Modeling of Pattern Dependent Pressure Non-uniformity at Die-scale for an Integrated CMP model

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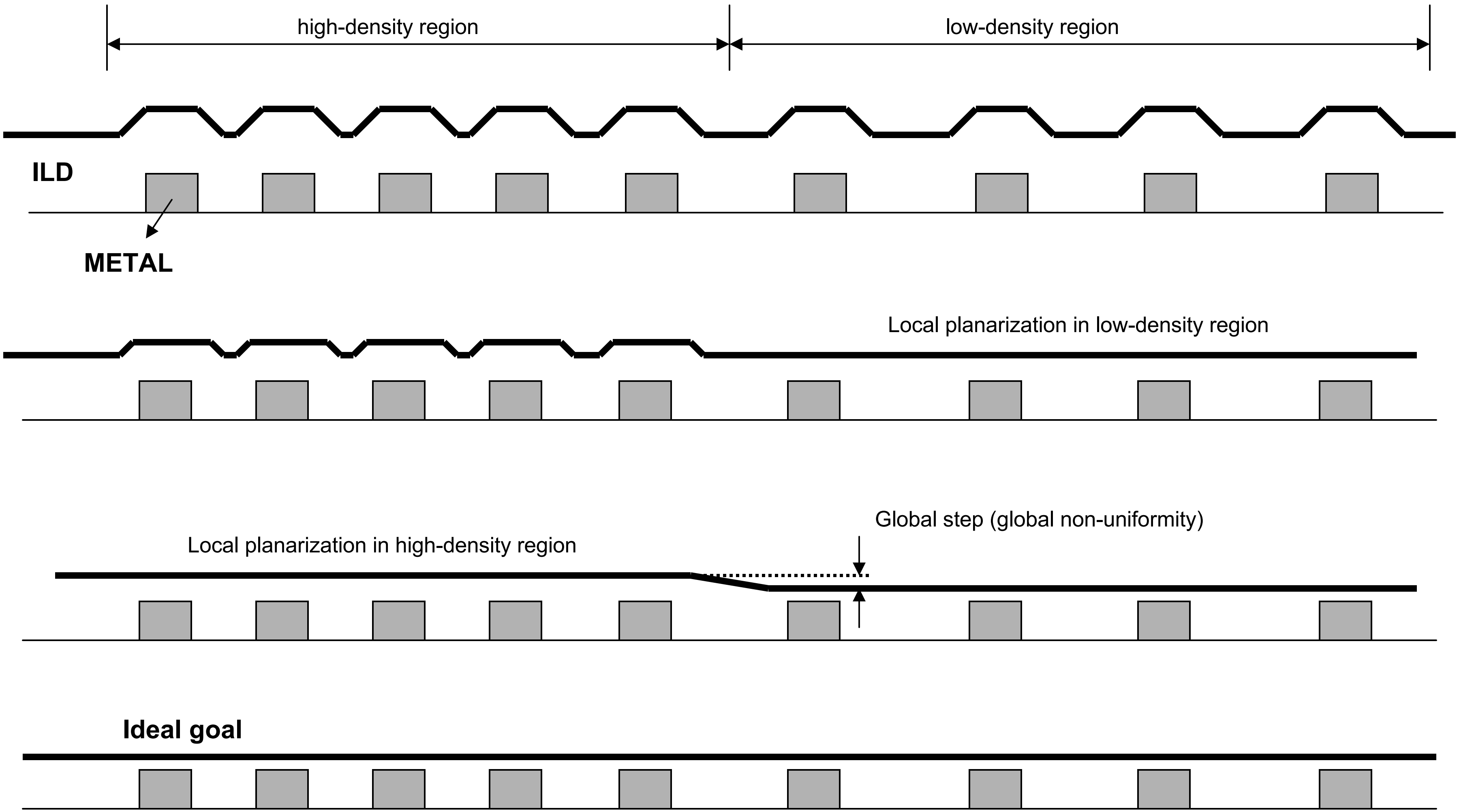
Contents

- Contact wear model and pattern density model
- FEM modeling
- Result and comparison with pattern density based oxide CMP model (MIT model)
- DOE tests with FEM model
- Future works

Contact wear model and pattern density model

Pattern density effect in CMP



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Contact wear model

$$w(x,y) = \frac{(1-\nu^2)}{\pi E}\int_w p(\xi,\eta)\frac{1}{\sqrt{(x-\xi)^2+(y-\eta)^2}}\,d\xi d\eta$$

$$P = \int_w p(\xi,\eta)\,d\xi d\eta$$

$$w(x,y) = f(x,y) + c \quad , \quad (x,y) \in w$$

$$w(x,y) \rangle f(x,y) + c \quad , \quad (x,y) \notin w$$

$$p(x,y) \geq 0 \quad , \quad (x,y) \in w$$

$$p(x,y) = 0 \quad , \quad (x,y) \notin w$$

$w(x,y)$: displacement of the surface

$p(\xi,\eta)$: contact pressure

$$\frac{\partial f(x,y,t)}{\partial t} = k(x,y)p(x,y,t)v(x,y,t)$$

most promising but
computationally too expensive

: Preston equation

(O.G.Chekina et al.
J.Electrochem. Soc., Vol 145, June 1998)

Pattern density dependent oxide model

Basic Form of Prestonian Model (empirical):

$$MRR = K_e P V$$

Pattern density oxide model (semi-empirical) :

$$MRR = \frac{K}{\rho(x,y)}$$

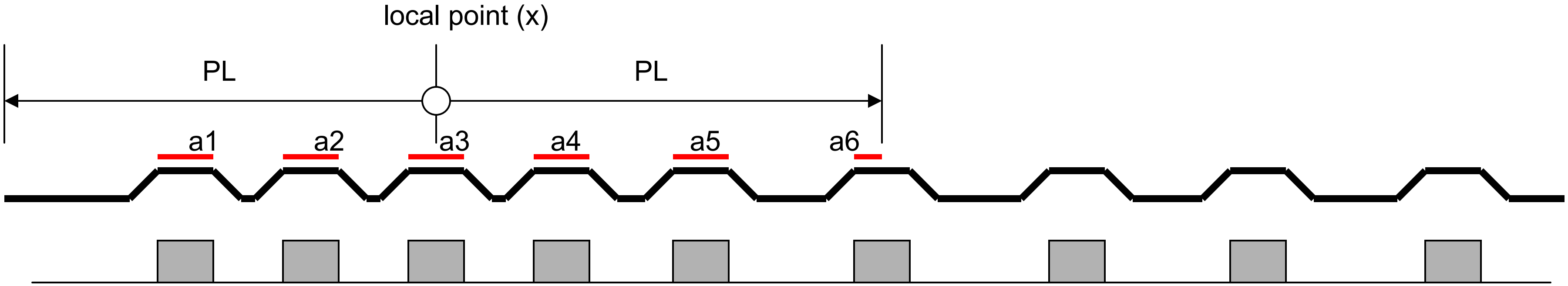
Approximation of the local contact pressure :

$$\boxed{p(x,y) = \frac{K}{K_e V}\frac{1}{\rho(x,y)} = k\frac{1}{\rho(x,y)}}$$

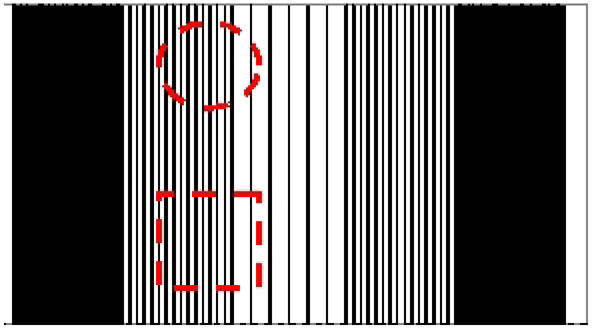
Accuracy : ~ a few hundred angstroms

(B.Stine et al. ,Proc. CMP-MIC Conf.
, Santa Clara, CA, Feb.1997)

Evaluation of Pattern Density



$$\rho(x) = \frac{\sum up\_area}{2PL} = \frac{a1 + a2 + a3 + a4 + a5 + a6}{2PL}$$



Shape of the window for local density evaluation and weighting function should be known

