EE 527 MICROFABRICATION

Lecture 8 Tai-Chang Chen University of Washington



EVAPORATION/APPLICATION OF THE COSINE LAW - 2

Uniformity of an evaporated film across a wafer:



$$\frac{dM_c}{dA_c} = \frac{M_e}{\pi r^2} \cos(\varphi) \cos(\psi)$$

reduction factor for edge thickness:

$$\frac{d_{edge}}{d_{center}} = \frac{r_0^2}{r_0^2 + r_w^2} \cos(\varphi) \cos(\psi)$$
$$= \left[\frac{r_0^2}{r_0^2 + r_w^2}\right]^2 = \frac{1}{\left[1 + \left(\frac{r_w}{r_0}\right)^2\right]^{-2}}$$

Example:

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 1_{1}

EVAPORATION/ELECTRON BEAM HEATED EVAPORATION - 1

- More complex, but extremely versatile.
- Can achieve temperatures in excess of 3000°C.
- Use evaporation cones or crucibles in a copper hearth.
- Typical emission voltage is 8-10 kV.
- Exposes substrates to secondary electron radiation.
 - X-rays can also be generated by high voltage electron beam.
- Typical deposition rates are 10-100 Angstroms/second.
- Common evaporant materials:
 - Everything a resistance heated evaporator will accommodate, plus:
 - Ni, Pt, Ir, Rh, Ti, V, Zr, W, Ta, Mo
 - Al₂O₃, SiO, SiO₂, SnO₂, TiO₂, ZrO₂



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EVAPORATION/ELECTRON BEAM HEATED EVAPORATION - 2

- 270° bent beam electron gun is most preferred:
 - Filament is out of direct exposure from evaporant flux.
 - Magnetic field can be used for beam focusing.
 - Magnetic field can be used for beam positioning.
 - Additional lateral magnetic field can be used to produce X-Y sweep.
- Sweeping or rastering of the evaporant source is useful for:
 - Allows a larger evaporant surface area for higher deposition rates.
 - Allows initial charge to be "soaked" or preheated.
 - Allows evaporant source to be more fully utilized.
- Multiple pocket rotary hearth is also preferred:
 - Allows sequential deposition of layers with a single pump-down.
 - Allows larger evaporation sources to be used.



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EVAPORATION/ADSORPTION

- Adsorption is the sticking of a particle to a surface.
- Physisorption:
 - The impinging molecule loses kinetic (thermal) energy within some residence time, and the lower energy of the molecule does not allow it to overcome the threshold that is needed to escape.
- Chemisorption:
 - The impinging molecule loses its kinetic energy to a chemical reaction which forms a chemical bond between it and other substrate atoms.



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EVAPORATION/CONDENSATION OF EVAPORANT-1

- Condensation of a vapor to a solid or liquid occurs when the partial pressure of the vapor exceeds the equilibrium vapor pressure of the condensed phase at this temperature.
- The vapor is "supersaturated" under these conditions.
- Molecules impinging upon a surface may:
 - Adsorb and permanently stick where they land (rare!).
 - Adsorb and permanently stick after diffusing around on the surface to find an appropriate site.
 - This can lead to physisorption or chemisorption.
 - Adsorb and then desorb after some residence time $\tau_{\mathsf{a}}.$
 - Immediately reflect off of the surface.



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EVAPORATION/CONDENSATION OF EVAPORANT-2

- Incident vapor molecules normally have a kinetic energy much higher than *energy* of the substrate surface.
- Whether an atom or molecule will stick depends upon how well it can equilibrate with the substrate surface, decreasing its energy to the point where it will not subsequently desorb.
 - If the impingement rate stops, then the adsorbed molecules will all eventually desorb.
 - Condensation of a permanent deposit will not occur, even for low substrate temperatures, unless the molecules interact.
- Within the mean residence time, surface migration occurs and clusters form.
- Clusters have smaller surface-to-volume ratios, and therefore desorb at a reduced rate.
- Nucleation of a permanent deposit is therefore dependent upon clustering of the adsorbed molecules.

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EVAPORATION/OBSERVED GROWTH OF A DEPOSITED FILM

- Adsorbed monomers
- Subcritical embryos of various sizes
- Formation of critically sized nuclei
- Growth of nuclei to supercritical size and depletion of monomers within their capture zones
- Nucleation of critical clusters within non-depleted areas
- Clusters touch and coalesce into new islands, exposing fresh substrate areas
- Adsorption of monomers onto fresh areas
- Larger islands grow together leaving holes and channels
- Channels and holes fill to form a continuous film



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EVAPORATION/MODES OF THIN FILM GROWTH

(1) Volmer-Weber: (island growth):

M. Volmer and A. Weber, Z. Phys. Chem. 119, p. 277 (1926).

(2) Frank-Van der Merwe: (layer growth; ideal epitaxy):

F. C. Frank and J. H. Van der Merwe, Proc. R. Soc. London, Ser. A 198, p. 205 (1949).

(3) Stranski-Krastanov: (layers + islands):



J. N. Stranski and L. Krastanov, Ber. Akad. Wiss. Wien 146, p. 797 (1938).



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EVAPORATION/CONDENSATION CONTROL

- Control of condensation of the evaporant is achieved through the control of substrate temperature T_s.
- Higher substrate temperatures:
 - Increase thermal energy of adsorbed molecules.
 (Shortens the residence time.)
 - Increase surface diffusivity of adsorbed molecules.
 - Performs annealing of deposited film.
- Substrate heaters:
 - Quartz IR lamps from frontside
 - Ta, W, or Mo foil heaters from backside
 - Graphite impregnated cloth heaters from backside
- Too much heat will desorb the deposited film, evaporating it away! (But this can be used for cleaning...)



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EVAPORATION/EVAPORATION SYSTEM REQUIREMENTS

- Vacuum:
 - Need 10⁻⁶ torr for medium quality films.
 - Can be accomplished in UHV down to 10^{-9} torr.
- Cooling water:
 - Hearth
 - Thickness monitor
 - Bell jar
- Mechanical shutter:
 - Evaporation rate is set by temperature of source, but this cannot be turned on and off rapidly. A mechanical shutter allows evaporant flux to be rapidly modulated.
- Electrical power:

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EVAPORATION/EVAPORATION SUPPORT MATERIALS

- Refractory metals:
 - Tungsten (W); MP = 3380°C, P* = 10⁻² torr at 3230°C
 - Tantalum (Ta); MP = 3000°C, P* = 10⁻² torr at 3060°C
 - Molybdenum (Mo); MP = 2620°C, P* = 10⁻² torr at 2530°C
- Refractory ceramics:
 - Graphitic Carbon (C); MP = 3700°C, P* = 10⁻² torr at 2600°C
 - Alumina (Al₂O₃); MP = 2030°C, P* = 10⁻² torr at 1900°C
 - Boron nitride (BN); MP = 2500°C, P* = 10⁻² torr at 1600°C
- Engineering considerations:
 - Thermal conductivity
 - Thermal expansion
 - Electrical conductivity
 - Wettability and reactivity



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