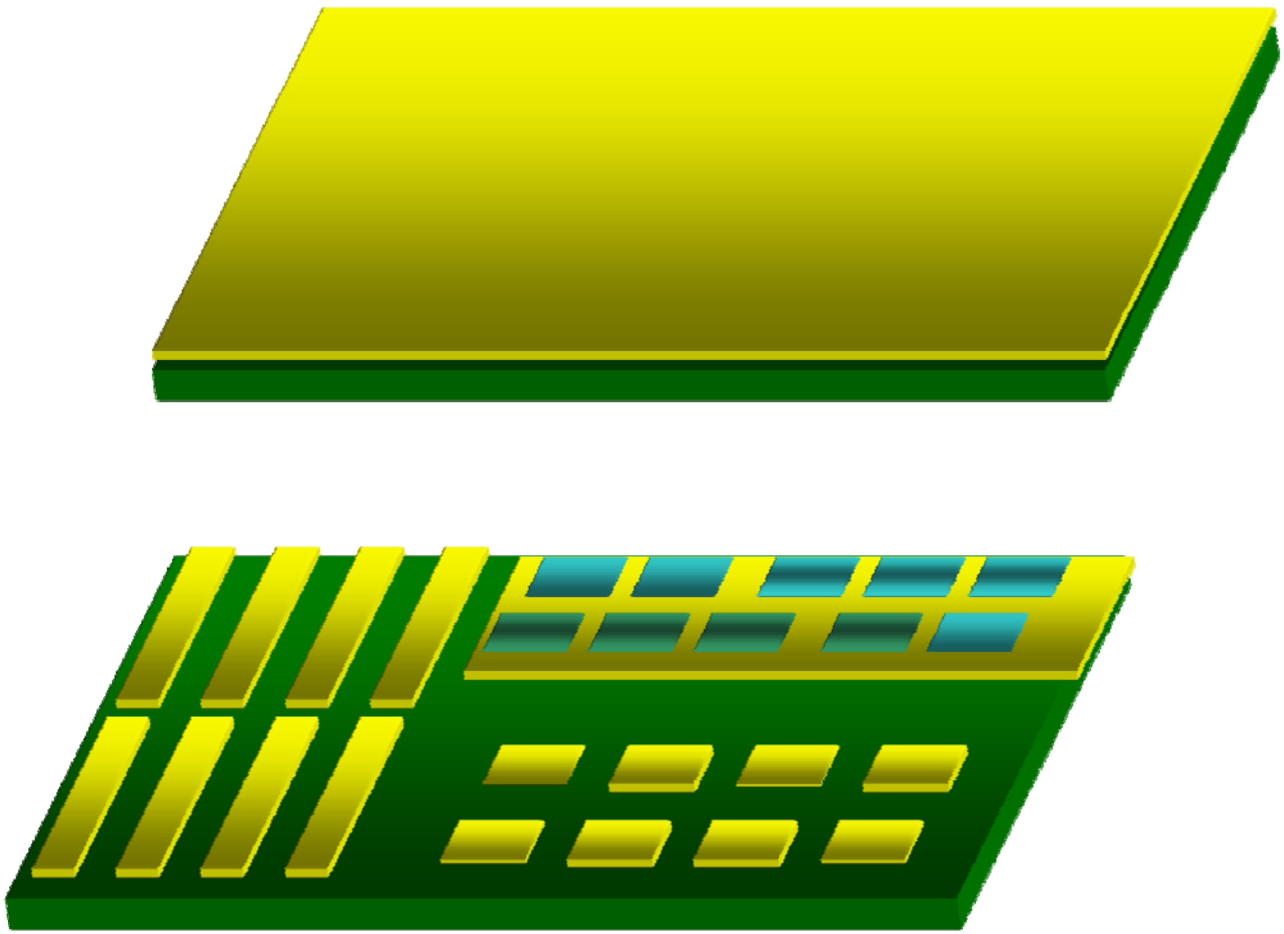
- Laser materials/medium/types
- Wavelength (1st, 2nd, 3rd harmonic)
- Fluences (energy density)
- Number of pulses and pulse duration

Laser Processing : annealing, melting, ablation, micromachining, writing and imaging

Focus


Laser Flunce (energy density)
Laser Annealing
Laser Ablation
Laser materials Interaction

Schematic illustration of 2D & 3D Laser Processing



Tunable Capacitors

$$C = \varepsilon \varepsilon_0 A / d$$

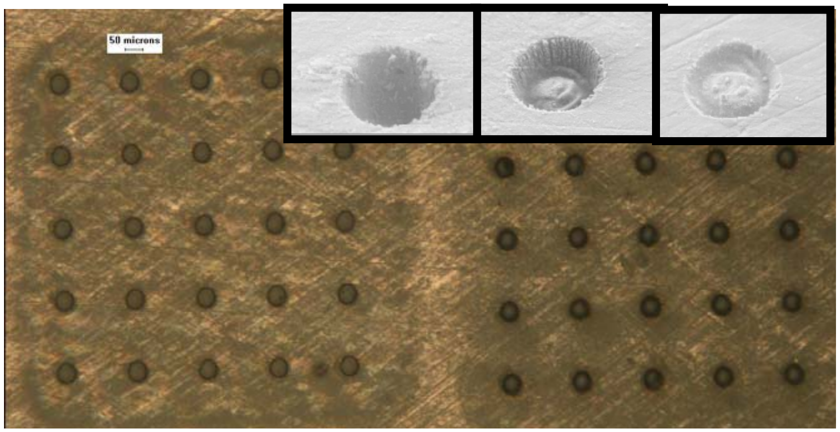
C = capacitance (farad)
A = area (m^2)
d = coating thickness (m)

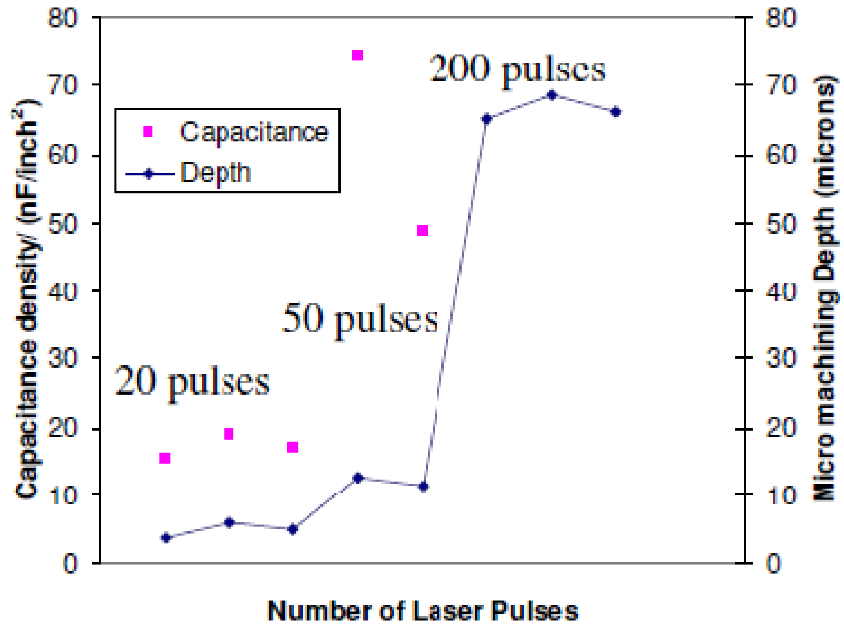
ε_0 = 8.854 x 10^{-12} F/m
ε = dielectric constant

- Change coating/dielectric thickness
- Change composition (dielectric constant)
- Combinatorial synthesis is an approach that enables the creation of large composition "libraries" of materials.