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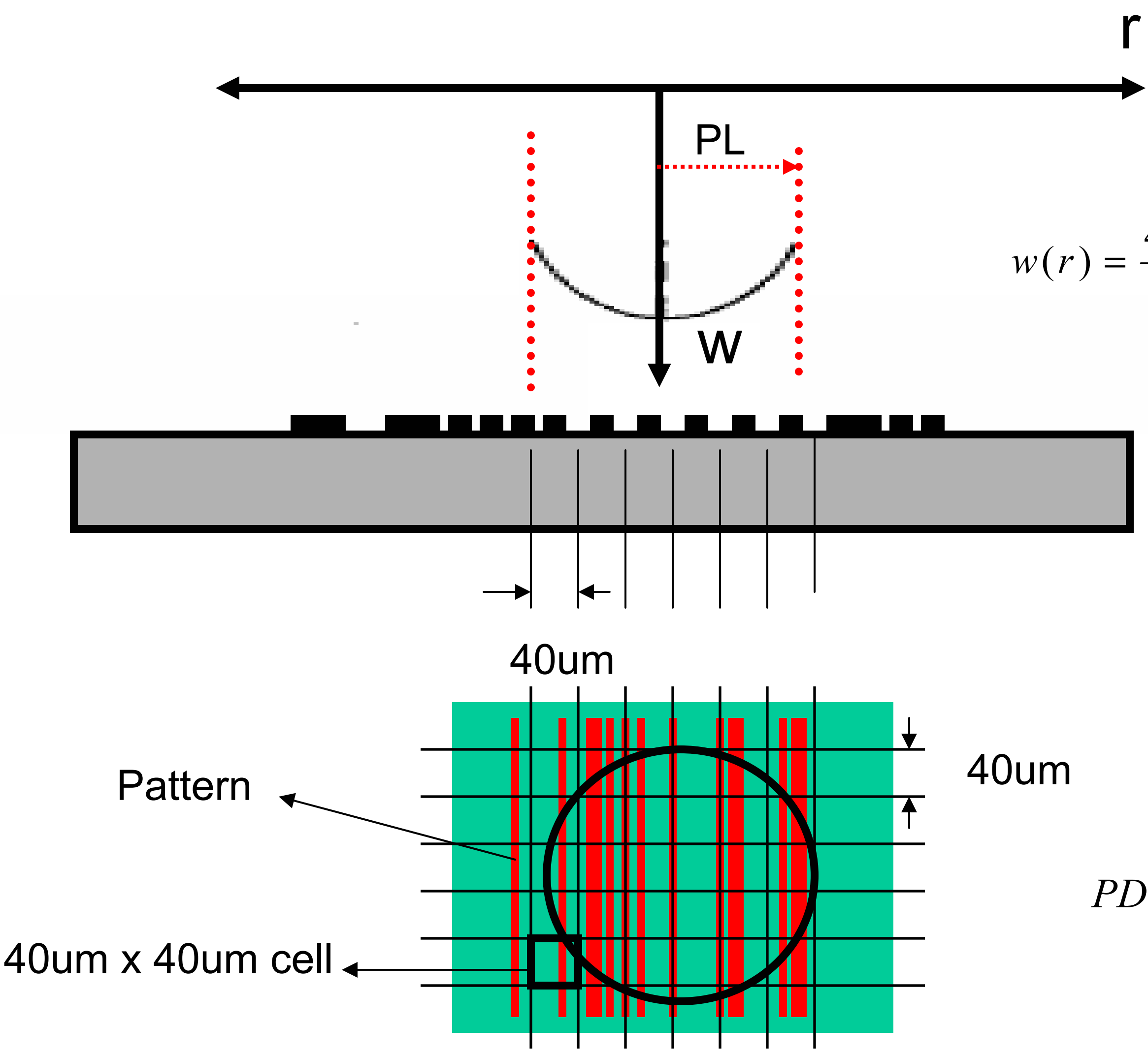
Elliptic weight function from pad deformation profile



$$w(r) = \frac{4(1-\gamma^2)qr}{\pi E}\int_0^{\frac{\pi}{2}}\sqrt{1-\frac{r^2}{PL^2}\sin^2\theta}\,d\theta$$

$$PD_E = \sum_{i,j}\left(\frac{w(i,j)\times PD(i,j)}{\sum_{i,j} w(i,j)}\right)$$

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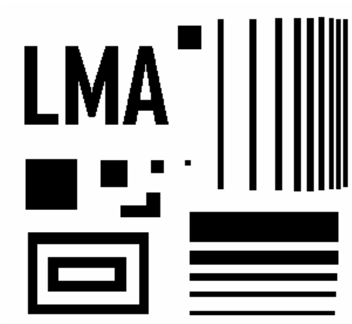
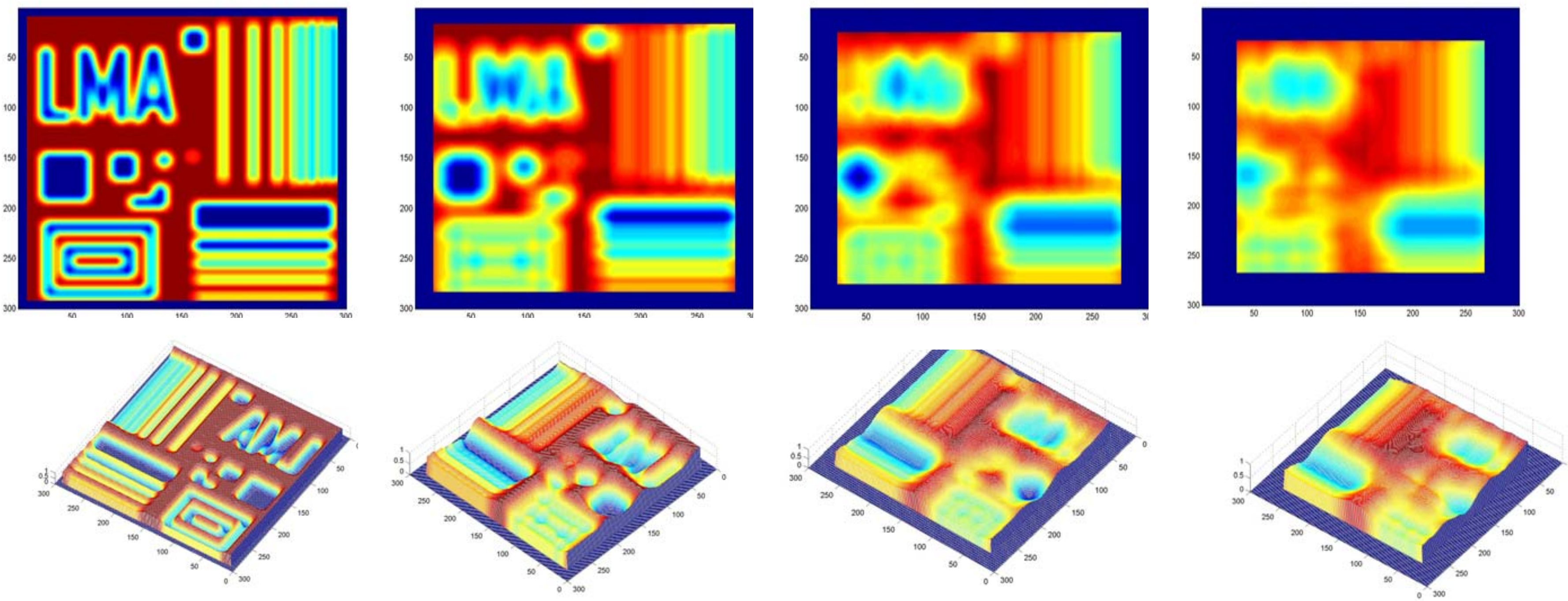
Example of effective pattern density change with PL





PL=320um PL=640um PL=960um PL=1280um

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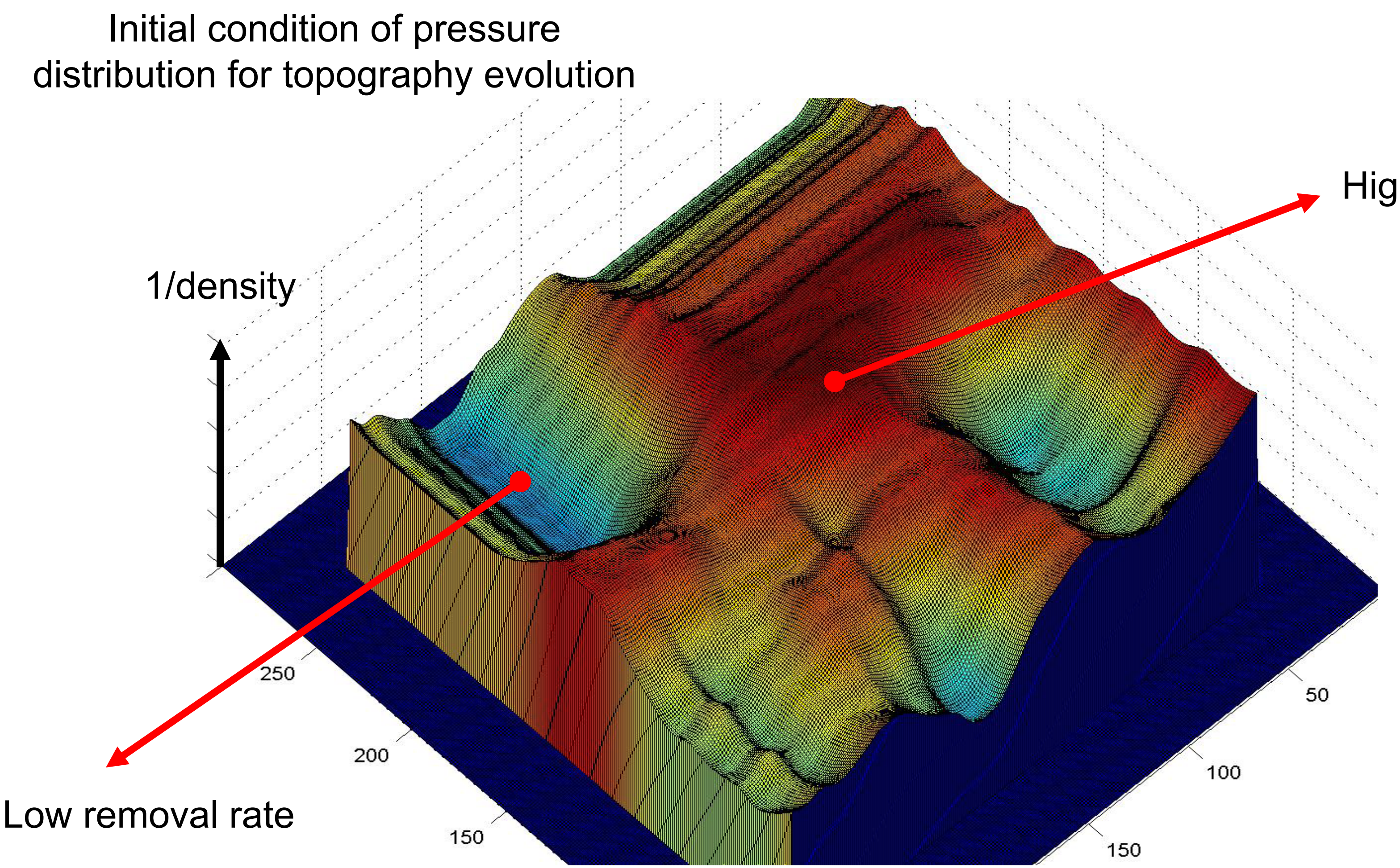
Example of an effective pattern density map

