EE 527 MICROFABRICATION

Lecture 18 Tai-Chang Chen University of Washington



STANDING WAVES - 1

- Short exposure wavelengths can create standing waves in a layer of photoresist. Regions of constructive interference create increased exposure.
- These can impair the structure of the resist, but can be eliminated by:
 - use of multiple wavelength sources
 - postbaking
- Effects are most noticeable at the edge of the resist.



 1_{1}

STANDING WAVES - 2

- Standing waves are enhanced by reflective wafer surfaces.
- If the wafer or substrate is transparent, reflections from the aligner chuck can create standing wave patterns, also.
 - This can be eliminated by using:
 - a flat black chuck (anodized aluminum)
 - an optical absorber under the wafer (lint free black paper)
 - a transparent glass chuck (used on Karl Suss MJB3)
- Exposures can be greatly miscalculated by the presence of standing waves and reflective wafers or chucks.



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PROXIMITY EXPOSURE EFFECT - 1



50:50 grating

dark field

Optimum exposure depends upon the pattern!!!

Adjacent clear (bright) regions add additional exposure to a given region because of overlap from Gaussian tail of the linespread function.



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PHASE SHIFTING MASKS





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MODULATION TRANSFER FUNCTION IN PHOTOLITHOGRAPHY





PROXIMITY (DIFFRACTION) EFFECTS ON FEATURE





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CORNER COMPENSATION OF FEATURES





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REDUCTION STEPPERS

- By making the mask plate larger, the defect tolerance can be greatly improved.
- Projection and reduction optics are now required.
- Originally, most systems were 10:1 reduction.
- The first commercially successful one was the GCA 4800 DSW system.
- Now, most DSW systems are 4:1 reduction.
 - Less reduction allows for larger step areas and larger chips.



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ADVANTAGES OF POSITIVE PHOTORESISTS

- They are more commonly used in the IC industry.
- They are superior to negative photoresists because:
 - They do not swell during development.
 - They are capable of finer resolution.
 - They are reasonably resistant to plasma processing operations such as dry etching.



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PHENOLIC RESINS - 1

- Phenolic resins are condensation polymers of aromatic alcohols and formaldehyde.
- Phenolic resins are readily cross-linked by thermal activation into rigid forms.
- Most phenolic resins are readily dissolved by aqueous alkaline solutions:
 - NaOH; contains Na⁺ so it is NOT CMOS compatible.
 - KOH; contain K⁺ so it is NOT CMOS compatible.
 - NH₄OH; it is CMOS compatible, but it is hard to keep at a constant concentration due to evaporation of NH₃.
 - TMAH (CH₃)₄NOH; it is CMOS compatible and the most common base for use in positive photoresist developers.



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PHOTOREACTION IN A POSITIVE PHOTORESIST





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DISSOLUTION OF PHENOLIC RESINS

- Because of the OH groups, phenolic resins are hydrophilic and are readily dissolved by aqueous alkaline solutions.
- Diazonaphthaquinone (DQ) is a hydrophobic and non-ionizable compound.
- When phenolic resins are impregnated with DQ, they become hydrophobic and their dissolution is greatly inhibited.
- After exposure, DQ is converted into indene carboxylic acid (ICA) which is hydrophilic and very ionizable.
 - This allows the developer to wet and penetrate the novolac resin.
- Phenolic resins which contain ICA instead of DQ are readily dissolved by aqueous alkaline developers.



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DQ SIDE REACTIONS - 1 H_2C CH3 HO novolac resin a ketene The ketene can Lack of humidity in a form cross-links clean room will with the novolac if dehydrate the $H_2($ insufficient water photoresist and is present-- just promote this the opposite of CH_3 reaction. what is desired ... cresol ester This is one reason why positive photoresist is so sensitive to humidity! Ketene scavengers, e.g. amines, are sometimes added to reduce this. WASHINGTON © UWEE TC Chen Winter 2014

DQ SIDE REACTIONS - 2

This reaction always occurs to some extent, it causes the red color of photoresist, and it is benign as long as the DQ content is not overly depleted.

This reaction is more prevalent in the unirradiated areas where the DQ has not been consumed by the photolysis reaction.

This reaction is one of the basic shelf-life limits to positive photoresist.





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PHYSICAL REQUIREMENTS ON THE PHOTOACTIVE COMPONENT

- Need an overlap of the absorption spectrum with the emission spectrum of the exposure source, e.g. a Hg lamp.
- Need bleachability at the exposure wavelength so that the photoreaction is able to reach the resist-substrate interface.
- Need compatibility with the base resin (novolac) so that the two form a single, miscible phase.
- Need thermal stability so that the photoactive dissolution inhibitor does not break down at prebake temperatures.
- Photoactive dissolution inhibitors are often modified to alter their spectral absorption, thermal stability, and miscibility characteristics.



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PRIMARY COMPONENTS OF A POSITIVE PHOTORESIST

- Non-photosensitive base phenolic resin (~48% by weight)
 - usually novolac
- Photosensitive dissolution inhibitor (~4% by weight)
 - usually a DQ-derived compound
- Coating solvent (~48% by weight)
 - usually a mixture of:
 - ~80% 2-ethoxyethyl acetate, ← this is the hazardous component
 - ~10% n-butyl acetate, and
 - ~10% xylene.
- Above weight ratios are typical for a 1-2 μm thick resist viscosity.
 - Thicker resists will have less coating solvent, thinner resists more.



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