Levitation and Propulsion of Microscale Targets

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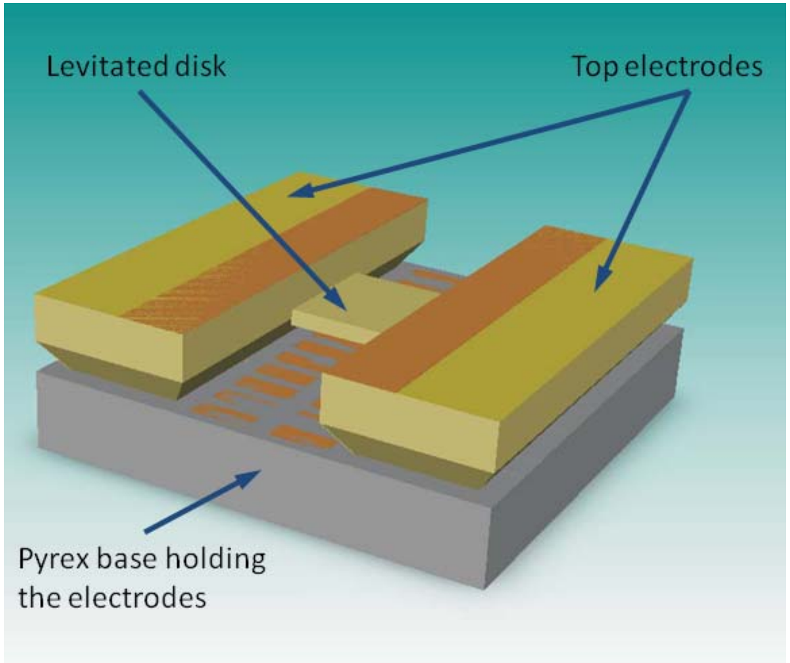
Scope

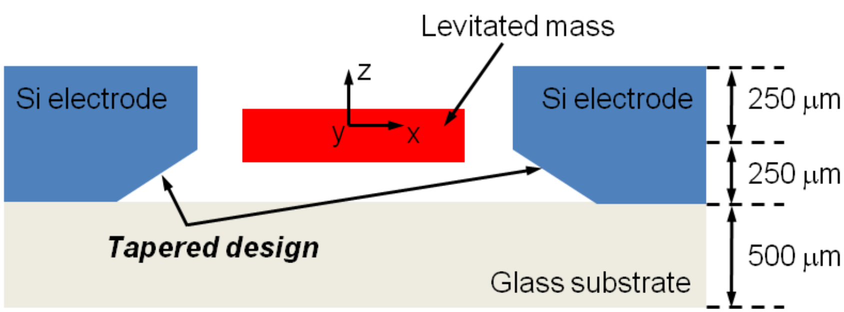
- Levitate and accelerate micro scale targets
- Two different approaches considered:
  - **Electrostatic (ES)**
  - **Electromagnetic (EM)**
- Physics and electronic interface design
- Micro fabrication of proposed designs and sample targets

Techniques Considered

1. **Electrostatic**
   - Electrostatic forces for both levitation and propulsion of the targets
   - Demonstrated before for inertial sensing app's
   - A wide range of materials can be levitated
   - Requires a feedback system for stable levitation

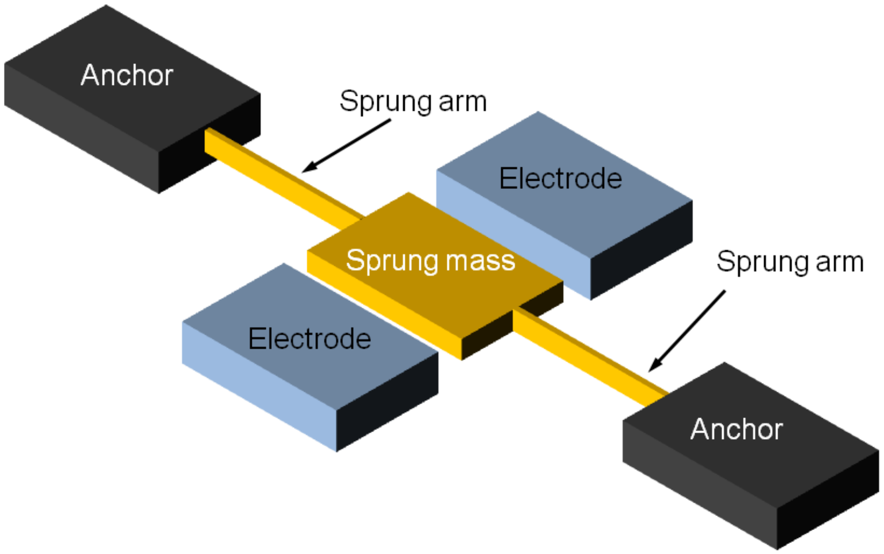
Electrostatic Levitation & Propulsion

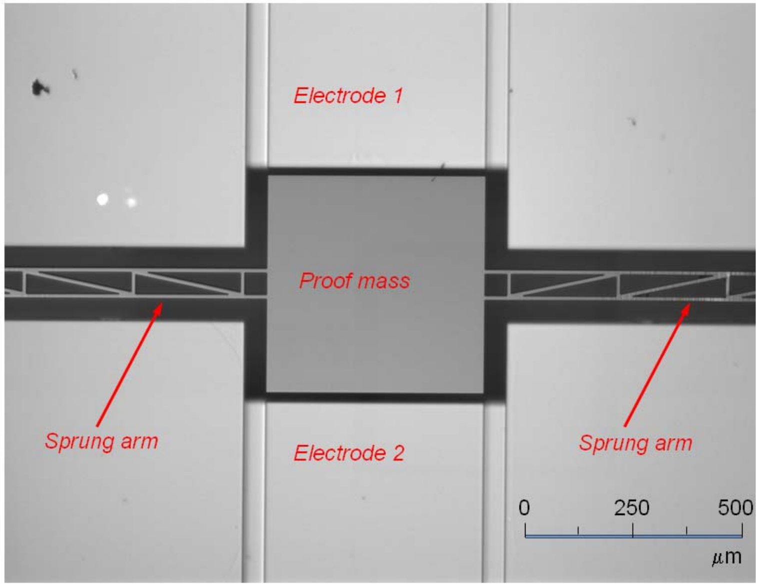




- First generation ES design:
  - Fringing fields for levitation
  - Similar to a linear micromotor
  - Tapered profile enables inherent vertical stability
  - Frictionless propulsion and controlled delivery velocity
  - Lateral stability and capacitive sensing are problematic issues
  - Difficult to achieve rotational control

Electrostatic Levitation – Test Design





- A test design is developed and fabricated to measure design parameters such as ***capacitance and levitation force***
- Test results revealed that capacitive coupling between the electrodes is low for feedback (low SNR)
- The levitation forces due to the fringing fields require a high voltage (>250V) to lift the object