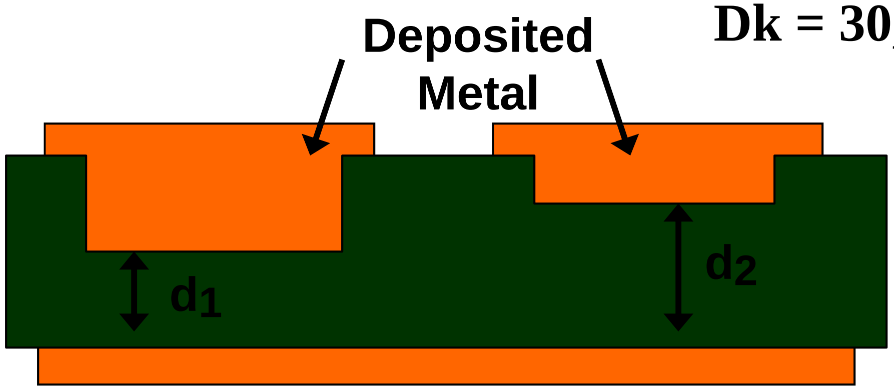
Variable Thickness Tunable capacitors

$$C = \varepsilon \varepsilon_0 A / d$$



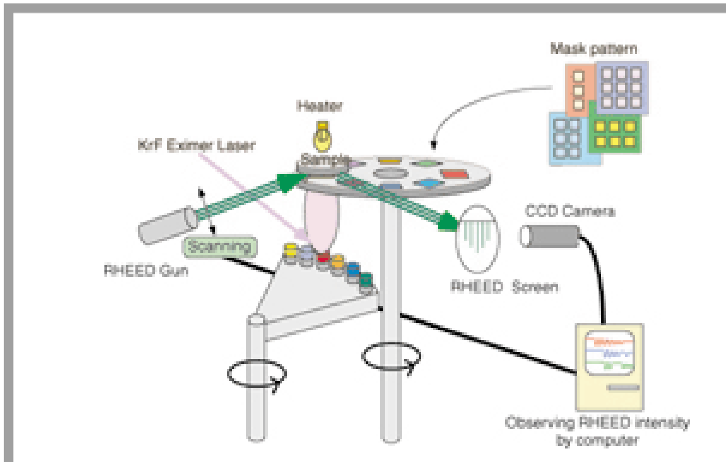


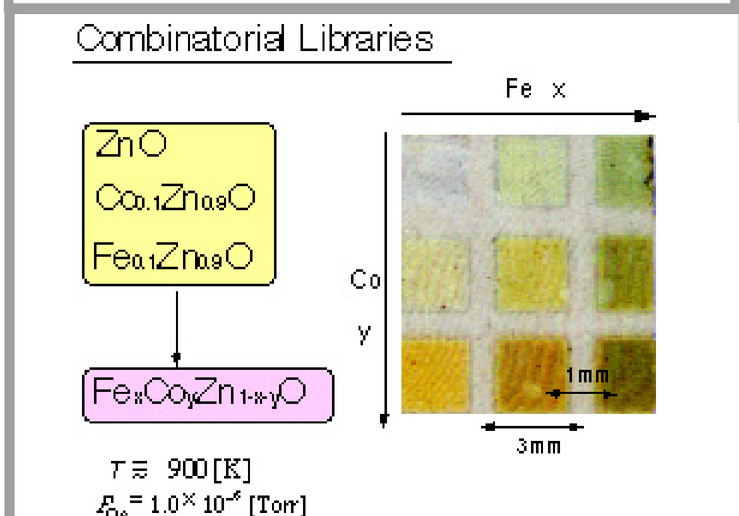
Dk = 30, 25 micron film

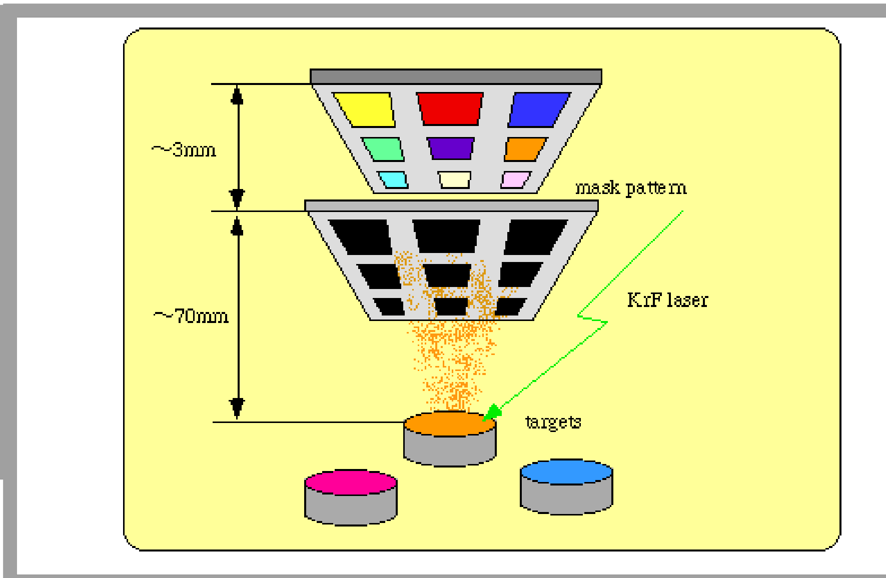


Combinatorial Synthesis through physical masking techniques : An Example

Koinuma Lab(Tokyo Institute of Technology)







- Available 6 targets
- Use mask to deposit at a specific spot
- Alternate target to change final composition

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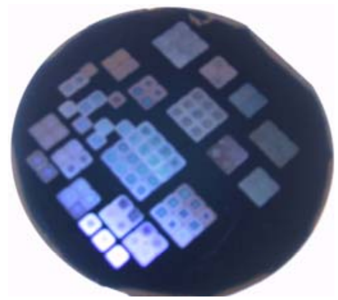
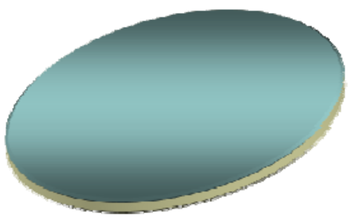
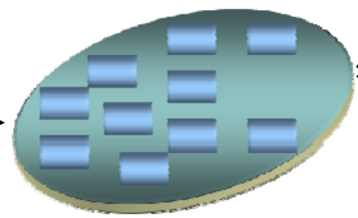
$Ba_xTi_yO_z$ thin film with variable capacitance