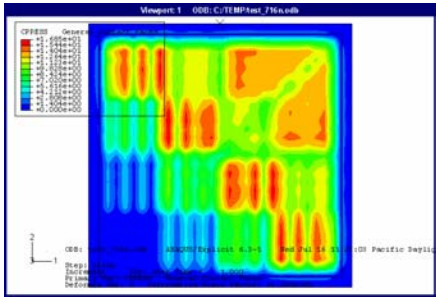


FEM modeling

Difficulties with FEM modeling

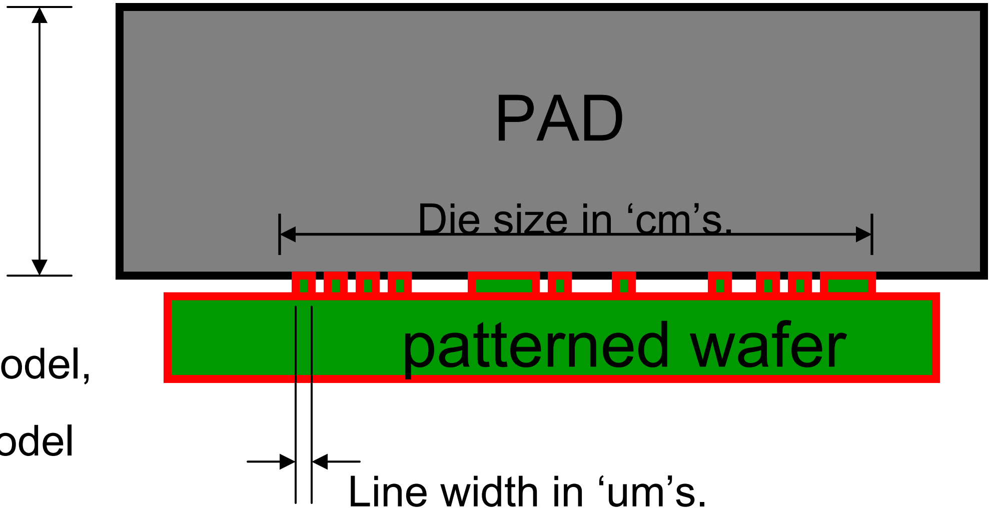
$$p(x,y) = \frac{K}{K_e V}\frac{1}{\rho(x,y)} = k\frac{1}{\rho(x,y)}$$

p(x,y) can be calculated with FEM…



But,

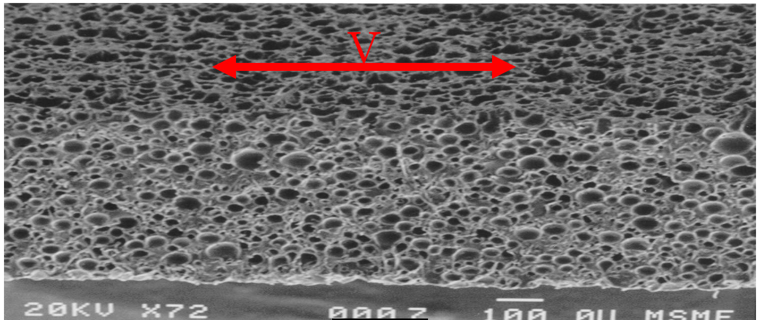
Pad thickness in 'mm's.



~ 1E10 meshes for a 3D model,

~ 1E5 meshes for a 2D model

Simplification



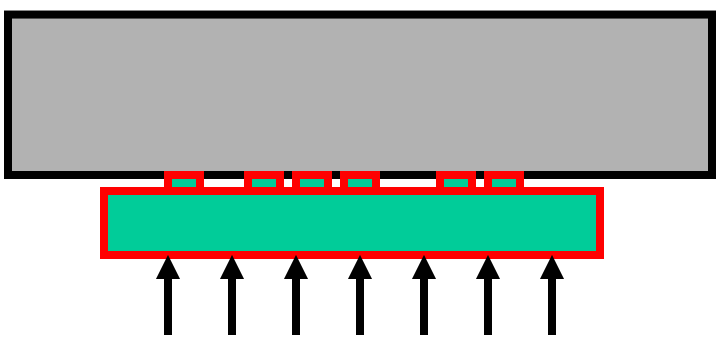
Real PAD :

Random pore structure,

Rough surface,

Moving over pattern,

Visco-elasticity

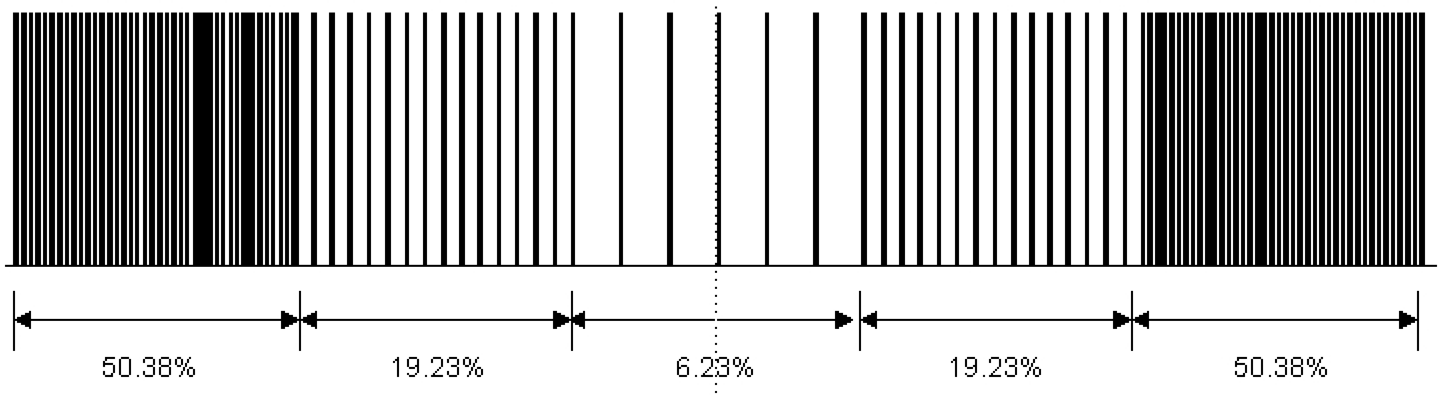


Static model with smooth pad surface without pore :

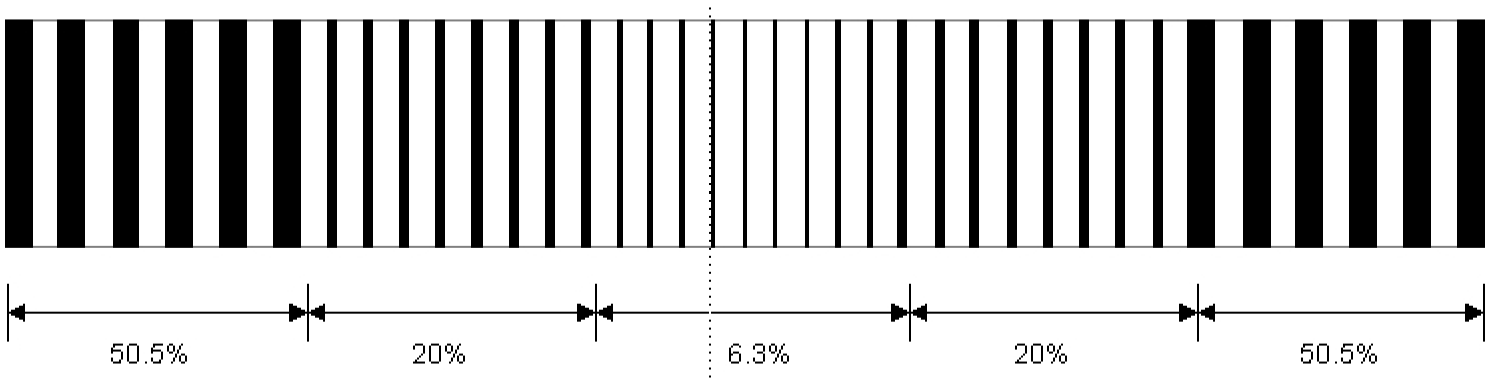
E’, v’ = fn (E,v,Velocity,pore density,pore size etc…)