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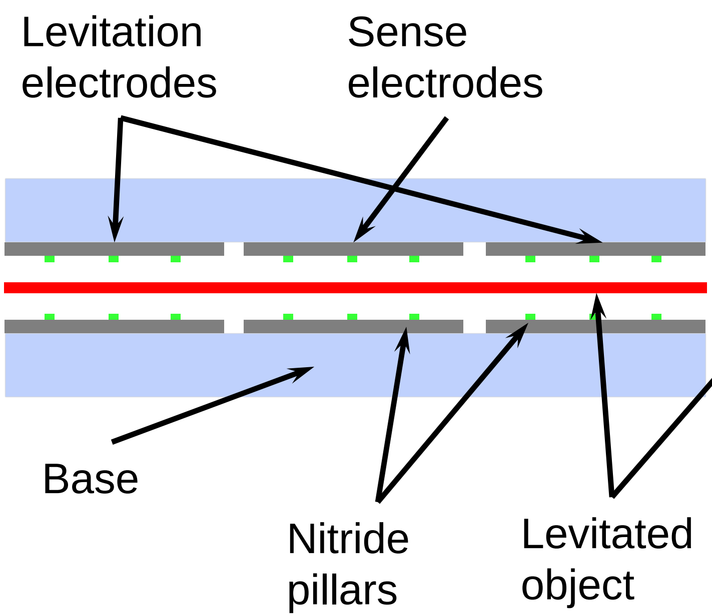
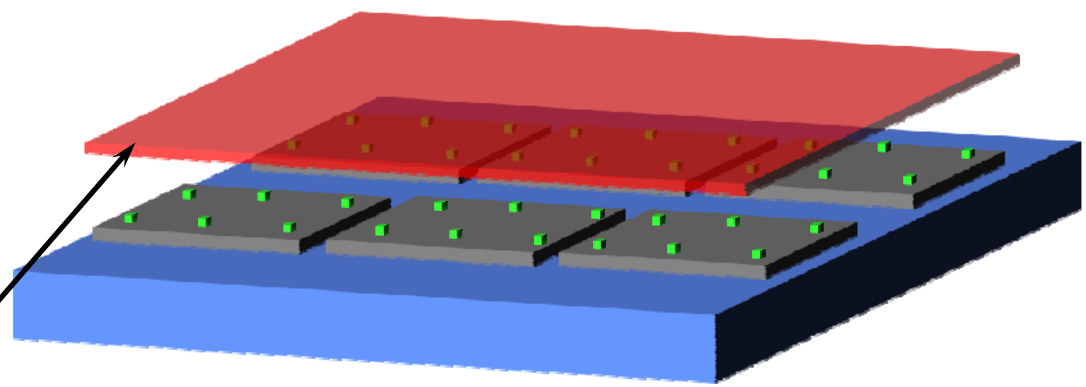
Electrostatic Levitation – 2nd Gen.

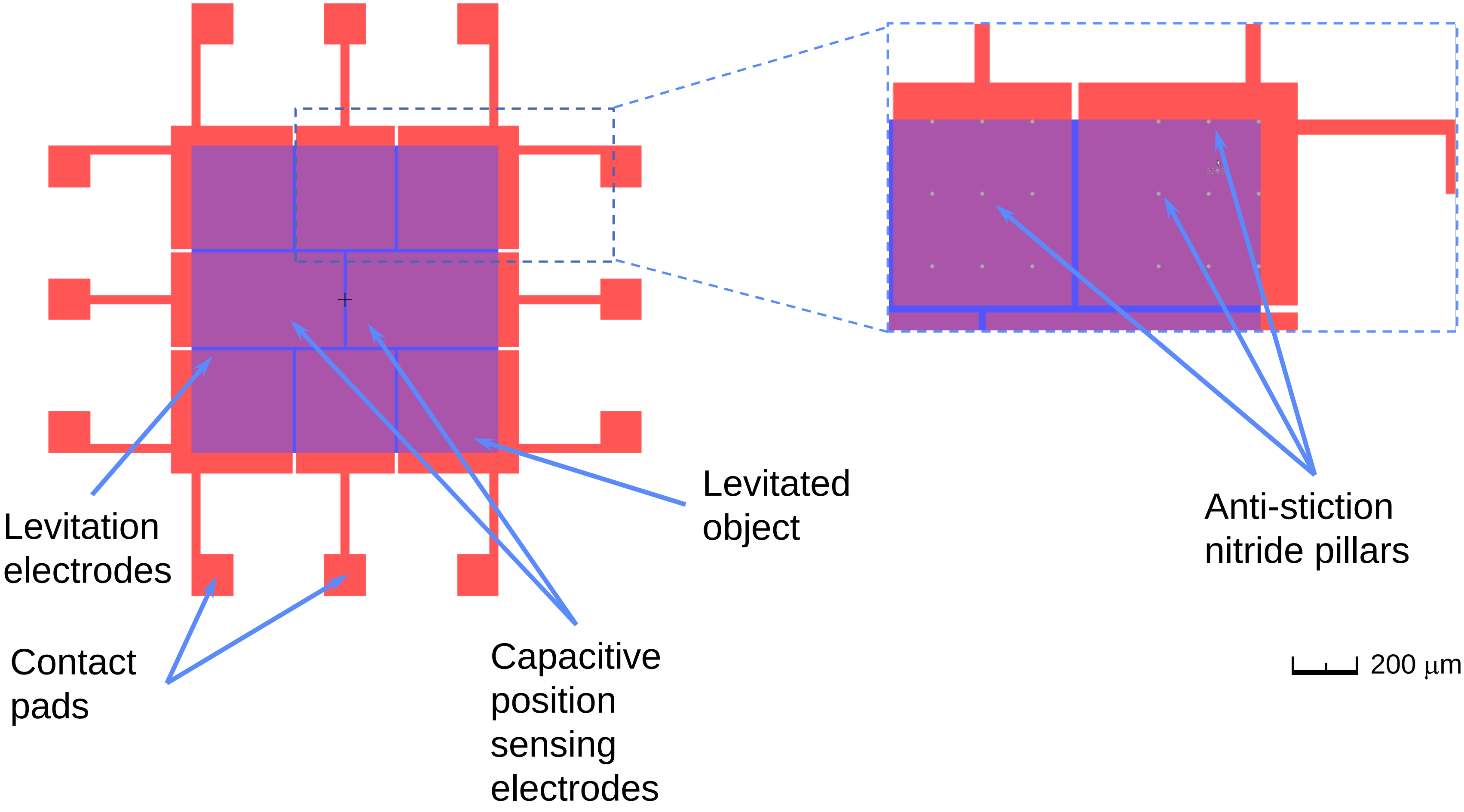
- The 1st gen. ES design is modified to an inverted parallel plate ES levitator
- The improved design features increased capacitance, reduced levitation voltage, and improved stability
- Nitride pillars used to reduce the friction btw. the electrodes and the target and hence initial levitation voltage decreased





Isometric view of the inverted parallel plate levitator (top part removed for simplicity)