Variable
Laser Pulse

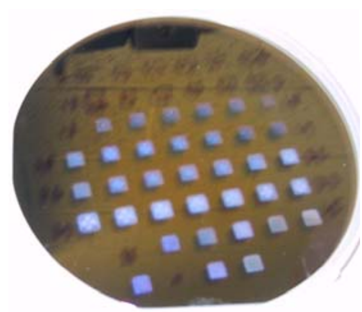


Crystallinity

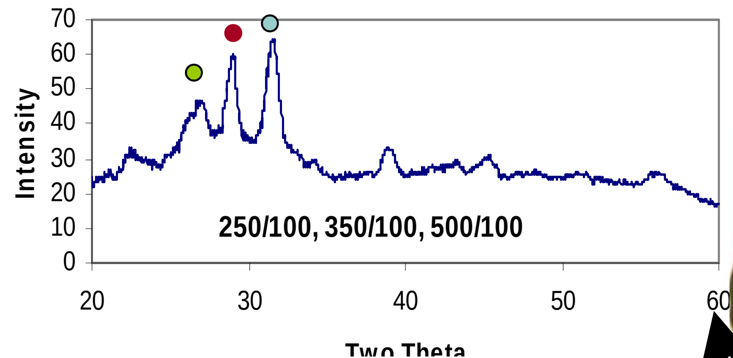
Phase Content

Morphology

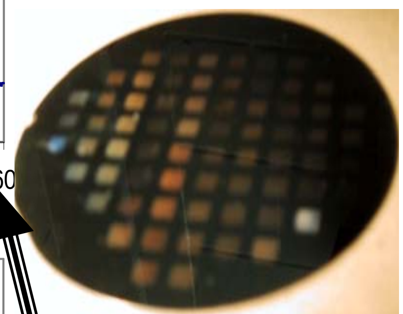
$BaTiO_3$ thin film deposited
on Si/plastic Substrate