Test pattern design

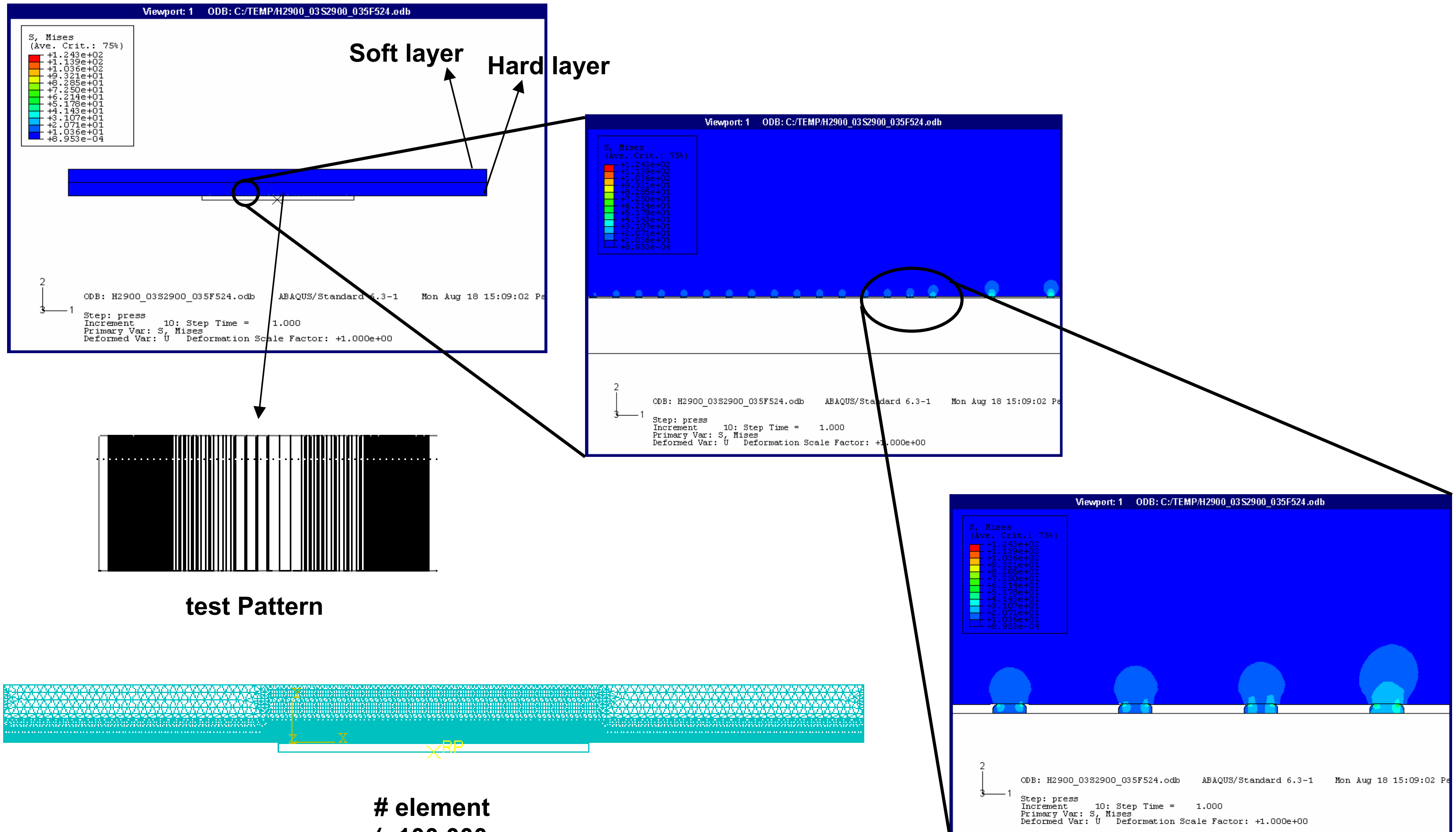
Constant line width (25um)



Constant space (200um)



FEM Model



element (~100,000)

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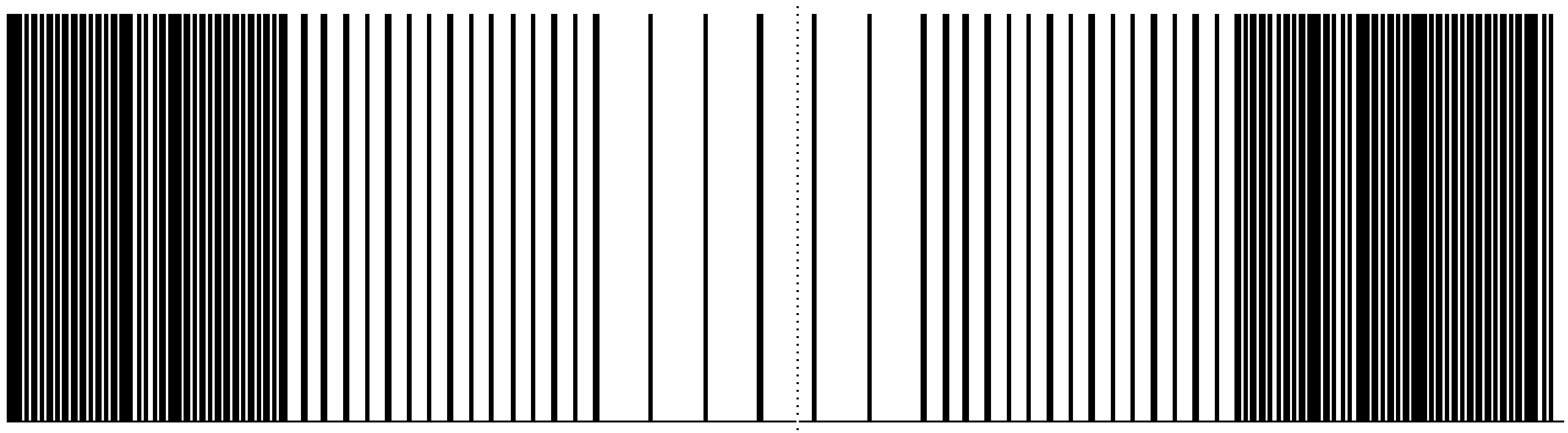
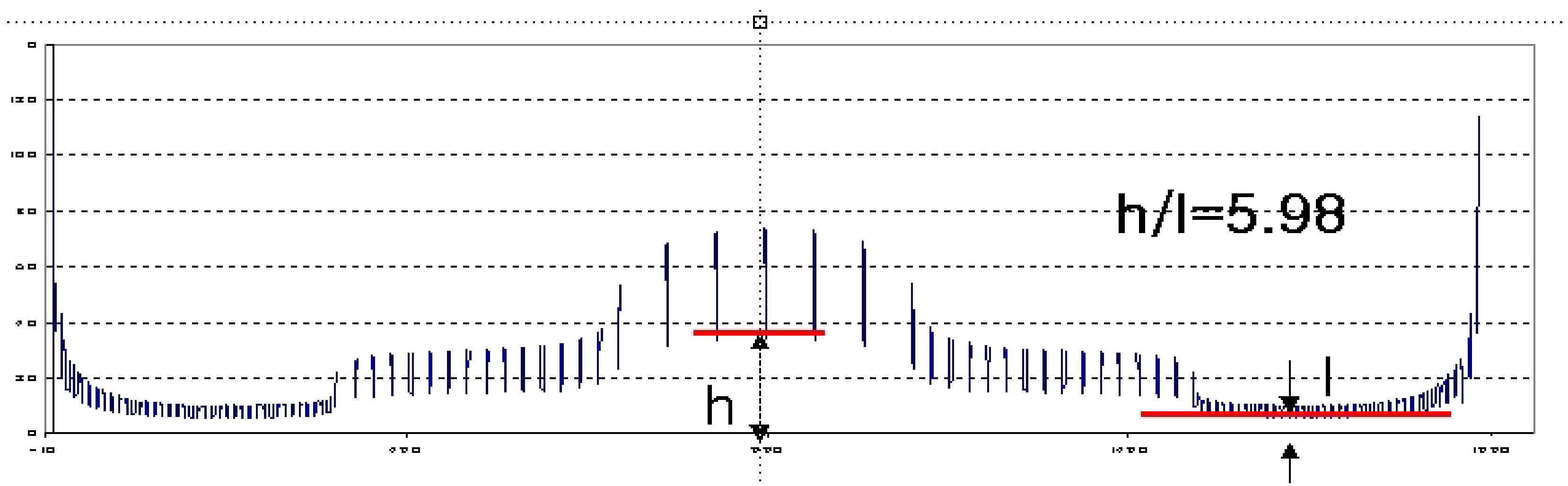
LMA