Layout of the ES Levitator



Parallel plate ES design with anti-stiction pillars

Techniques

1. Electrostatic (ES)

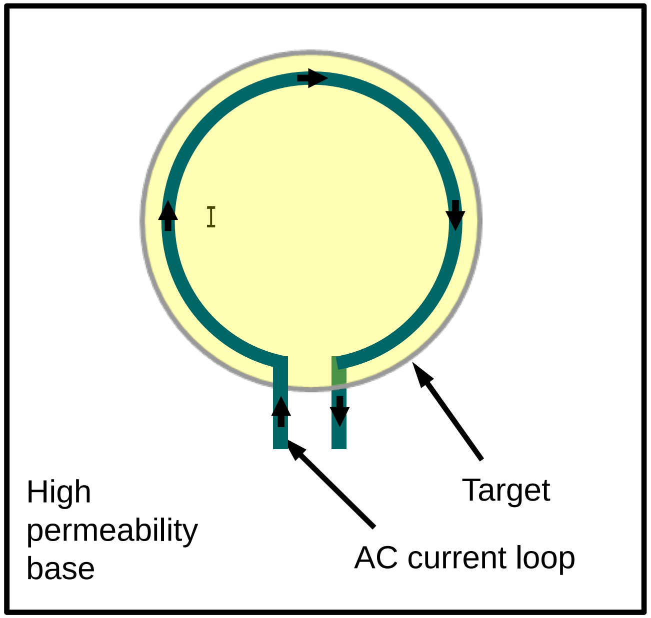
2. Electromagnetic (EM)

Techniques Considered

2. Electromagnetic

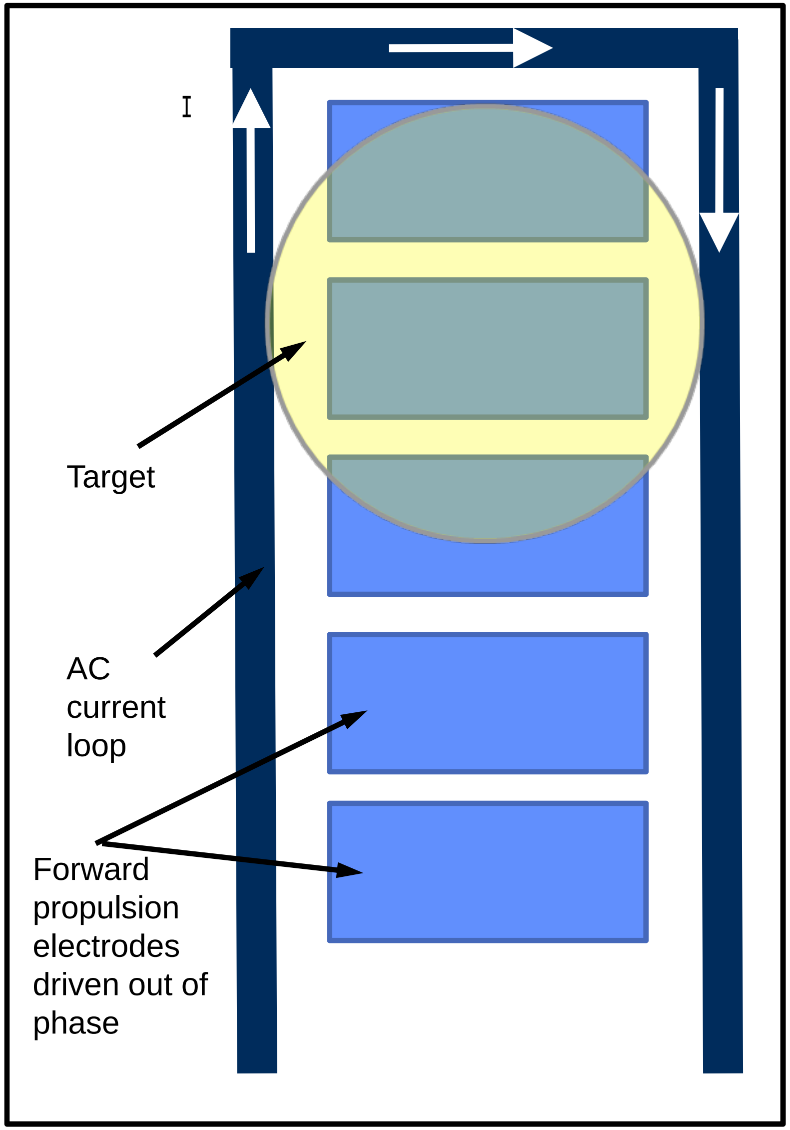
- EM induction for levitation, ES forces for propulsion
- Inherent vertical and lateral stability through physical construction, hence a feedback system is not required
- Levitation requires high frequency AC currents (10-20MHz, 0.5-1A)
- Feasible for low resistance metals (e.g. Al, Au, Cu)

Schematics of EM Levitators



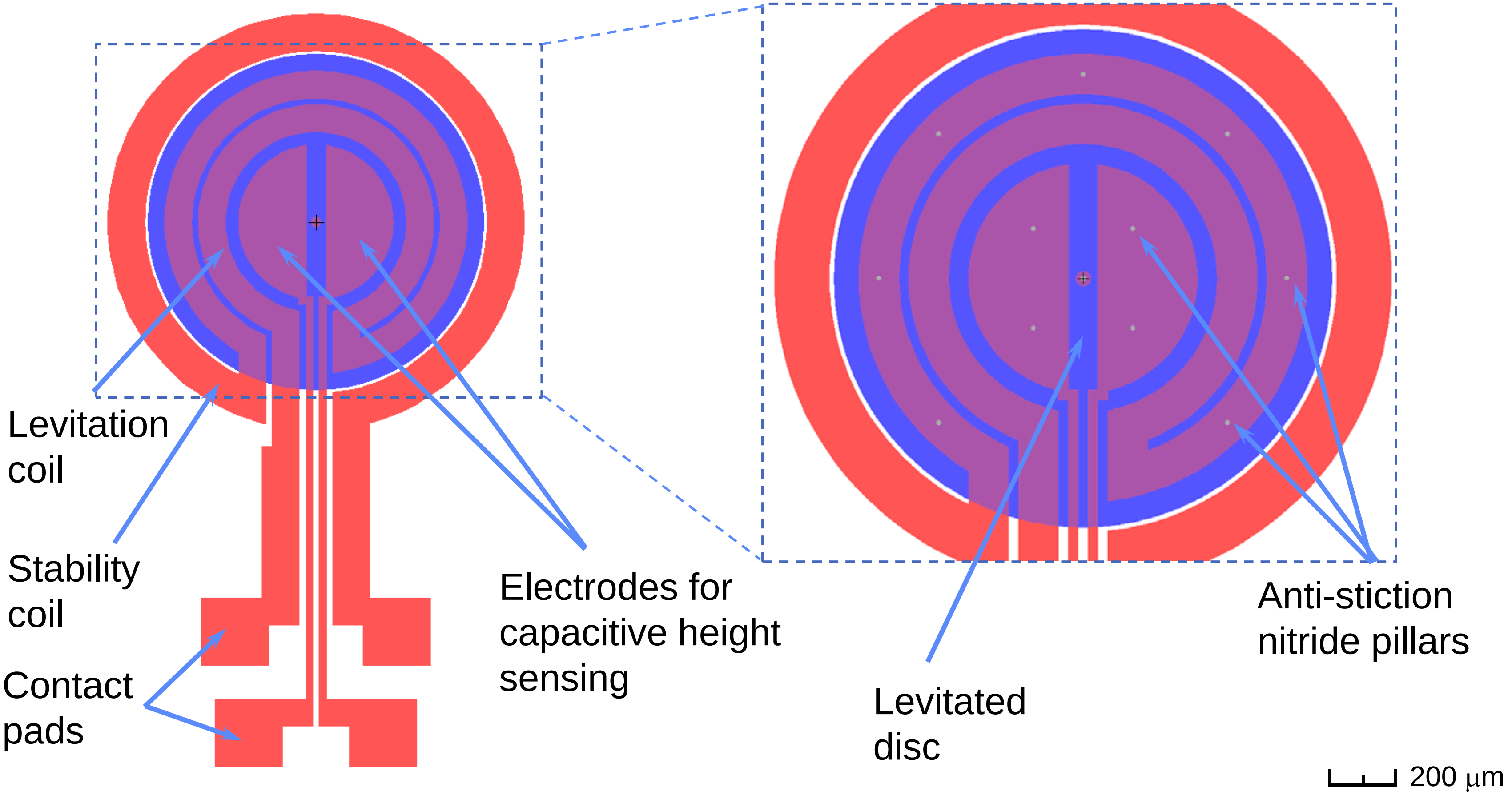
Circular track (levitation only)

