EE 527 MICROFABRICATION

Lecture 14

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PHOTOMASK GEOMETRICAL DESIGN CONSIDERATIONS - 2

Physical layout design rules

- Alignment markers
  - Layer-to-layer and cumulative
  - Visual, coarse, fine, vernier
  - Marker placement
- Proximity and density effects
- Process shrinks and bloats
- Corner compensation
- Process test patterns
- Diagnostic devices and probe pads
- Dicing and packaging marks

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PHOTOMASK MATERIALS

- Substrates:
  - Soda lime glass: poor transmission, >8.9 ppm/C, n = 1.515
  - Borosilicate glass (Pyrex): 350 – 2000 nm, 3.25 ppm/C, n = 1.474
  - Quartz (fused silica, SiO_2): 220 – 2000 nm, 0.55 ppm/C, n = 1.458
  - Sapphire (Al_2O_3): 190 – 5000 nm, 5.3 ppm/C, n = 1.780
- Blocking layer: generally need an optical density (OD) > 4.0
  - Fe_2O_3 (least expensive)
  - Cr (best finish and uniformity)
- Standard mask plate thicknesses for the Oriel aligners:
  - 4-inch square mask plate: 0.062 inches
  - 5-inch square mask plate: 0.093 inches
- Pellicles: used only for projection systems
- Master versus daughter plates, polarity reversals, mirror reversals
- Transparency films:
  - Overhead xerox transparencies using toner: forget it – they don't work!
  - Professional phototransparencies: need emulsion coatings for OD > 3.0

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PHOTOMASK FABRICATION

- Photoplotter
  - Least expensive: ~$250/plate
  - Used most commonly in the PCB industry
  - Resolution down to ~25 microns = 1 mil
- Direct-write laser
  - Intermediate cost: ~$350 to $650/plate
  - Vector pattern generation
  - Resolution down to ~2.5 microns
- Direct-write e-beam
  - Most expensive: ~$2500/plate (entry level) + beam time charge
  - The Etec MEBES system was the original, MEBES-IV is current
  - Raster scan with vectored subfields
  - Resolution down to ~20 nm

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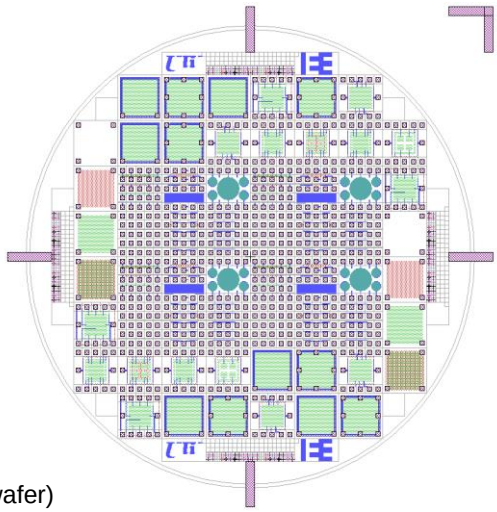
EXAMPLE: EE-527 MASK SET M4 (6-MASK SET)



(100 mm wafer)

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PHOTOMASK DESIGN LAYER SETUP

- Example for the EE-527 M4 mask set:

Mask Number	Layer Name	Layout Color	Process Type	Polarity	Alignment
1	Align		etch	dark field	
2	PDiff		etch + diffuse	dark field	
3	NDiff		etch + diffuse	dark field	
4	Active		etch	dark field	
5	Contact		etch	dark field	
6	Metal1		deposit + liftoff	dark field	

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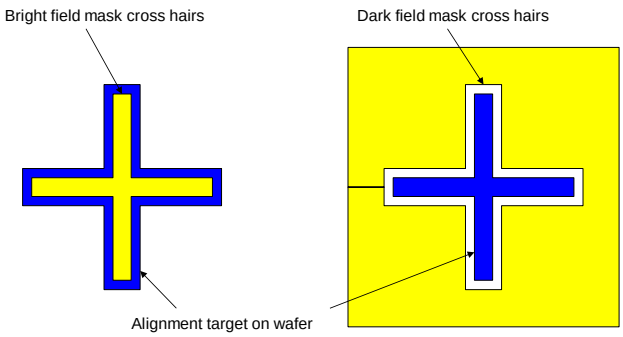
MASK POLARITY

- Bright field: drawn features are opaque – easy to align
  - Make the alignment cross hairs are smaller than the wafer targets.
- Dark field: drawn features are transparent – requires building in windows for alignment
  - Make the alignment cross hairs are larger than the wafer targets.