Contact stress in constant line width model





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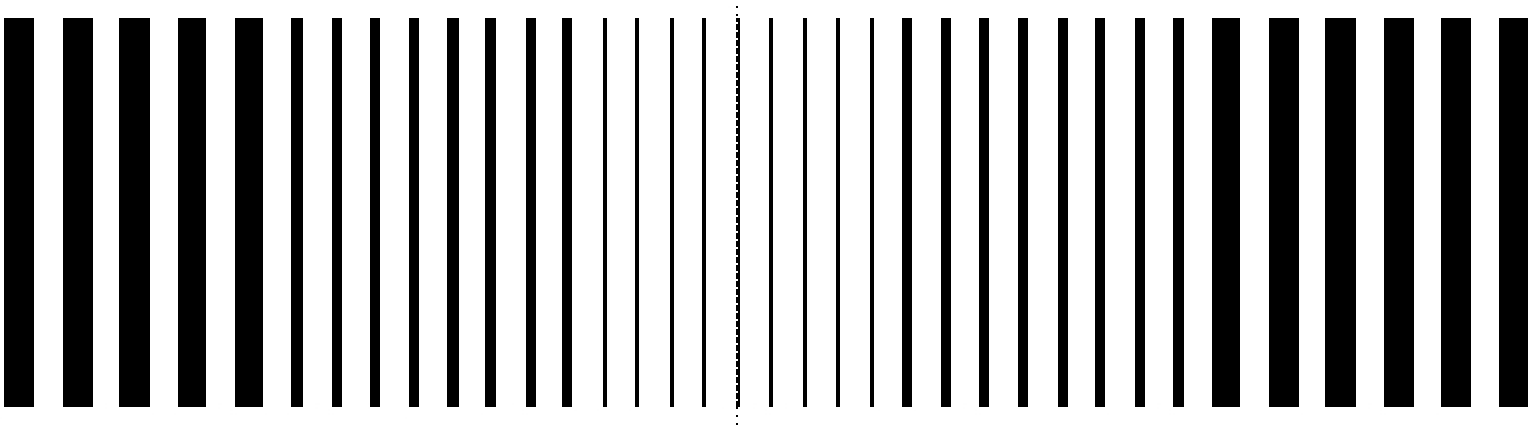
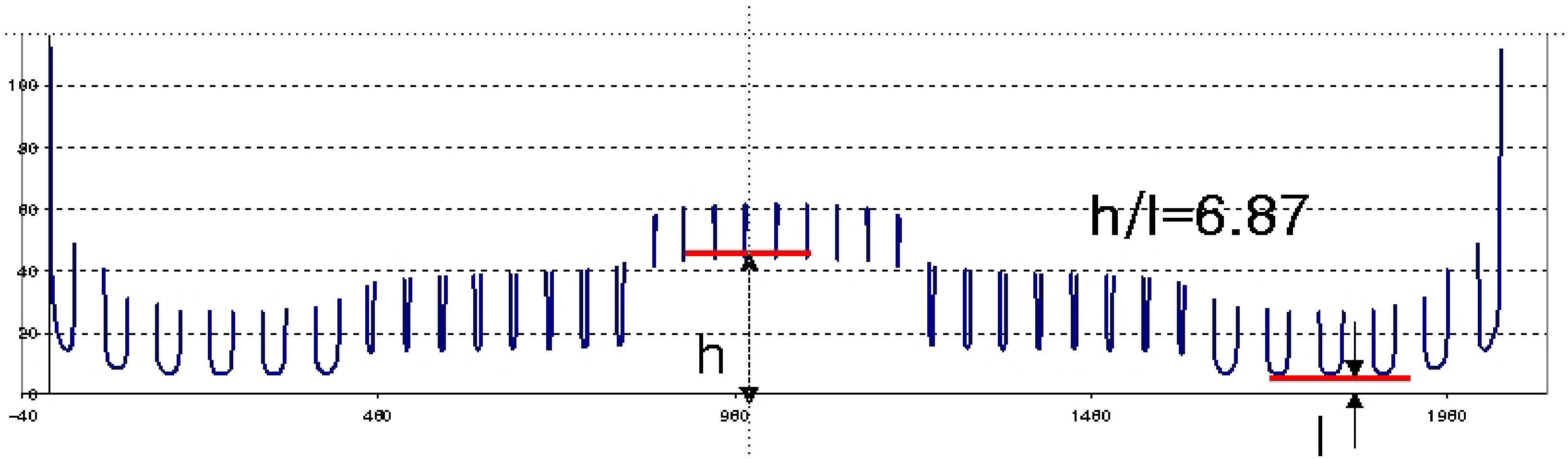
Contact stress in constant space model





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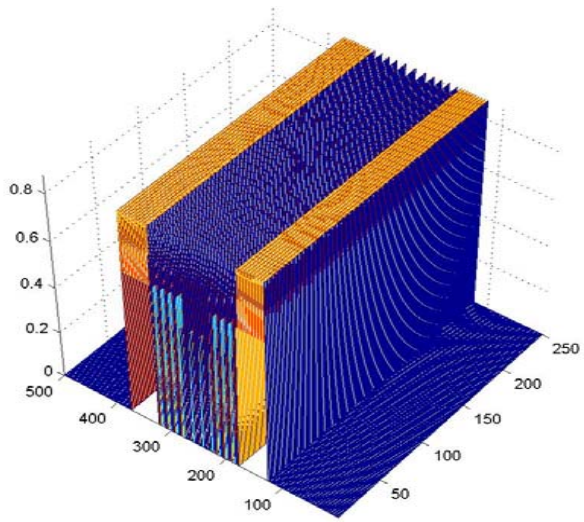
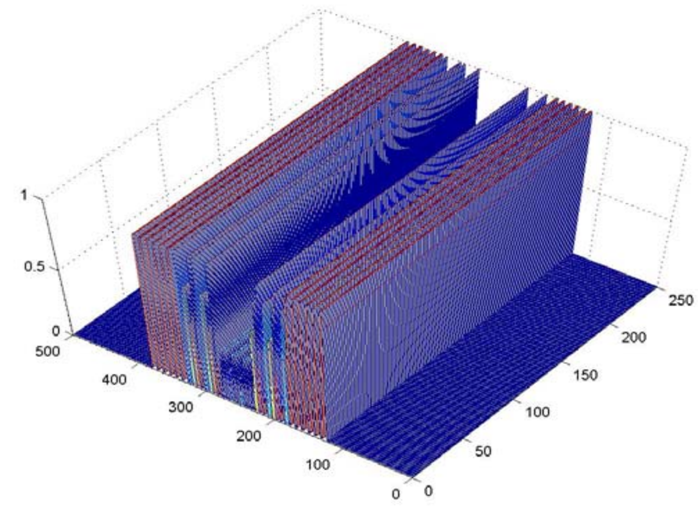
Result and comparison with pattern density based oxide model

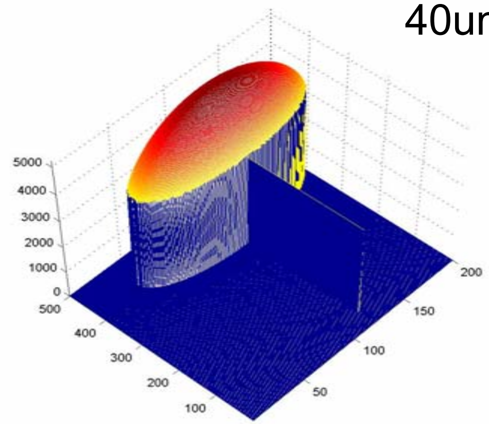
Effective density with elliptic weight function



Density map for const. LW pattern with 40um x 40um cells



Density map for const. space pattern with 40um x 40um cells



Shape of elliptic weight function

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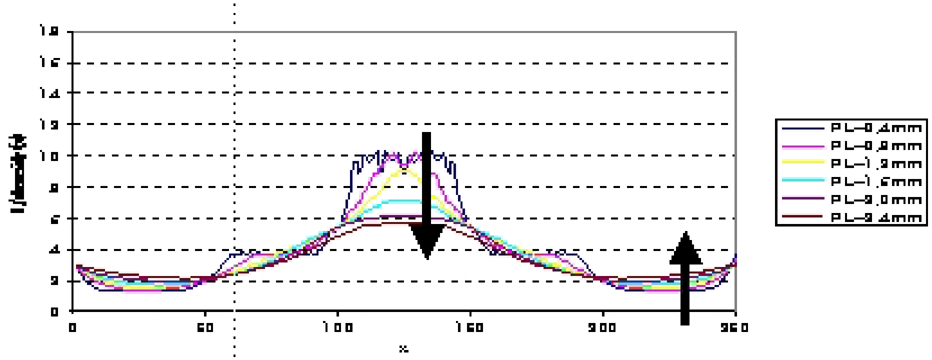
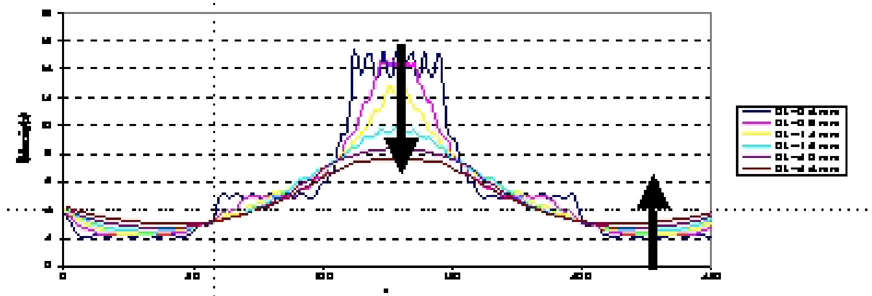
Density profile with weight function