Disc diameter	500 μm
Disc thickness	10 μm
Levitation height	20-50 μm
Current amplitude	0.5 A
Current frequency	10 MHz
Typical materials	Al, Cu, Ag



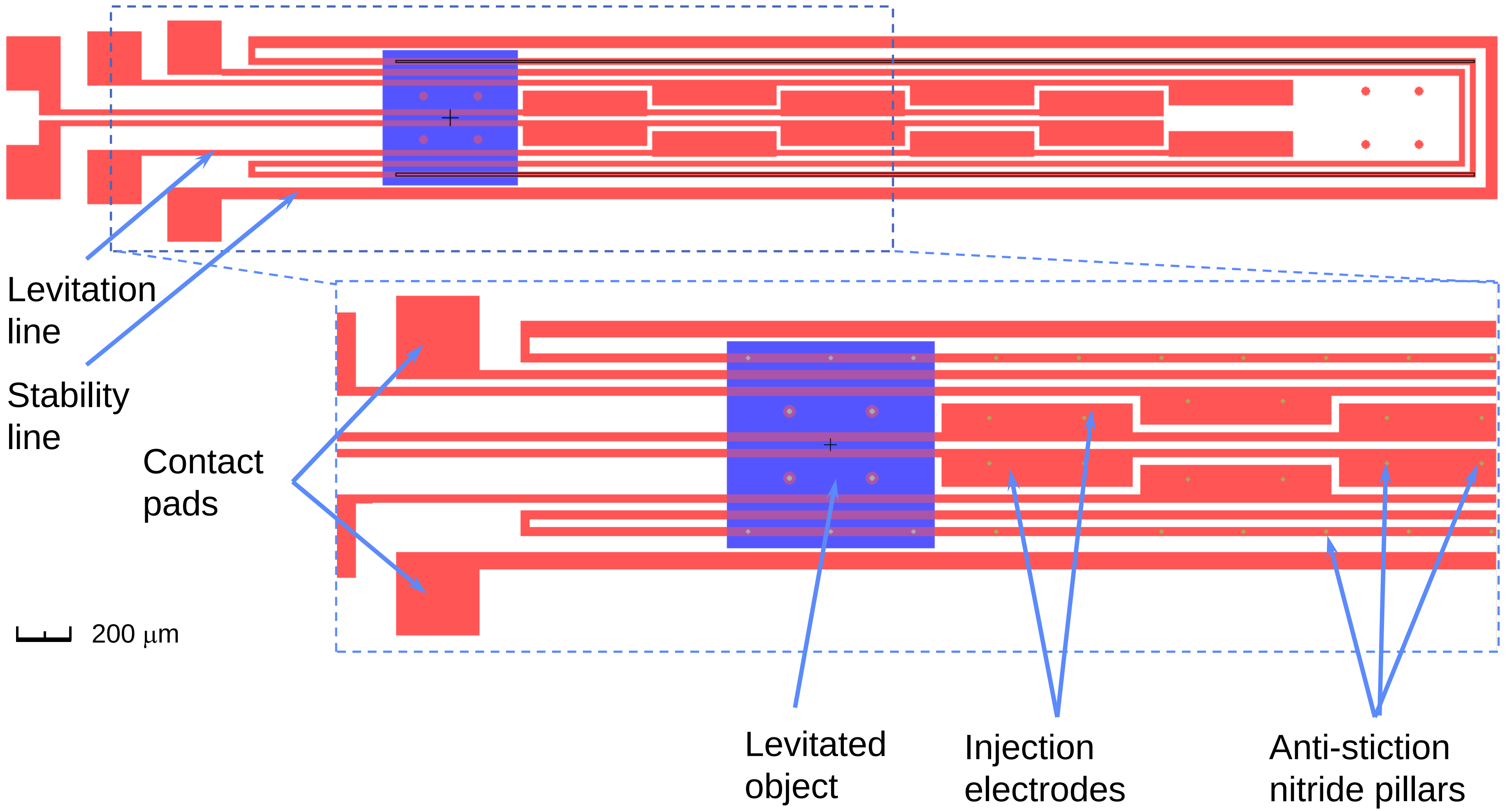
Linear track (levitation and propulsion)

Layout of the Circular EM Levitator



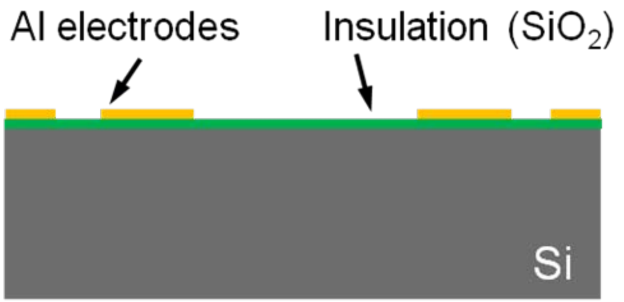
Circular EM design with stability coils and anti-stiction pillars