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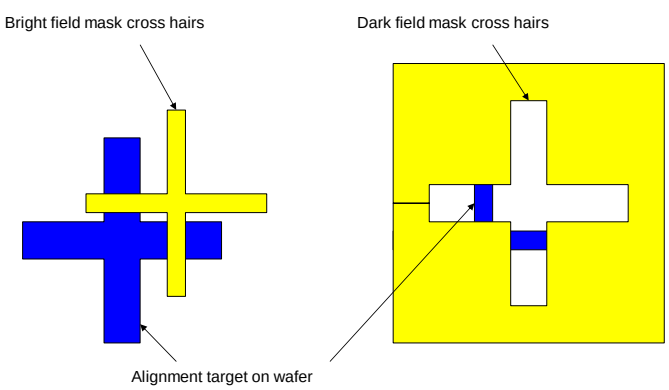
MISALIGNMENT

- Different views for bright field versus dark field:
  - In both cases, the mask (in yellow) is shifted up and to the right:



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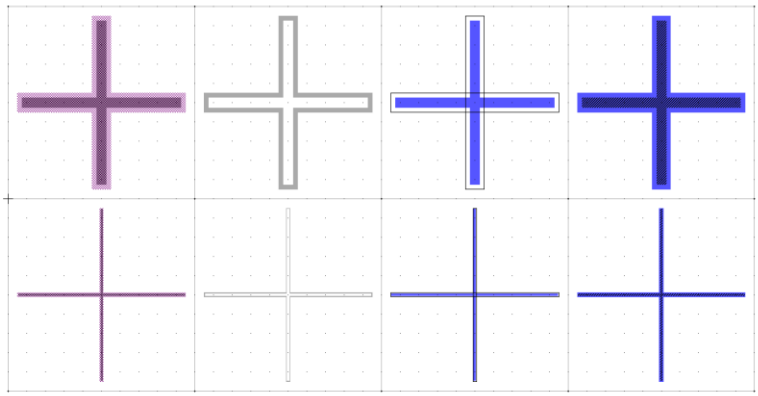
WAFER ALIGNMENT MARK TARGETS AND CROSS HAIRS

- Coarse: 50 μm targets with 100 μm cross hairs
- Fine: 10 μm targets with 20 μm cross hairs
- Usually adequate for contact alignment to within ±1 μm.



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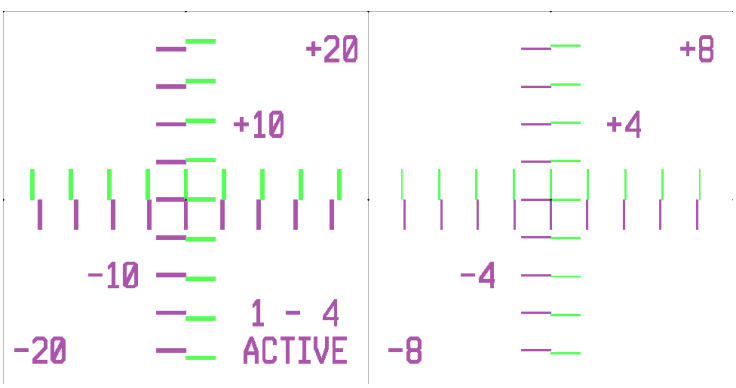
VERNIERS TO MEASURE ALIGNMENT ACCURACY

Pitch of vernier ticks is increased by 5 μm (coarse) and 2 μm (fine) from mating ticks on the prior mask.
By finding the pair of mating ticks which matches best, the alignment error can be determined to ±0.5 μm.



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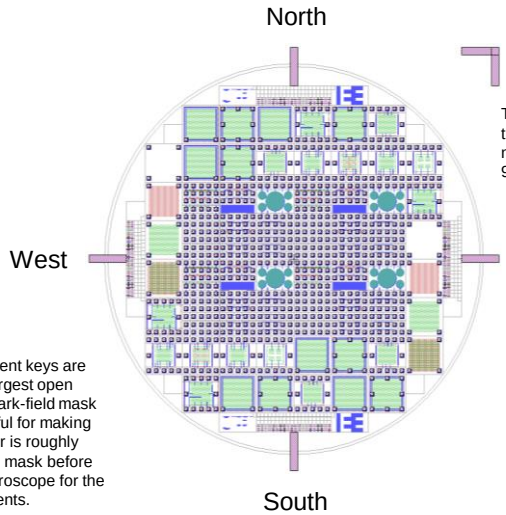
EE-527 M4 MASK SET: VISUAL ALIGNMENT KEYS



The NE marker guarantees that the mask and wafer are not accidentally rotated by 90 degrees.

Visual alignment keys are usually the largest open feature in a dark-field mask and very useful for making sure the wafer is roughly aligned to the mask before using the microscope for the finer adjustments.

