EUV at 22nm node: tolerance for shot noise?

R. Bristol, M. Shell, T. Younkin, S. Putna.

Intel Components Research

IEUVI wkshp, 2/28/2008

“Shot Noise” (here, photon noise)

- EUV photons (92eV) are 14.3x as energetic as 193nm photons.
- So there’s fewer of them -> having a few more or less may be a significant % change. Looks like an effective dose fluctuation appears from one feature to the next. This Impacts contact size variation, LWR, etc.
- Let’s look at some estimated magnitudes of these fluctuations for EUV at nominal 22nm node features sizes.
- Several fine models exist which address details of the implications of these fluctuations (such as LWR); we will restrain to simply counting photons in the feature of interest.

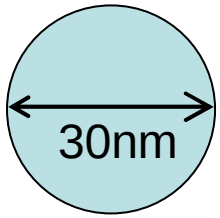
Basic method

- Simple counting exercise of photons in small features in resist. Fluctuations then calculated with Poisson statistics.
  - Technically, photons are governed by Bose-Einstein statistics, but at the high T and incoherence of the source plasma this becomes Poisson (Gaussian at large N).
  - Also throw in # of acids generated via quantum efficiency.
- Many other sources of fluctuations are not included.
- Ref: Bristol et al SPIE ’02, ’07

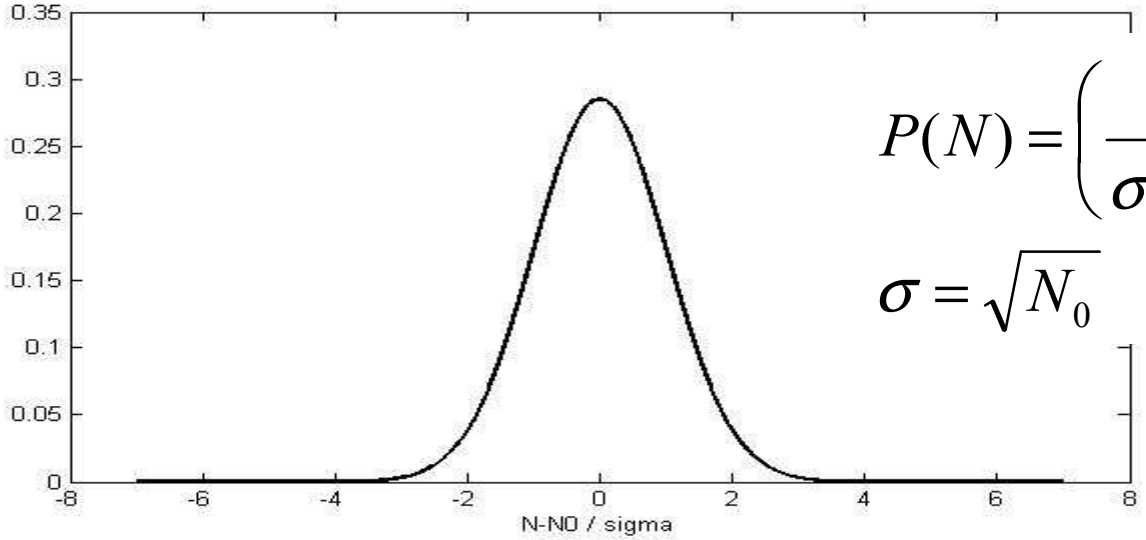
“22nm” node example features

- 30nm round contact = 707nm2

- Could also apply to be any other 700nm^2 feature of interest.
  - Section of gate, critical interconnect region, etc.



Shot noise stats: Gaussian Distribution
(for large N)



$$P(N) = \left(\frac{1}{\sigma\sqrt{2\pi}}\right) e^{-\frac{(N-N_0)^2}{2\sigma^2}}$$

$$\sigma = \sqrt{N_0}$$

- # photons landing on a feature: most fall near the average value of N_0.
  99.7% land within +- **3σ**.

- For ~1B features, some with have +- **6σ** about mean.
  - Extreme Example: if N_0=100, then a few actually get 40 or 160 photons.

- # EUV photons: N_0 = Area(nm^2) * Dose(mJ/cm^2) * 0.67 photons

Example: 30nm contacts @ 15mJ

➔ Only absorbed photon # fluctuations for now.

N_{abs} = Area(nm^2) * Dose(mJ/cm^2) * 0.67 photons

A=707nm^2, α = 0.3 ➔ N_{abs} = 1421.