Layout of the Linear EM Levitator

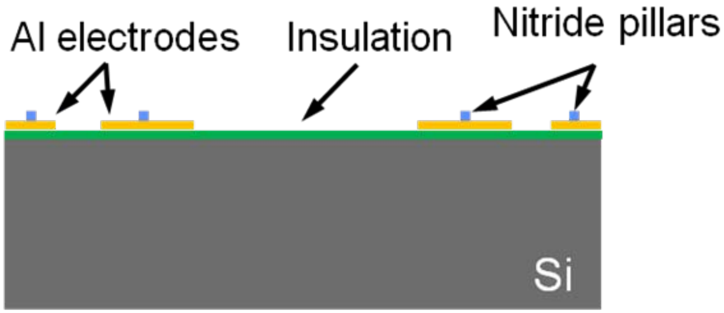


Linear EM design with stability coils and anti-stiction pillars

Micro Fabrication of the Levitators



A. Deposit and pattern Al electrodes and contact pads

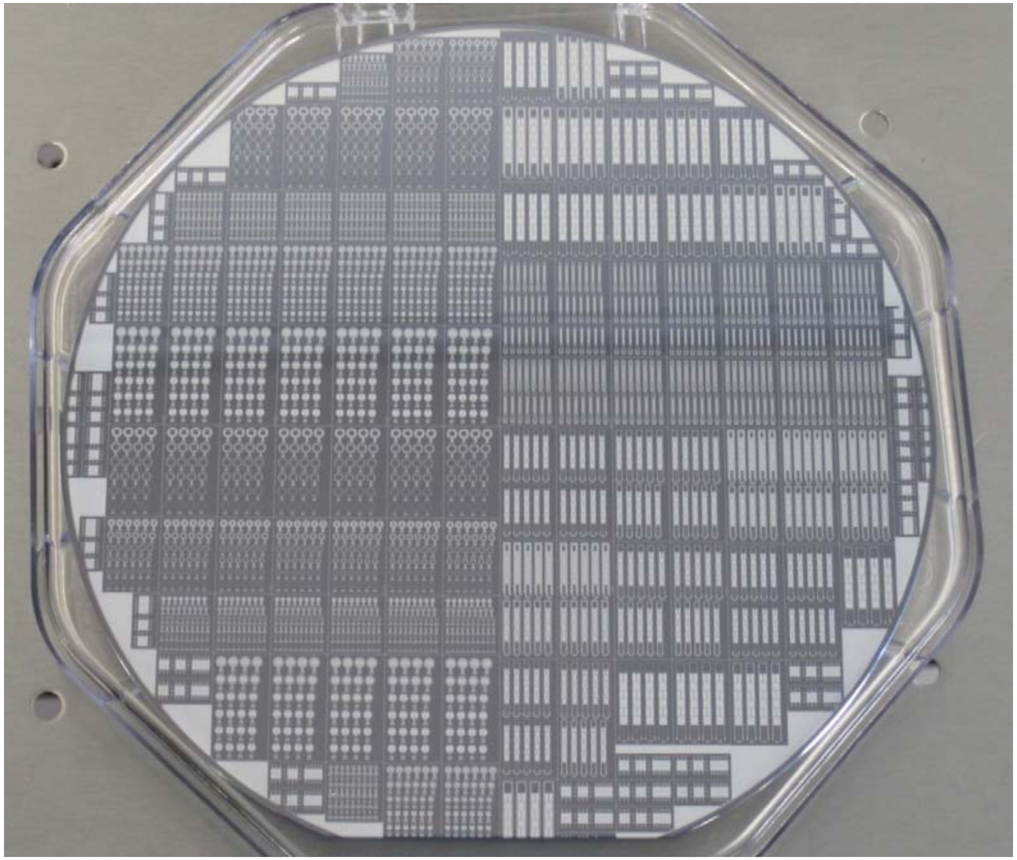


B. Deposit and pattern nitride pillars

FABRICATION OF THE ELECTRODES AND CONTACT PADS

- ***ES & EM levitators are fabricated concurrently using the same mask set***
- Two mask process
- ***Evaporation and lift-off*** techniques have been used for fabrication
- 7-10 μm aluminum as the structural material
- 1 μm thick nitride pillars to reduce friction
- From a single 6 inch wafer about 2500 devices can be obtained

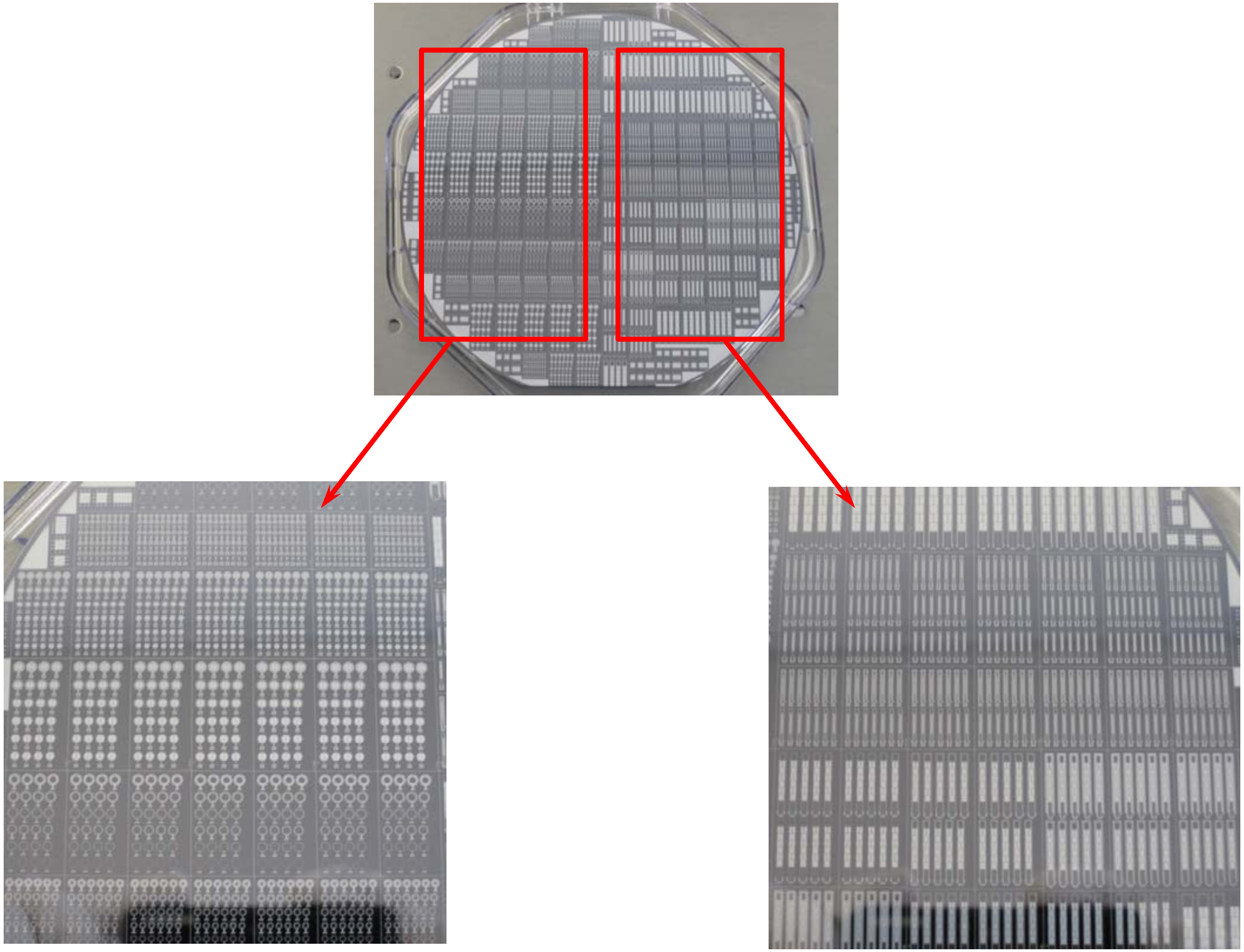
Wafer Level Fabrication



A fabricated 6-inch wafer before dicing

- A fabricated 6-inch Si wafer just before dicing
- Light areas: aluminium
- Dark areas: Si substrate
- Total 2500 devices
- Devices grouped for handling and testing