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PROCESS DIAGNOSTICS

- Each mask set should provide test structures by which to troubleshoot problems and monitor the fabrication process.
- Process diagnostics:
  - photoresist tuning: prebake / exposure / development
  - doping levels: sheet resistance
  - metal conductivity: sheet resistance
  - MOS oxide: field-effect, threshold voltage, MOS capacitors
  - interlevel dielectric breakdown strength and capacitance: MIM capacitors
  - via reliability and resistance: via chains
  - contact reliability and resistance: contact chains
- Device diagnostics:
  - test transistors, diodes, or sub-circuits
    - variable gate widths
    - variable gate lengths
    - ring oscillator
    - pn-junction diode I-V and leakage
    - Schottky diode I-V and leakage

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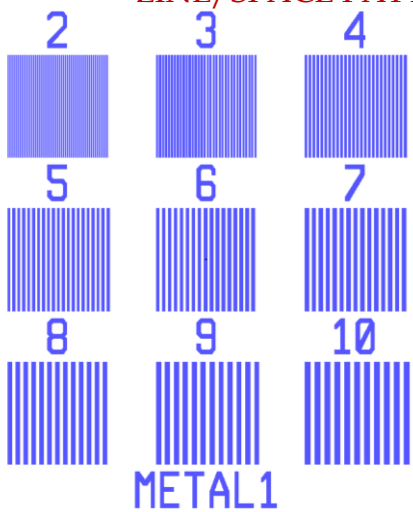
PROCESS DIAGNOSTIC: PHOTORESIST LINE/SPACE PATTERNS



Proper prebake, exposure, and development should produce a 50:50 line and space pattern.

This pattern is usually easy to tune with an optical microscope and avoids the need for using an SEM.

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PROCESS DIAGNOSTIC: 4-POINT RESISTIVITY (SUBSTRATE)

- 100 μm dia. contacts, 1000 μm and 500 μm spacings:

Diagnostic Probe Pads :

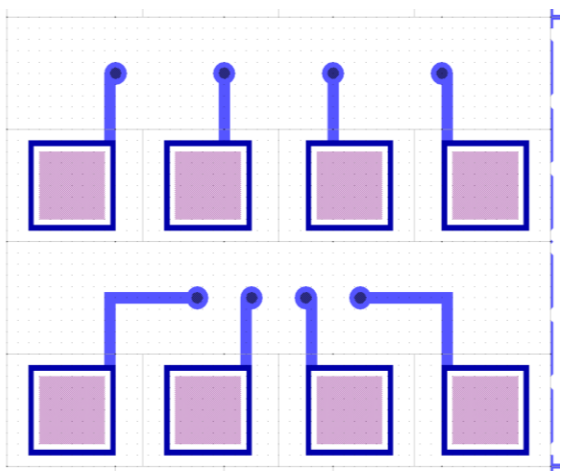
800 μm x 800 μm square,

1250 μm pitch,

approx. = 0.050 in pitch,

designed for use with a standard 4-point probe head.

The photolithographically defined contacts provide a much higher accuracy 4-point probe measurement than most commercial 4-point probe heads!



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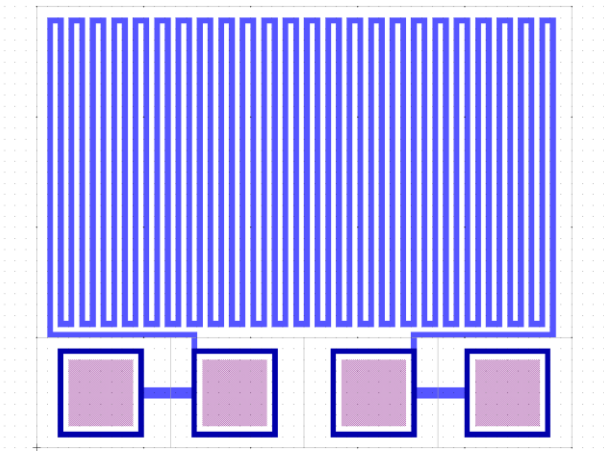
PROCESS DIAGNOSTIC: METAL SHEET RESISTANCE

- 2751 squares in M1; same pattern also for M2:



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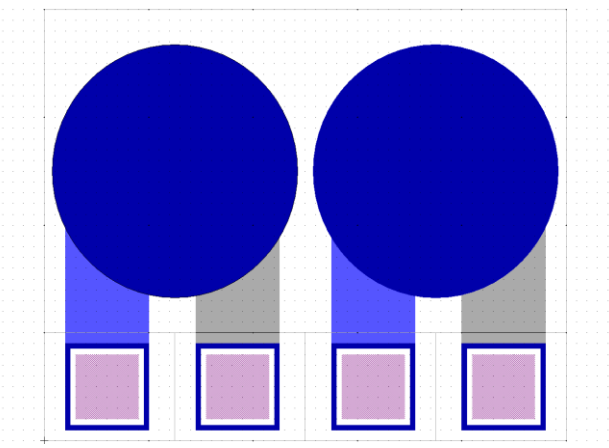
PROCESS DIAGNOSTIC: INTERLEVEL DIELECTRIC CAPACITORS