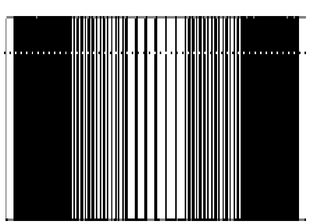
Constant LW pattern :



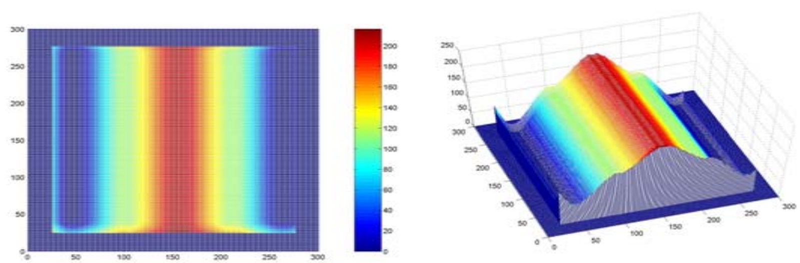
Constant space pattern :



Effective pattern density with PL =1mm :



<pattern
>



<Effective pattern density>

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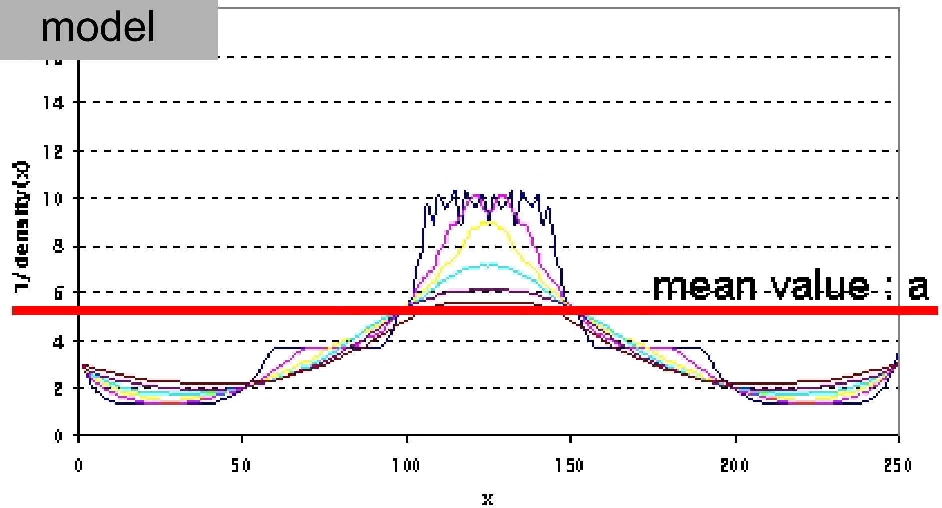
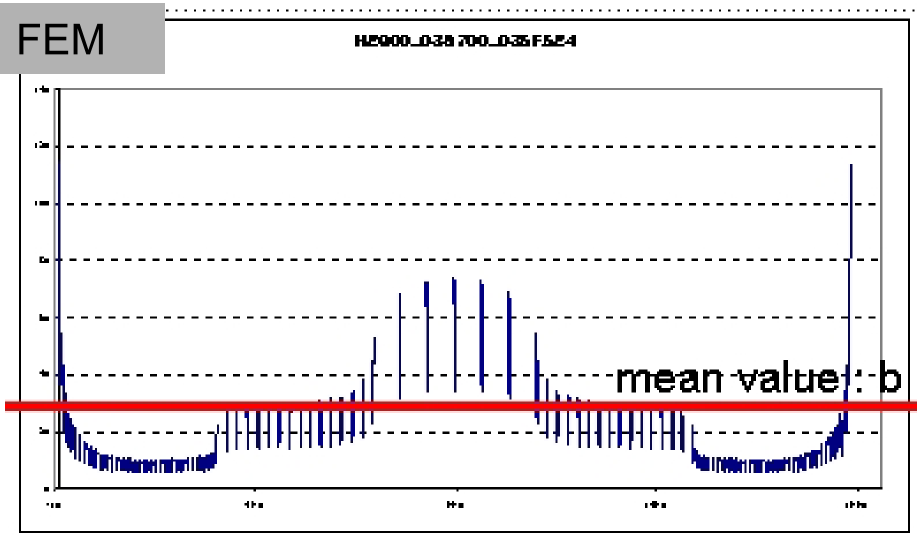
PL for the stress distribution from FEM

Density model



FEM



$$\boxed{p(x,y) = \frac{K}{K_e V}\frac{1}{\rho(x,y)} = k\frac{1}{\rho(x,y)}}$$

Square sum error :

$$\frac{\sum_{n=1}^{K}\left\{\frac{b}{a}\frac{1}{density(n)} - P(n)\right\}^2}{n}$$

PL :

PL value that minimize square sum error

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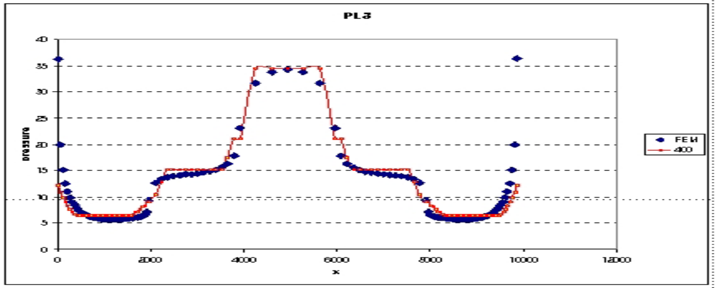
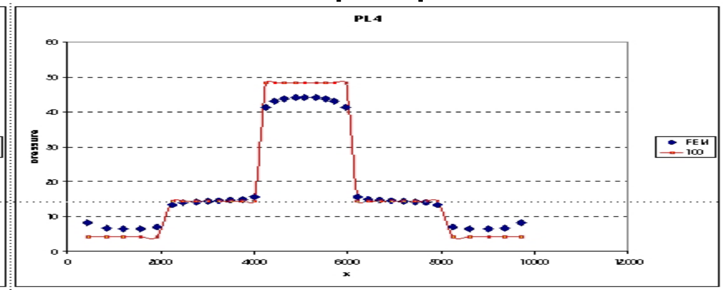
Comparison with pattern density based oxide CMP model

Constant line width pattern | **Constant space pattern**

Step weight function with square window

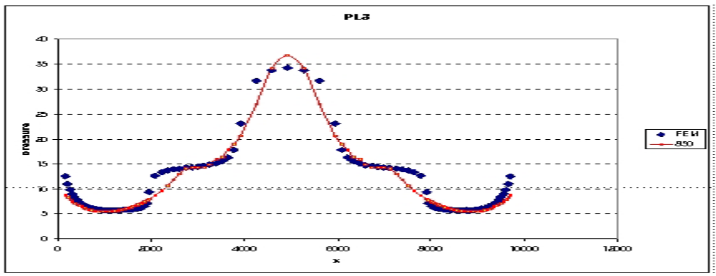


(PL = 0.4mm ,square sum error = 1.41)

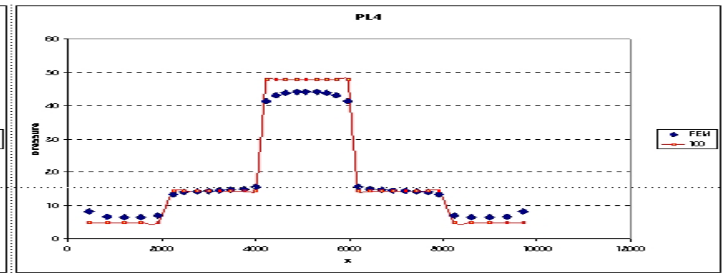


(PL = 0.1mm ,square sum error = 9.47)

Step weight function with circular window

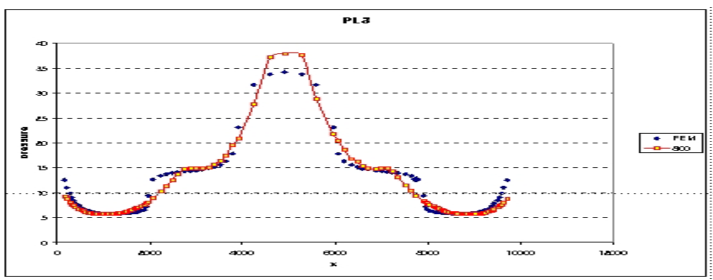


(PL = 0.85mm ,square sum error = 1.91)

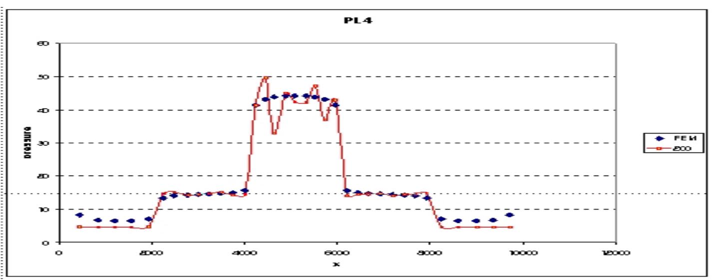


(PL = 0.1mm ,square sum error = 7.43)