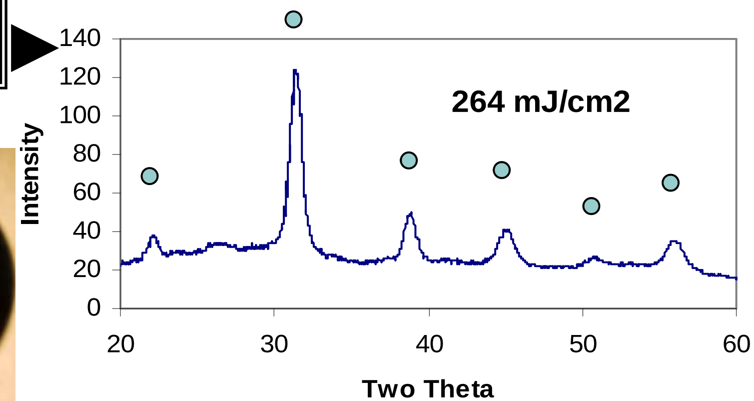


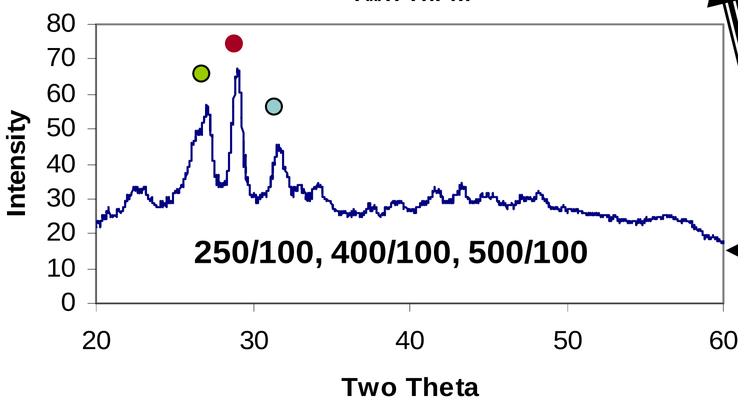
Crystallinity at different spots



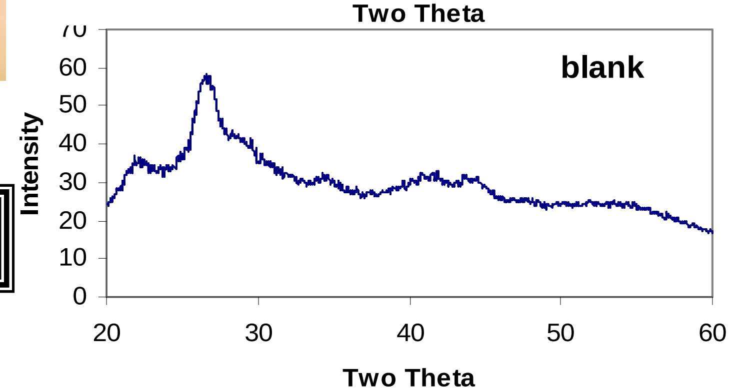
Pure $BaTiO_3$





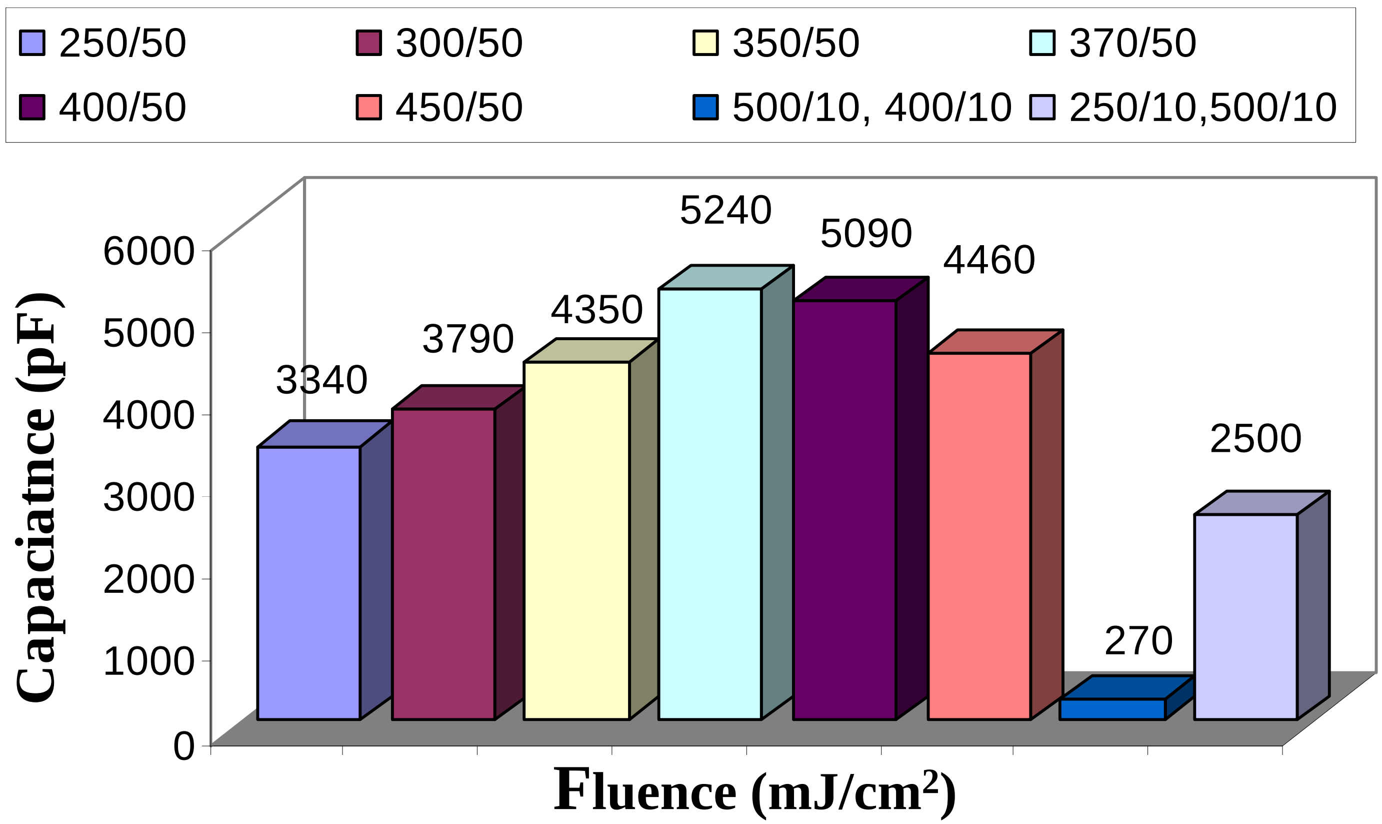


Mixed phase



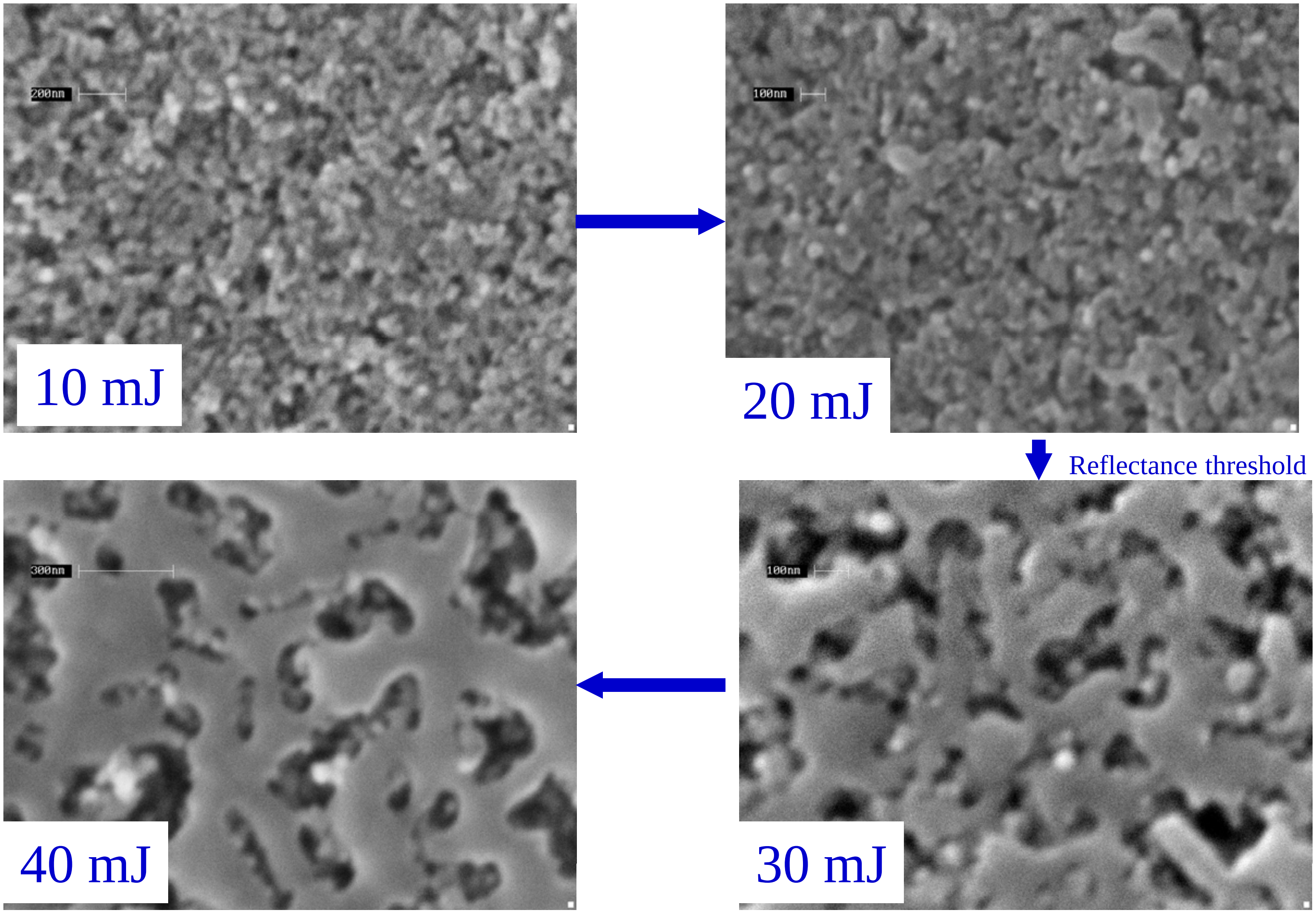
Pyrochlore(●), $Ba_2Ti_9O_{20}$ (●), $BaTiO_3$(●)