- radius = 1175 μm, overlap area = 4.3374 mm^2:



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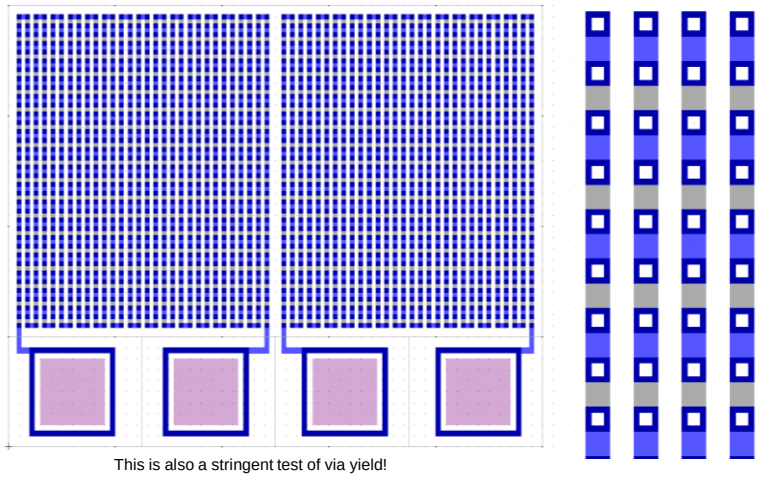
PROCESS DIAGNOSTIC: M1-VIA-M2 CHAINS

- 1080 (30 x 36) vias (20 μm sq.) in series, 2 instances:



This is also a stringent test of via yield!

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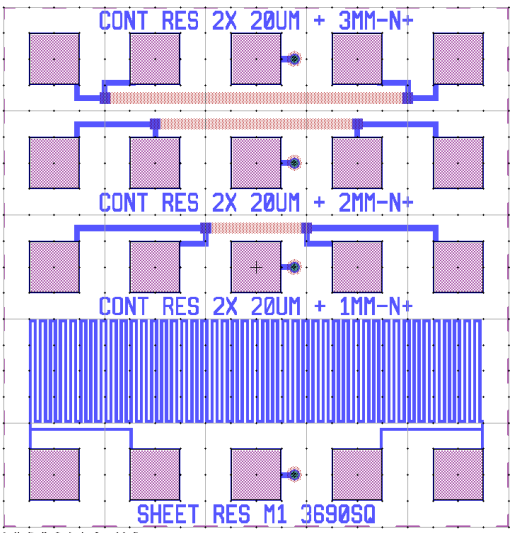
PROCESS DIAGNOSTIC: INTERCONNECT RESISTANCES



Upper three test structures provide a 4-wire Kelvin resistance measurement of 2 contacts (20 μm sq. ea.) plus three different lengths of n-type diffusion.

These three resistance measurements can be used to extract the resistance of each contact and the sheet resistance of the n-type diffusion.

The lower structure provides a measurement of the sheet resistance of Metal1 using 3690 squares.

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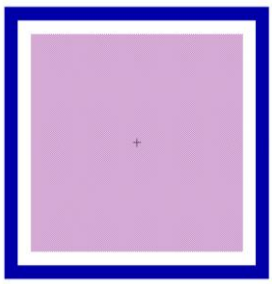
BONDING PADS

- Note: Bonding pads do not scale with Moore's Law!
  - A bond wire is still the same diameter as it has always been.
- Size is dictated by the bonding technology:
  - 100 µm sq. is large and generous, and allows at least 2 tries with either gold ball or aluminum wedge bonders.
  - 50 µm sq. is about the smallest practical for commercial ICs.
  - 200 µm sq. is used in the EE-527 masks.
- Probe pads may also be used:
  - Size depends upon the probe station.
  - 50 µm is good for general research.
  - 25 µm is reasonable with high end probes.
- Pogo pin pads: (huge!)
  - 200 to 1000 µm for wafer contact points.
  - Not common, but useful for R&D.
  - Good for very fast, low cost wafer testing.



USING MASK SETS EFFECTIVELY FOR R&D

- Mask sets are generally more effective when professionally produced, but this adds more cost.
- The investment in design and layout time should be offset by a mask set which covers as much ground as possible.
- Approaches:
  - Splits: Use different subsets of the same mask set to support several slightly different, but largely common process flows.
  - Options: Add a few additional masks for optional process steps to increase the overall versatility of the mask set.
  - Cells: Fabricate standard cells that are already tested and interconnect them differently using only the last metal mask.
  - Multiproject: (MPW) Include several different project die within the same mask set if the process flow can support them simultaneously.

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