Characterization of the Spatial Aspects of Line Edge Roughness

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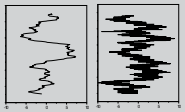
MOTIVATION

How is roughness (LER) described ?

Sigma is the RMS deviation from the mean edge

However sigma is not a complete descriptor of LER. Because....

1) Sigma does not describe Spatial roughness.



Two edges with equal sigma but different

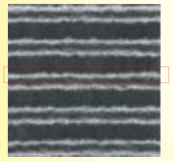
} **Need for spatial LER Analysis**

2) **Sigma depends on edge length L.**

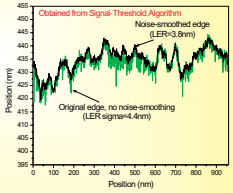
What are the parameters needed to characterize LER ?

EDGE DETECTION
(from many resist top-down SEM images)

Top-down SEM Image



Detected Line-Edge



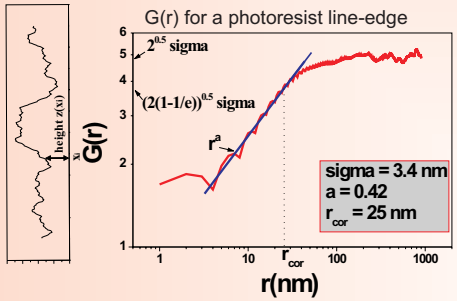
Edge detection using a signal threshold algorithm

SPATIAL LER ANALYSIS

Method 1 : Height-height correlation function

$$G(r) = \frac{1}{N}\left(\sum_{i=1}^{N}\left[z(x_i+r) - z(x_i)\right]^2\right)^{1/2}$$

G(r) for a photoresist line-edge



Line-edges are self-affine
(i.e., Invariant under anisotropic scaling)

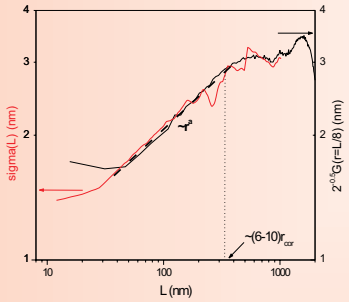
For $r<r_{cor}$: $G(r) \sim r^a$ or $sigma(L) \sim L^a$ => self-affine edge

For $r>>r_{cor}$: G(r) and sigma => constant

Best LER descriptors

sigma: RMS value => Vertical roughness
a: roughness exponent
r_{cor}: correlation length
} Spatial Roughness

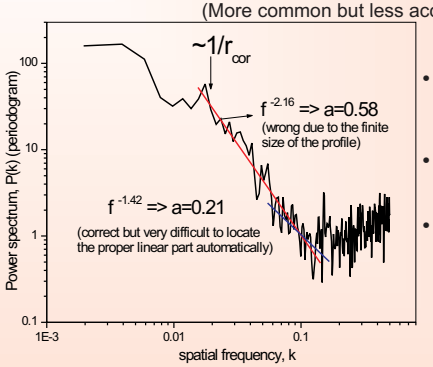
Method 2 : Sigma vs. Edge-Length L



- **(Sigma(L) behavior determined by (a,r_{cor})**
- **Sigma(L)~L^a and saturates for L > (6-10) r_{cor}**
- **Strong effect of length on LER**

Method 3 : Power Spectrum

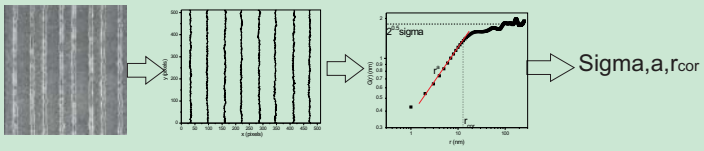
(More common but less accurate)



- $sigma^2 = \frac{1}{2\pi}\int P(k)\,dk$ **(Parseval's theorem)**
- **No systematic r_{cor} determination**
- **Theoretically $P(k) \sim k^{-(2a+1)}$ But unclear linear part in log-log plot => Unreliable (a) estimation**

SOFTWARE FOR LER CHARACTERIZATION
(Available from IMEL DEMOKRITOS)

Contact with G. P. Patsis, gpatsis@imel.demokritos.gr



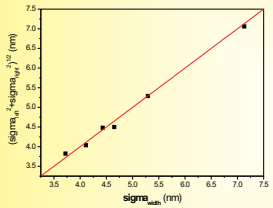
REFERENCES

1. G. P. Patsis, V. Constantoudis, A. Tserepi, and E. Gogolides, "Quantification of line-edge roughness of photoresists. Part I: A comparison between off-line and on-line analysis of top-down SEM images", J. Vac. Sci. Technol. B 21, 1008 (2003).
2. V. Constantoudis, G. P. Patsis, A. Tserepi, and E. Gogolides, "Quantification of Line Edge Roughness of Photoresists. Part II: Scaling and Fractal Analysis and the Best Roughness Descriptors" ,J. Vac. Sci. Technol. B 21, 1019 (2003).
3. G. P. Patsis, V. Constantoudis , A. Tserepi , and E. Gogolides , "Roughness analysis of lithographically produced nanostructures: off line measurement, scaling analysis and Monte Carlo simulations" , Microelectronic Engineering, 67-68, 319 (2003).

LER AND LWR ROUGHNESS

$$sigma_{width}^2 = sigma_{left}^2 + sigma_{right}^2 - \boxed{\frac{2}{N}\sum_{i=1}^{N}(z_{l,i}-\bar{z})(z_{r,i}-\bar{z})}$$

Edge correlations term



- **Experimental edges show that**

$$sigma_{width}^2 = sigma_{left}^2 = sigma_{right}^2$$

- **i.e. edge correlations = 0**

- **Edges uncorrelated**
- **$a_{rightt} = a_{left}$**

} **LWR is self-affine $a_{width}=a_{left}=a_{right}$**

$\min(r_{cor,left}, r_{cor,right}) < r_{cor,width} < \max(r_{cor,left}, r_{cor,right})$

CONCLUSIONS

1) LER and LWR are self-affine

2) Best LER and LWR descriptors are sigma, correlation length r_{cor}, and roughness exponent a

3) Sigma increases with edge-length L as L^a and saturates for L > (6-10) r_{cor}
=> Be careful to analyze resist edges of the same length.

4) Height-height correlation function G(r) more reliable for spatial LER analysis than FFT