Elliptic weight function



(PL = 0.8mm ,square sum error = 1.80)



(PL = 0.2mm ,square sum error = 8.41)

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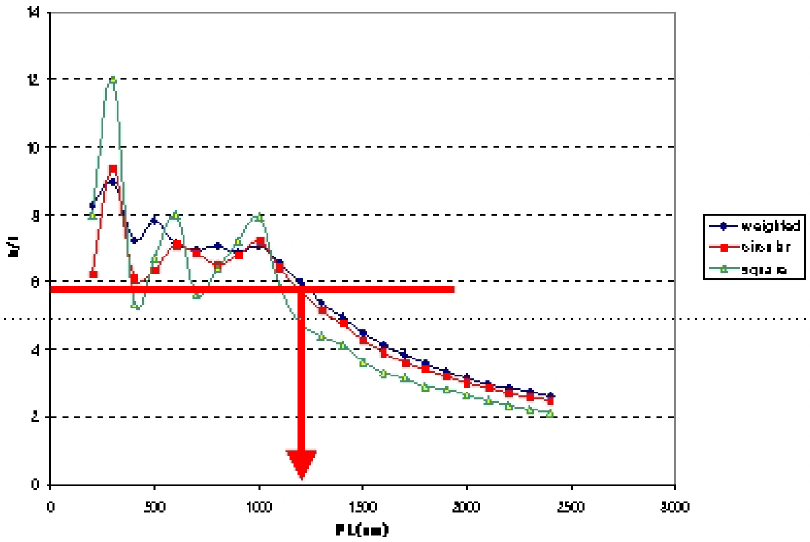
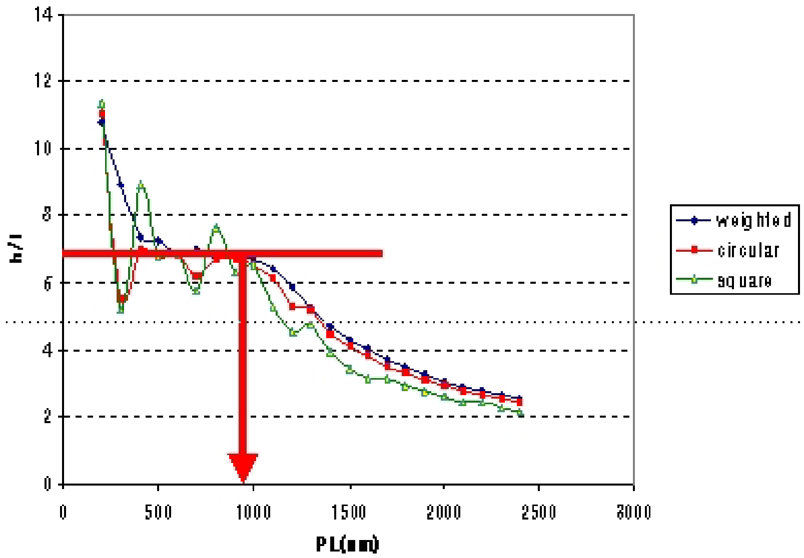
H/L ratio variation



Constant LW pattern



Constant space pattern

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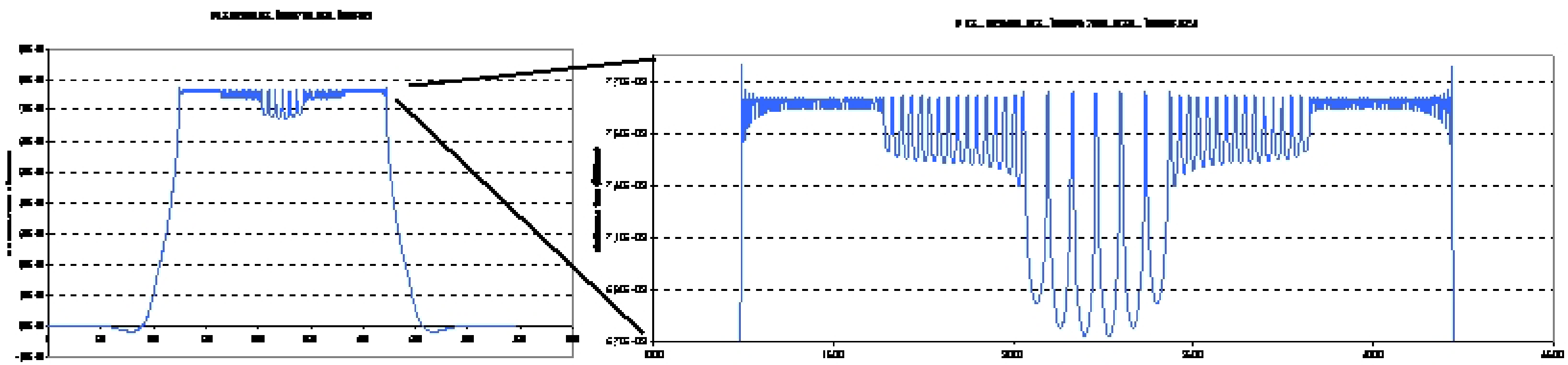
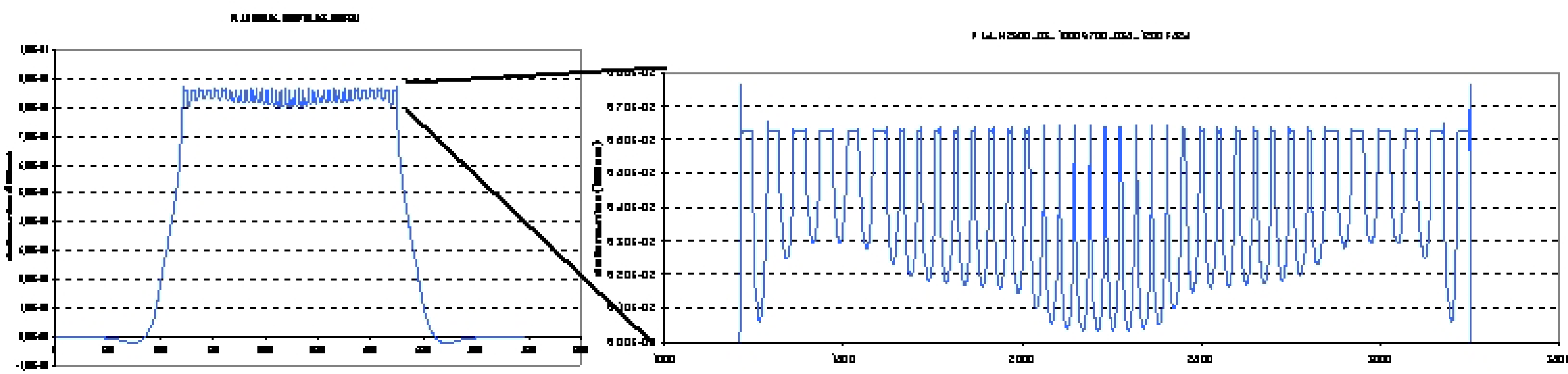
Pad deformation profile

Constant LW pattern



Constant space pattern



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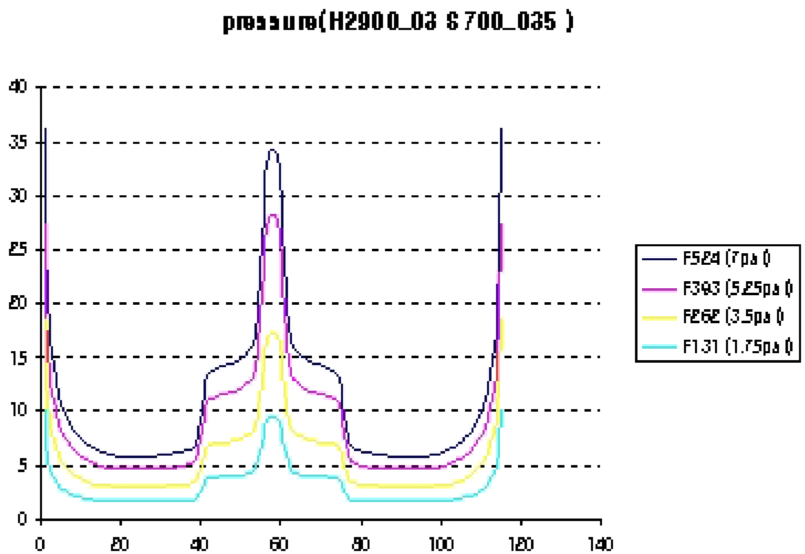
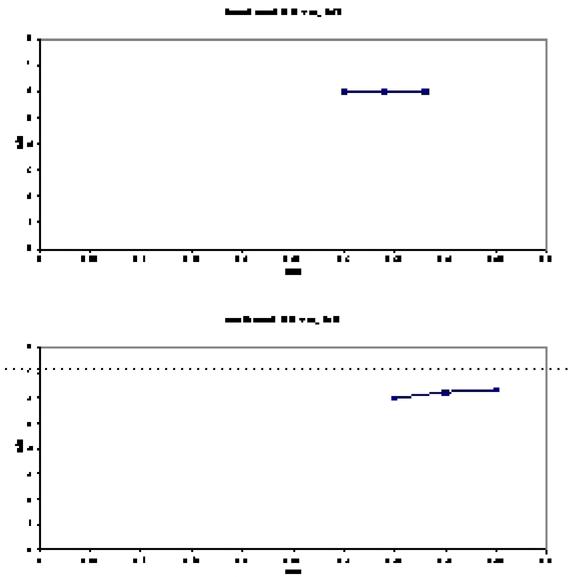
DOE test with FEM model