Capacitance profile

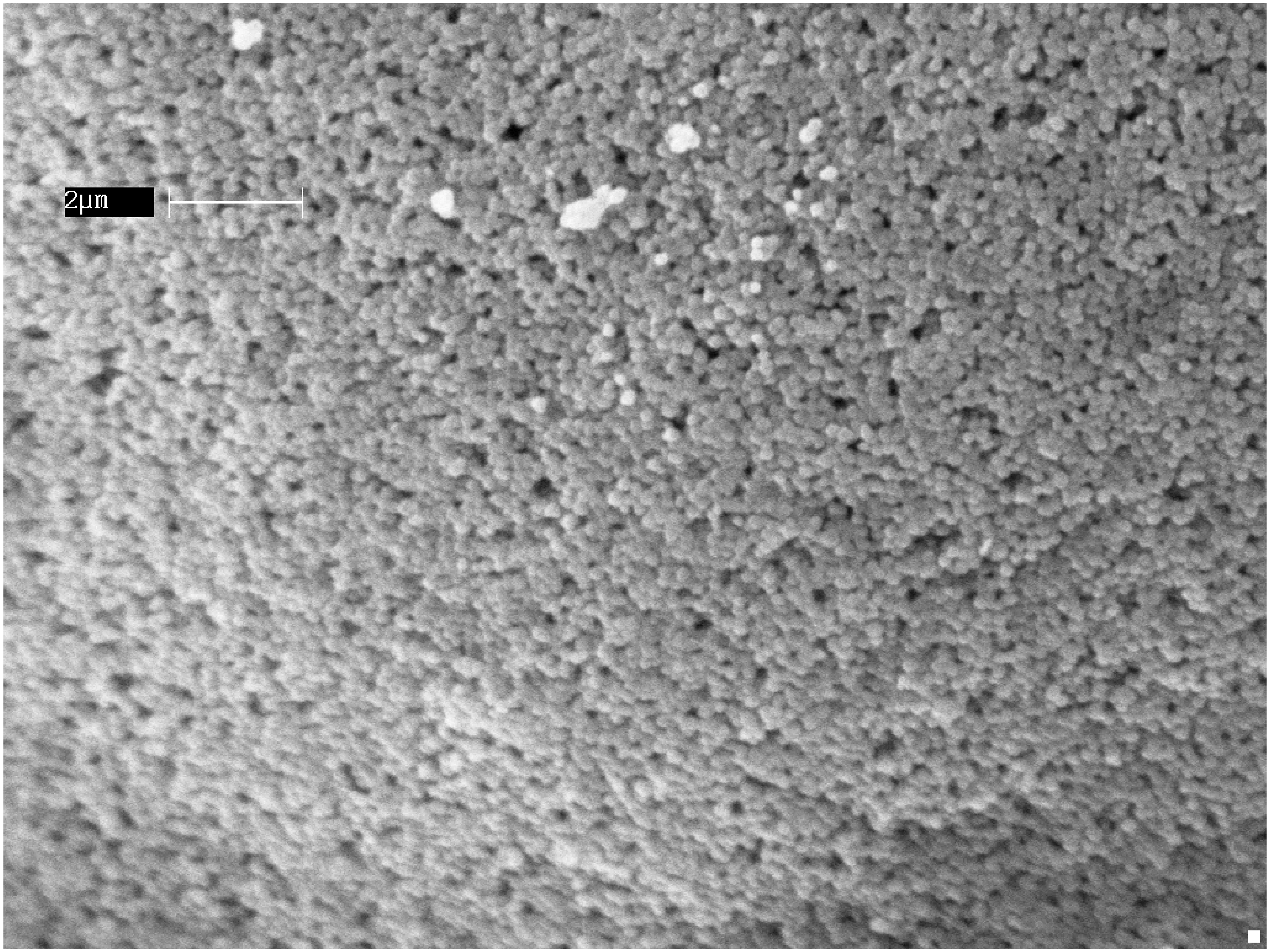


Room temperature Capacitance at 1 MHz frequency

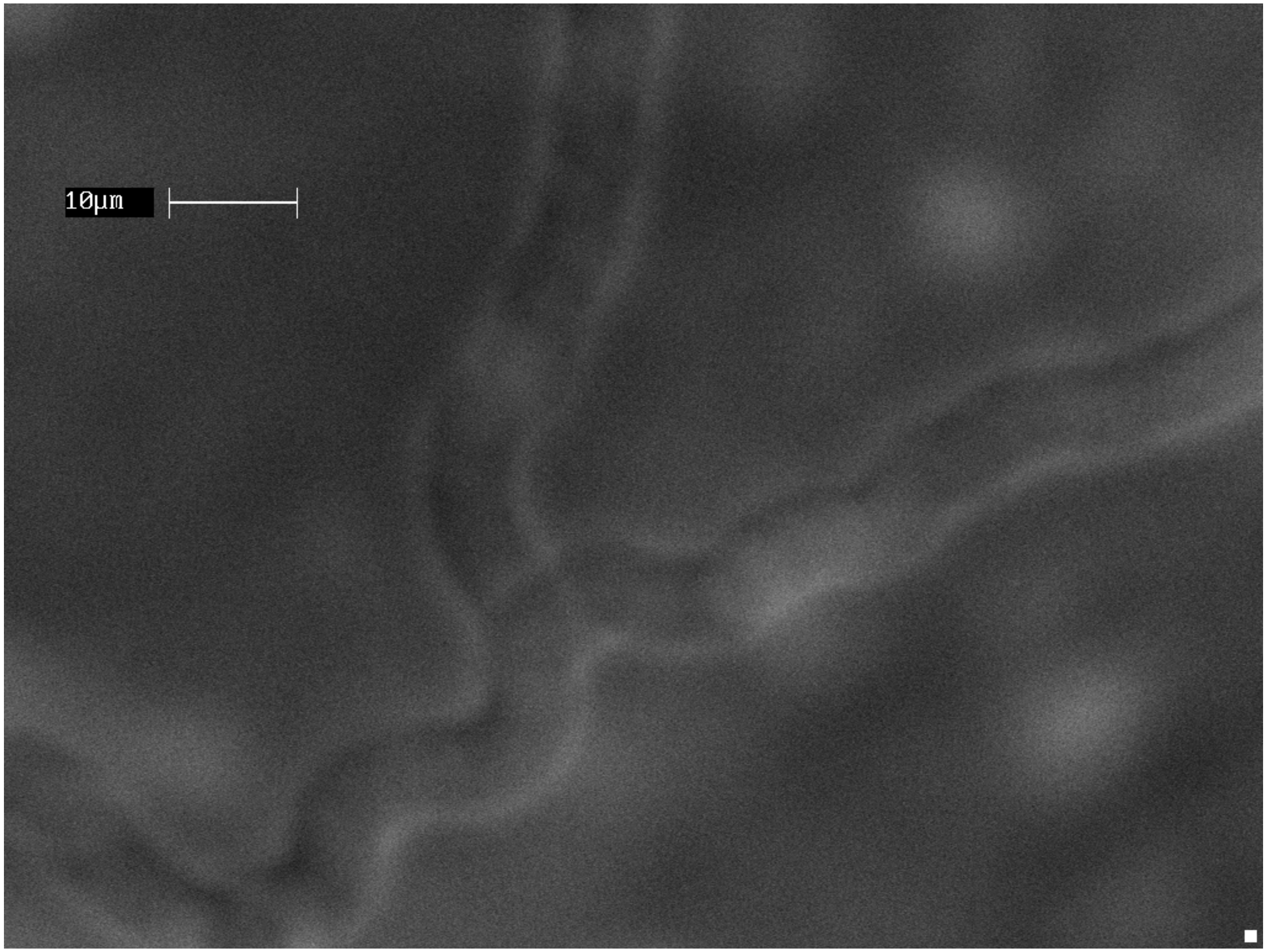
TiO_2 Nano Particle Film: Laser Sintering



$BaTiO_3$ nano particle film: Prior to laser annealing

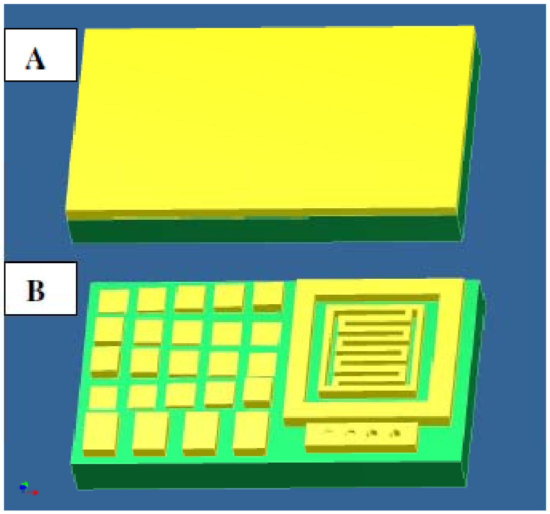


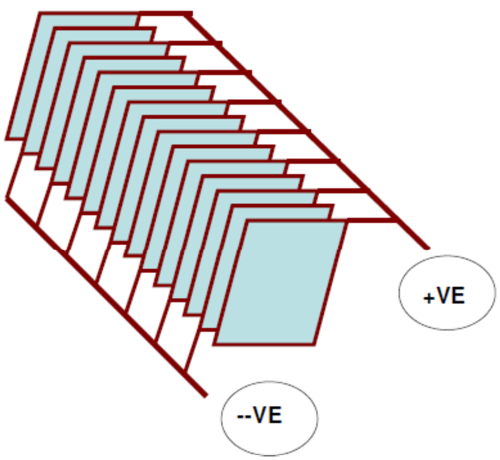
$BaTiO_3$ nanoparticle film: After laser annealing



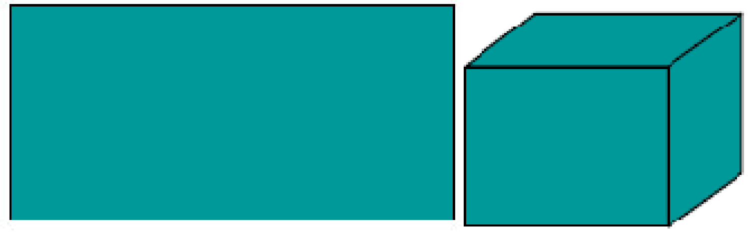
- Continuous surface
- Reparable Surface

Multilayer Embedded Capacitors (top and side view)