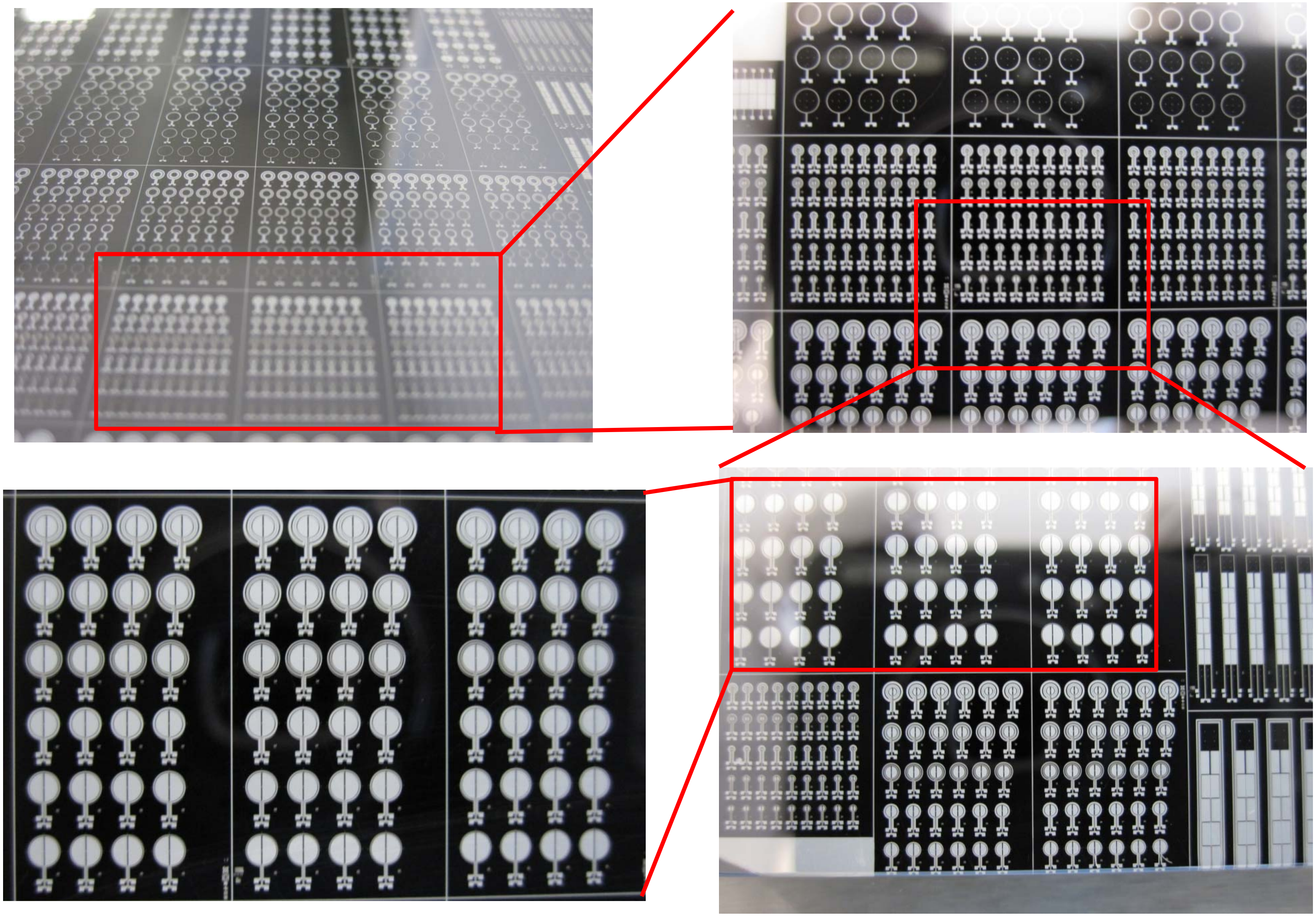
Wafer Level Fabrication



Circular levitators

Linear levitators

Circular EM Levitators



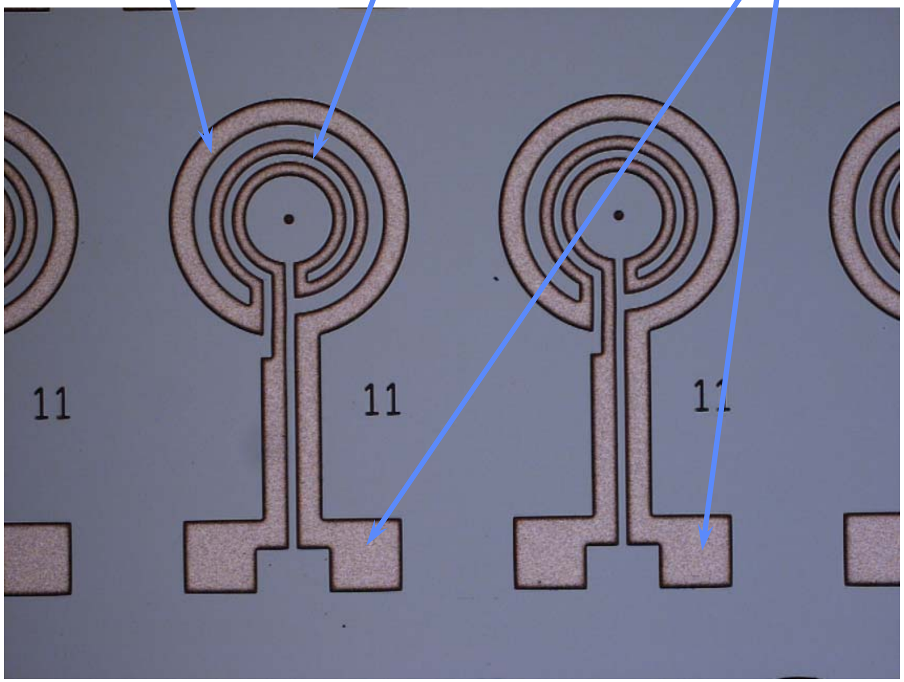
Circular EM Levitators

Stability coil

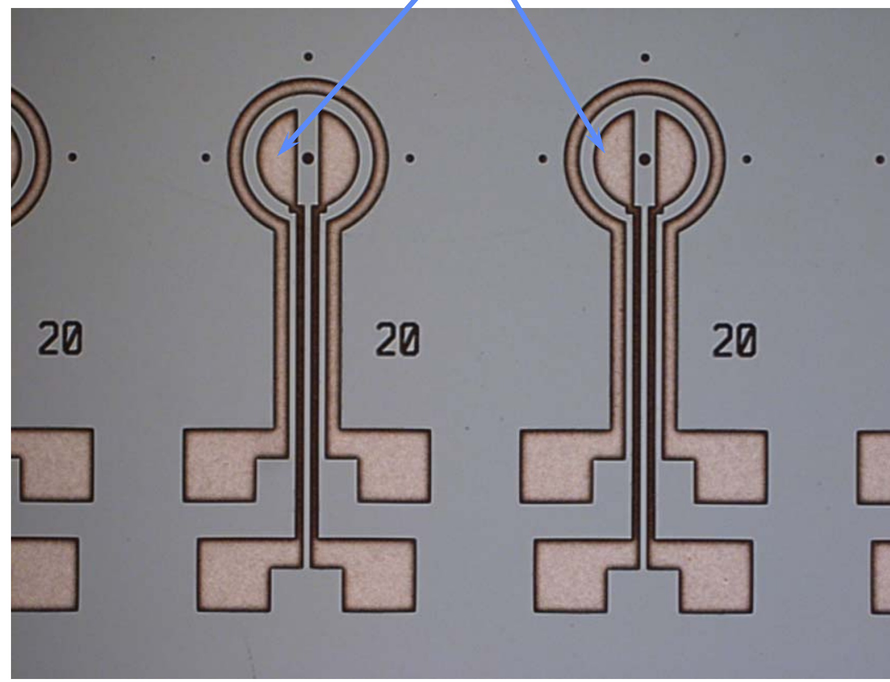
Levitation coil

Contact pads (200 x 200 μm)