➔ σ = sqrt(N_{abs}) = 92.

So 1B contacts will see a range in incident photon # from:

N_{abs} =	1195	to	1647
	-16%		+16%

➔ Therefore the process must be tolerant to effective dose fluctuations of ±16% due to photon shot noise (in addition to usual process latitude).

➔ Details of whether this might lead to shot-noise induced defects (e.g. gate to trench short) highly process dependent.

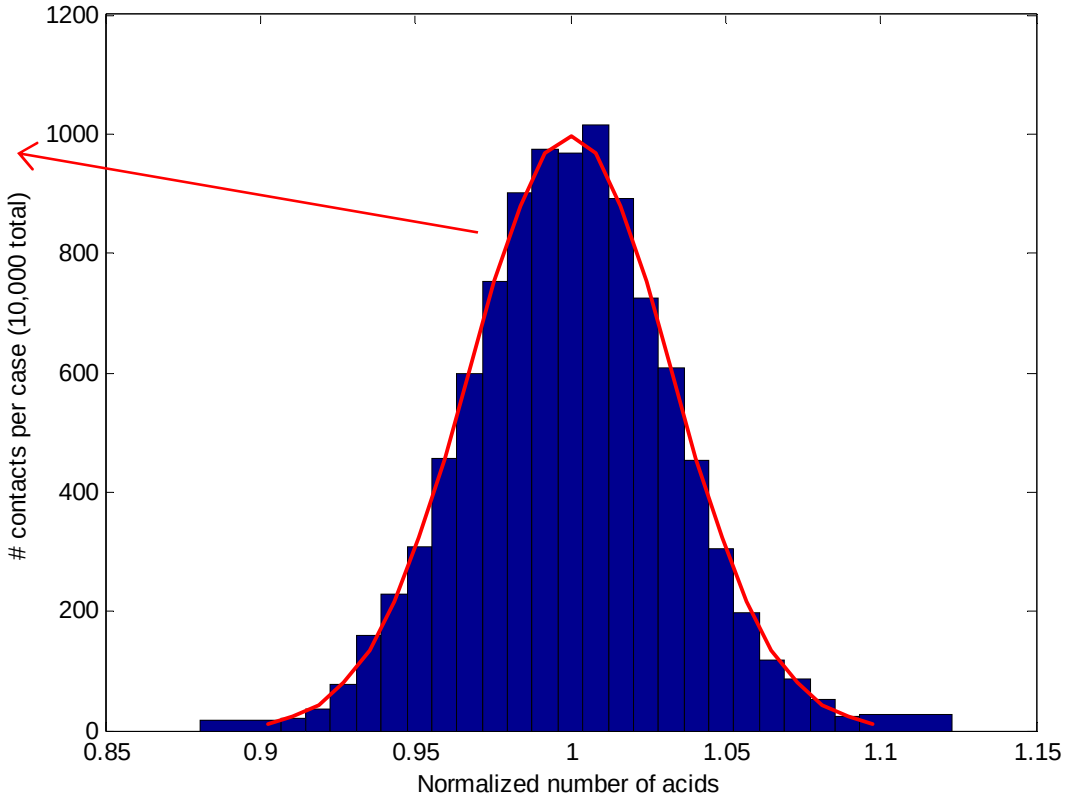
30nm “contacts” @ 10mJ, α = 0.3, ε = 2
➔Incident #, absorption, and acid generation

➔ For each contact, random number from Gaussian distribution determines absorbed # photons. For each of these, random number from Poisson-distribution (average of ε) gives actual number of acids activated.

$$P(N_{acid}) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(N_{acid} - \alpha\varepsilon N_{inc})^2}{2\sigma^2} \right)$$

$$\sigma_{acid} = \sqrt{\alpha N_{inc}} \sqrt{1 + \frac{1}{\varepsilon}}$$

6σ = 20%



Summary

- Simple Gaussian photon-counting for 30nm contacts to 6σ implies effective dose fluctuation of ±16% will appear.
- Including acid counting, fluctuation rises to ± 20%.
- Process must be tolerant of such fluctuations, otherwise shot noise induced defects may appear.
  - Contact landing gate shorting, interconnect shorting, etc
- Practical importance of this issue will only be seen with integrated 22nm patterning.
- Used α=0.3, 10mJ/cm^2, ε=2 but results not greatly sensitive to these choices (goes as sqrt(N)