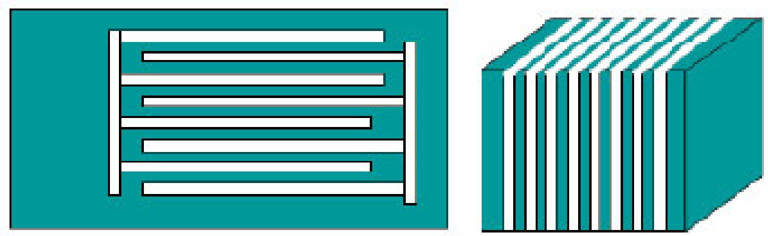




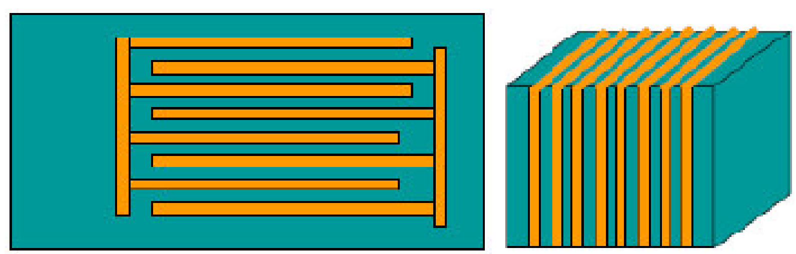
1. Capacitance layer



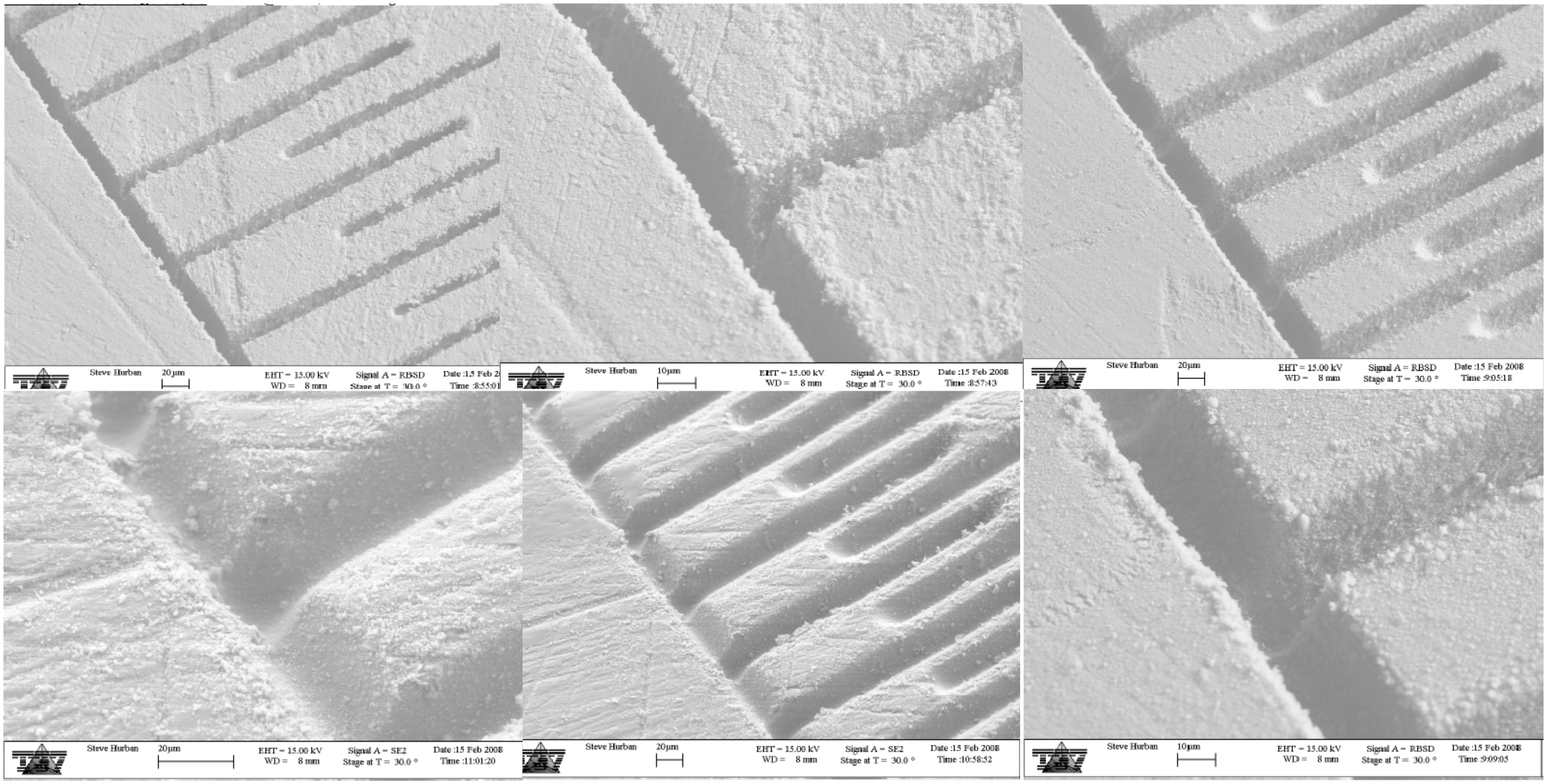
2. Laser micromachined channel within capacitance layer



3. Sputter Cu and electroplate Cu to fill the channel
4. Polish to remove surface Cu
5. Cu in the channel will act as electrodes



SEM : Laser Micromachined Channels



Capacitance Calculation

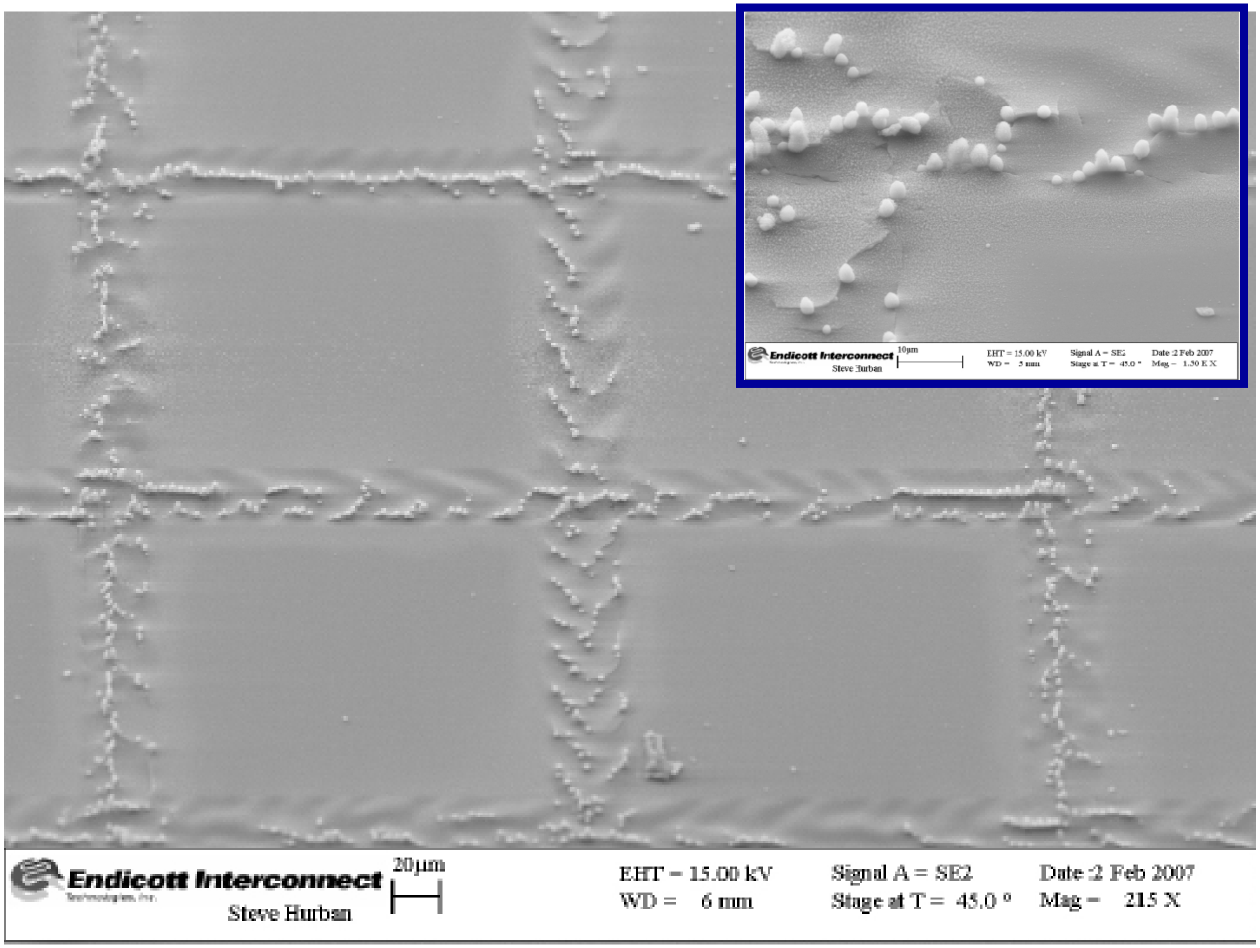
- Comparison between vertical and normal capacitors:
- Model I : 1 mil line, 1 mil space, 1000 mils long, Total Capacitors ~ 500 / inch2
- Model II : 0.5 mil line, 0.5 space, 1000 mils long, Total Capacitors ~ 1000 / inch2
- Model III : 0.25 line, 0.25 space, 1000 mils long, Total Capacitors ~ 2000 / inch2
- For vertical capacitors: space = thickness of capacitors
- Multilayer embedded capacitors C= C1+C2+C3+…….Cn)