Capacitive height sensing electrodes



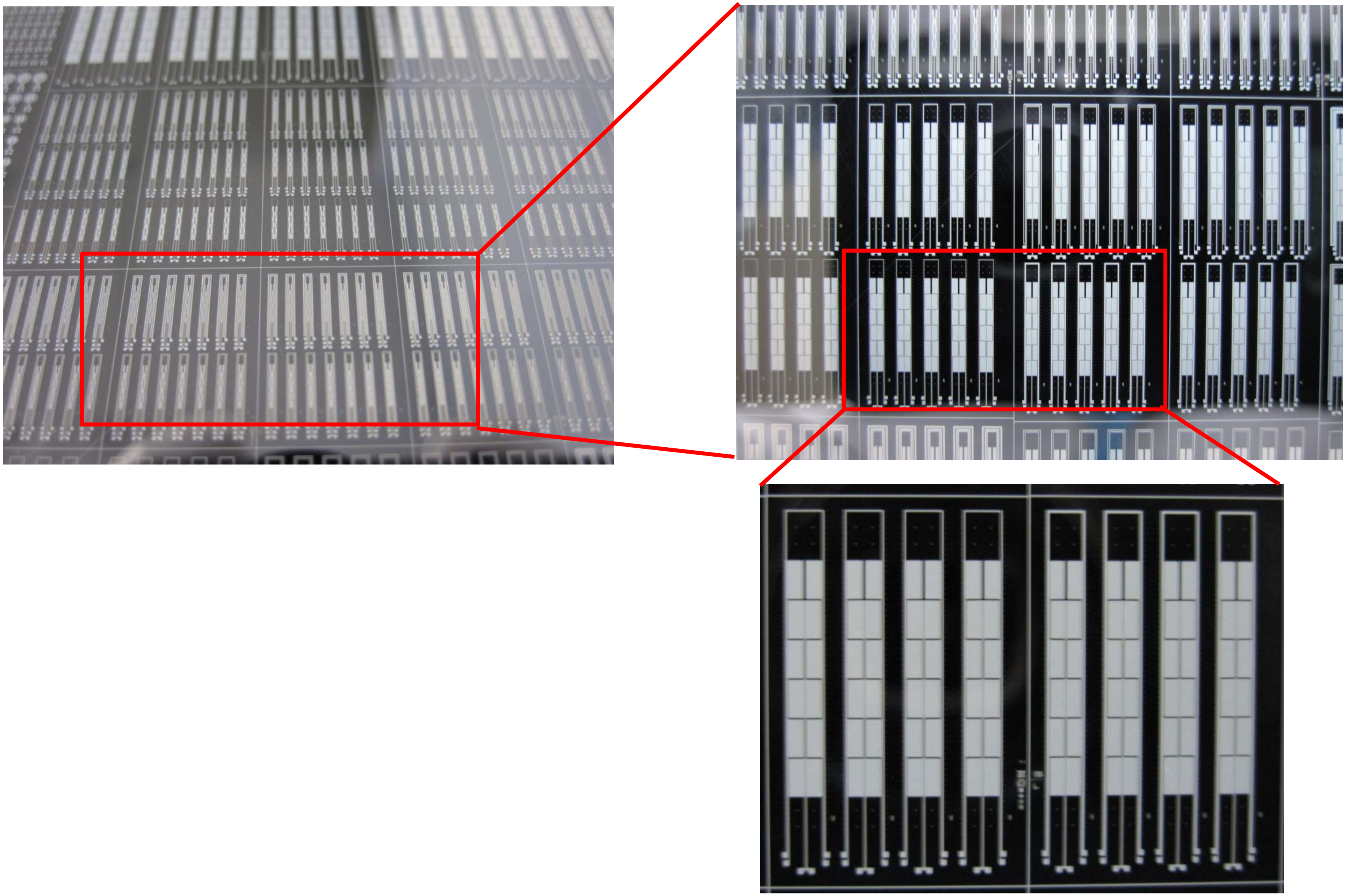
Circular EM levitator with stability coils



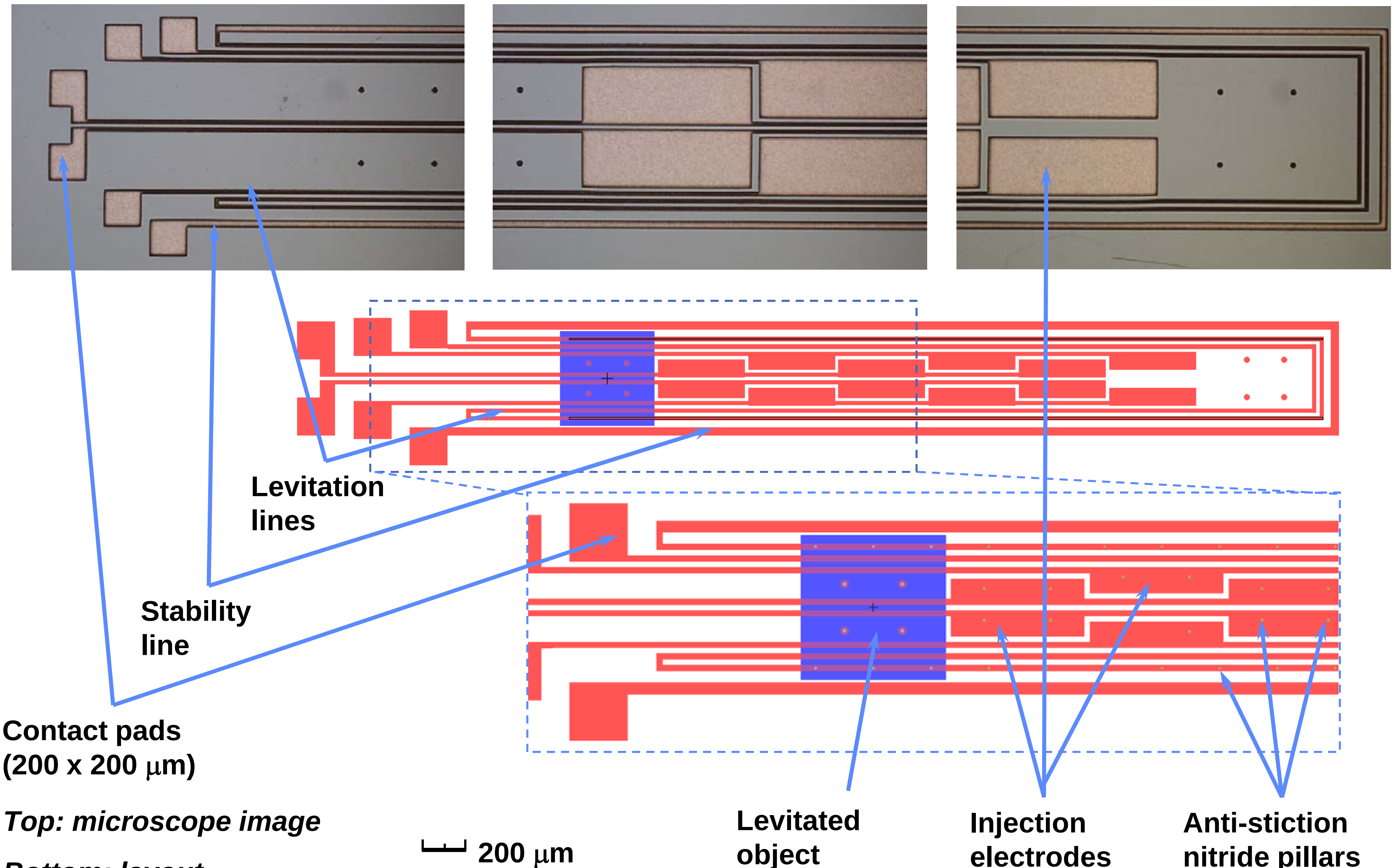
Circular EM levitator with position (height) sensing electrodes