*Capacitance layer thickness (mil)	Normal capacitance	Vertical multilayer embedded capacitors		
		1 mil line, 1 mil space	0.5 mil line, 0.5 space	0.25 line, 0.25 space
1 mil	6.74 nF/inch^2 Dk = 30	~3.37 nF	~13.49 nF	~53.98 nF
2 mils	3.37 nF/inch^2	~6.74 nF/inch^2	~26.98 nF/inch^2	~107.96 nF
4 mils	1.68 nF/inch^2	~13.48 nF	~53.96 nF	~215.92 nF

*Assuming Dielectric constant of materials = 30 Equation used in this calculation: C= $\varepsilon\varepsilon_0 A/d$

The total capacitance within the same volume as the normal capacitors

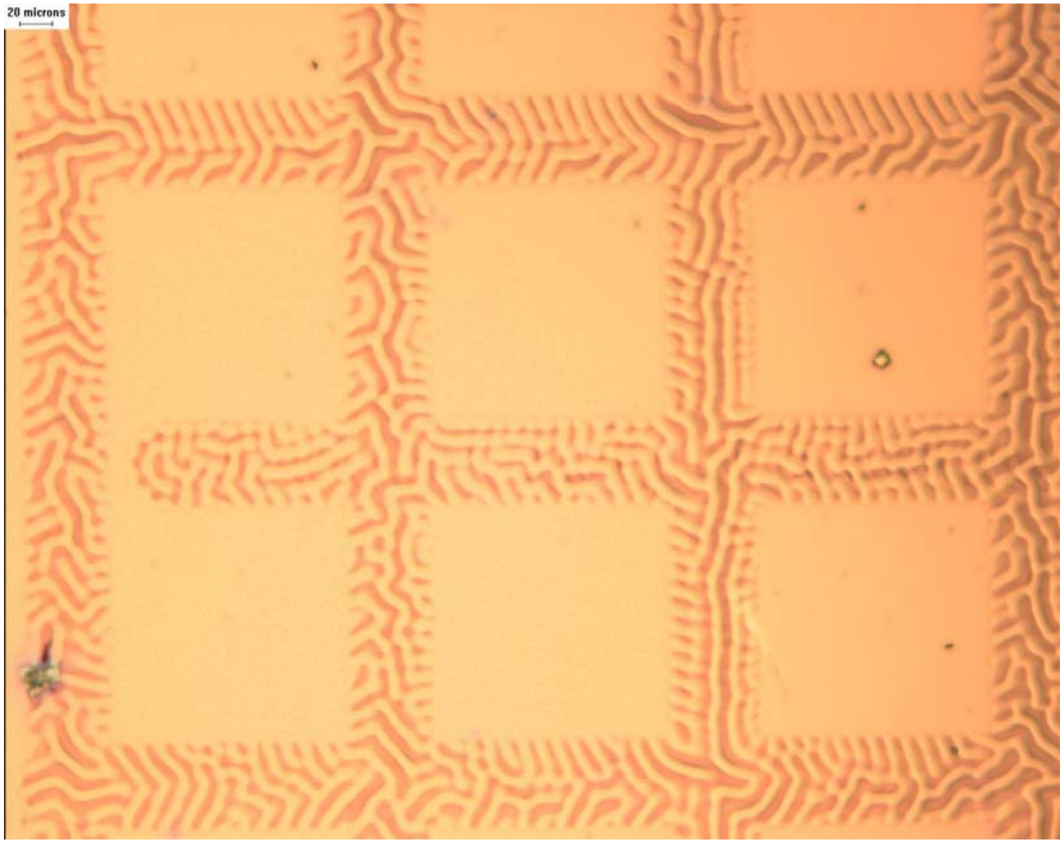
Laser Processing : patterned particle growth



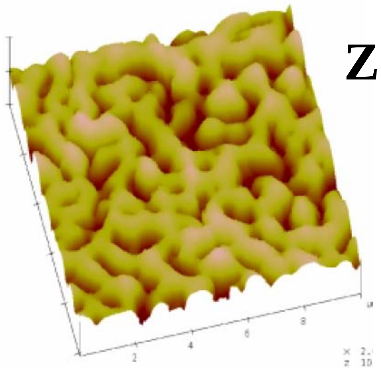
1st step of multi-functional capacitors

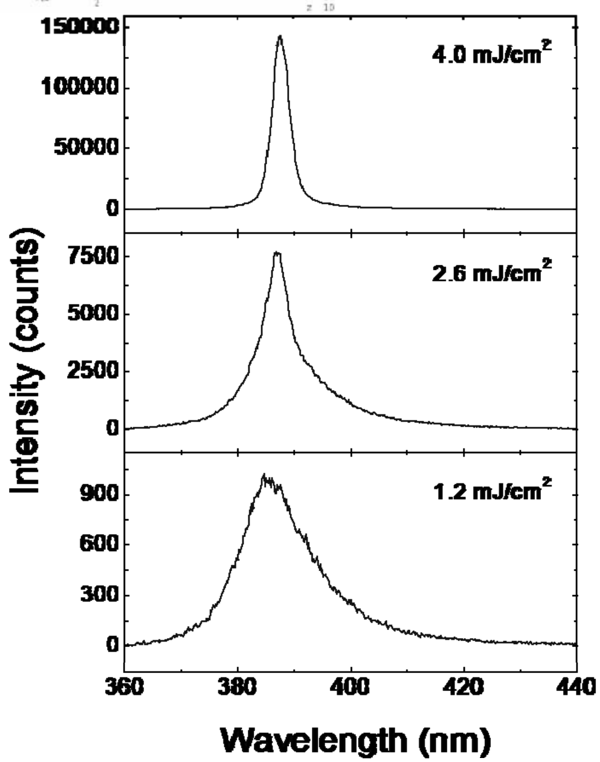
Optically active surface

Light bounces with in channels



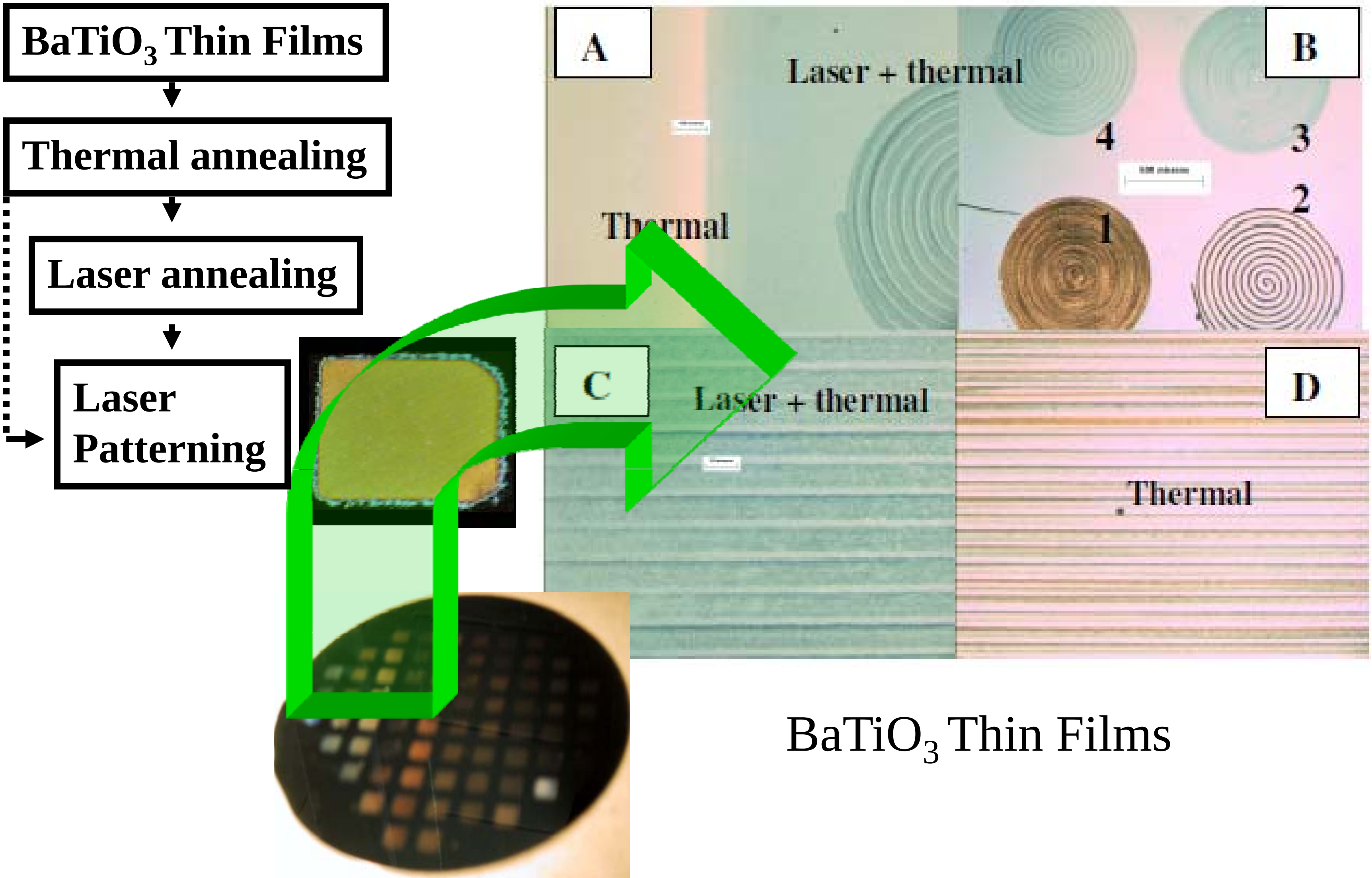
ZnO System





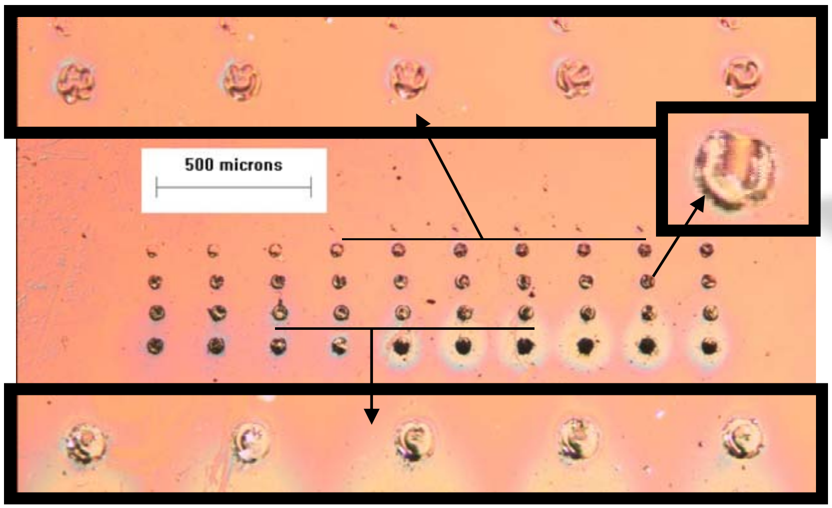
New optically active $BaTiO_3$ surface: New Direction for multifunctional capacitors.

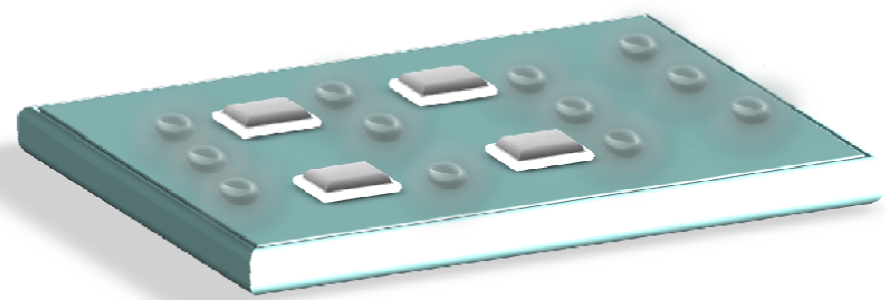
Regular 3-D Pattern



$BaTiO_3$ Thin Films

Array of Laser Annealed Spots: Towards Multifunctional Structures





Muli-functional layer:
Capacitor

Channels

Particles

Regular 3D pattern

Summary

- **EI developed laser processed nano-material systems for advanced packaging applications**
  - **Vertical Multilayer embedded capacitors**
  - **Tunable capacitors**
    - **Variable thickness capacitors**
  - **Library of new surfaces**
  - **Regular 3-D structures**
  - **Patterned particle growth**
- **Laser annealing can be used to develop pure $BaTiO_3$ phase as well as mixed phases of $BaTiO_3$, $Ba_2Ti_2O_7$ and $Ba_2Ti_9O_{20}$.**
- **Possible to tune the capacitance by changing $BaTiO_3$ phase content or by introducing low dielectric $Ba_2Ti_9O_{20}$ phase.**
- **Laser treatment improves nanoparticle sintering and reduces surface defects.**