200 μm

Linear EM Levitators



Linear EM Levitators



Top: microscope image

Bottom: layout

ES Levitators

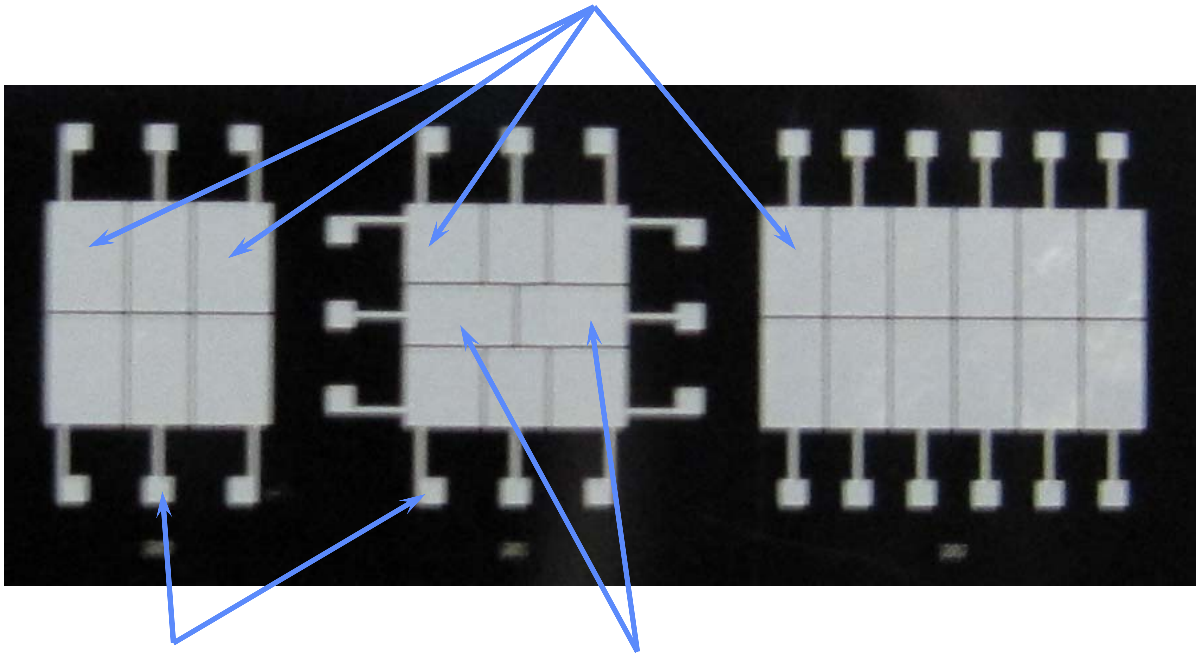
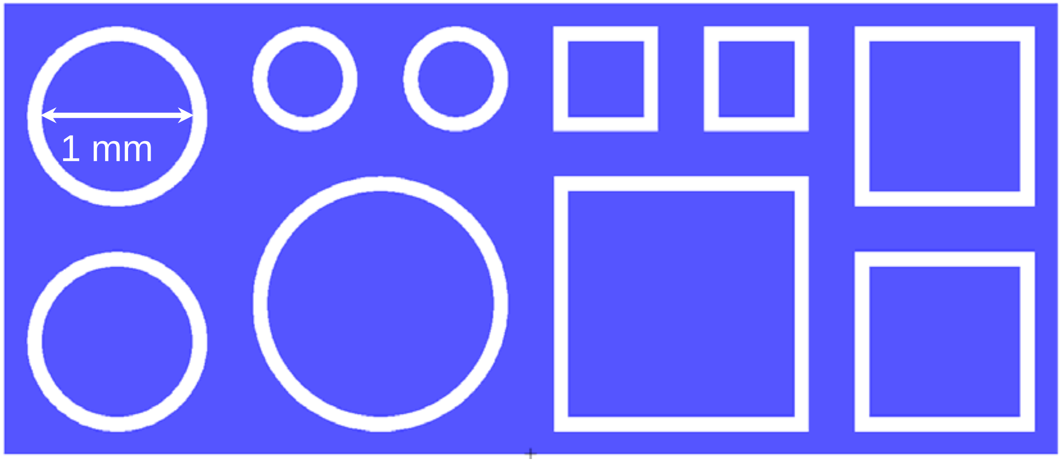


Photo image of different type of ES levitators

Micro Targets



Top view of a group of micro targets

- The targets are in house fabricated using a fabrication procedure similar to that of the devices
- A 6 inch wafer consists 822 groups with a total number of 8220 targets

- Each group consists of different sized (500-1500 μm) square and circular targets
- Possible to fabricate different sized and shaped targets
- Lift-off used to fabricate the targets from 10 μm thick evaporated aluminum
- The thickness of the targets can be controlled from several nm's to μm's

Summary of ES & EM Levitators

	ES	EM
Feedback (FB) controller	Necessary	Not necessary
Power levels	High voltage (250 V), low current	Low voltage (~10V), high current (0.5 A)
Stability	Stable in lateral direction. Open loop instability in the vertical direction, a FB controller is necessary	Stable in the vertical direction. Stability coils are required for lateral stability – but no FB controller necessary.
Typical levitated materials	Reasonable conductors, including semiconductors	Feasible for high conductivity materials (Al, Cu, Ag, Au)
Heating	No heating	Coils and disc will heat up
Operating input frequency	DC	AC @ 10 – 50 MHz
Fabrication complexity	Total 2-3 masks	Total 2-3 masks

Concluding Remarks

- Two different approaches considered
- Microfabrication procedure developed and used for the fabrication of the devices and the targets
- Both designs fabricated concurrently
- Fabrication procedure enables flexibility in the size and thickness of the targets

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