Pressure effect and pad Poisson ratio effect





linear relation between overall pressure and local contact pressure

no significant effect of pad Poisson ratio

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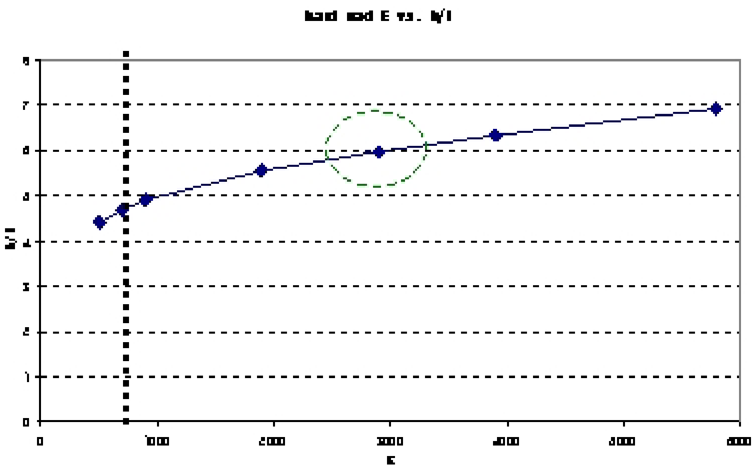
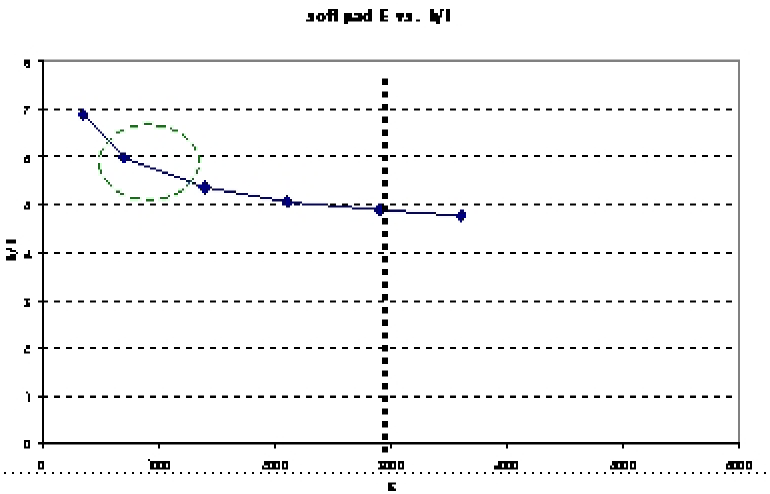
Pad stiffness effect



The stiffer the hard layer, the bigger the WIDNU



The stiffer the soft layer, the smaller the WIDNU

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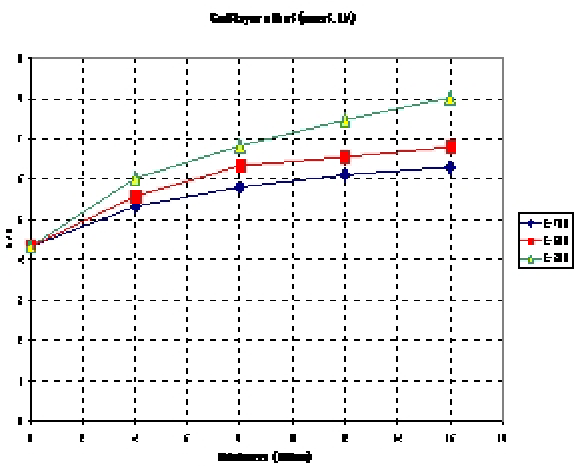
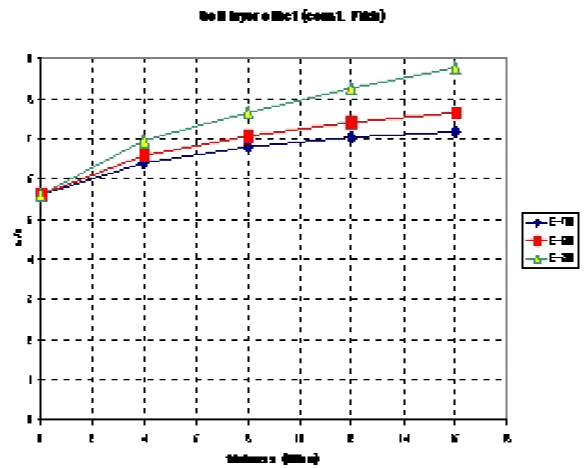
Pad thickness effect

Constant line width pattern

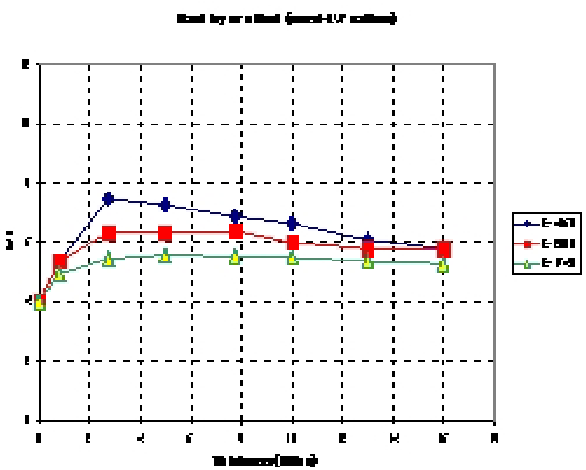
Constant space pattern

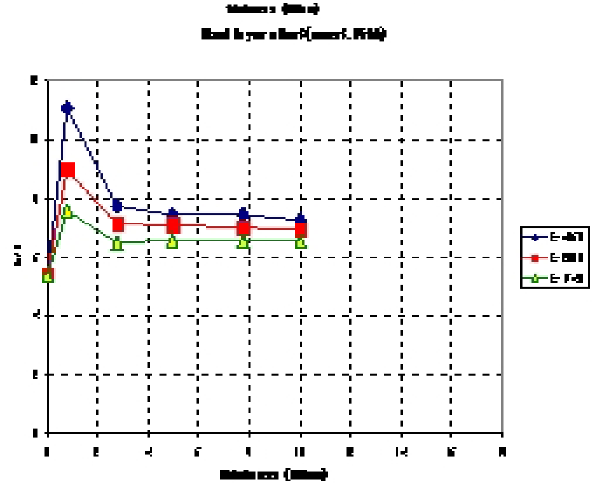
Soft layer





Hard layer





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2 Level full factorial DOE on FEM model

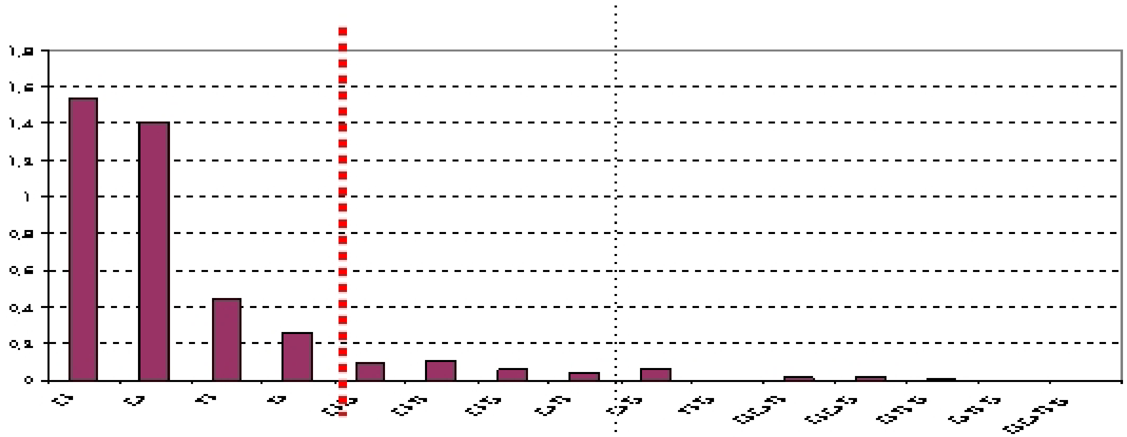
Eh	Es	Th	Ts	h/l
1740	300	10	10	6.329872
1740	300	10	16	6.774769
1740	300	16	10	5.962938
1740	300	16	16	6.271255
1740	700	10	10	5.48383
1740	700	10	16	5.684502
1740	700	16	10	5.27297
1740	700	16	16	5.381071
4060	300	10	10	7.943655
4060	300	10	16	9.120535
4060	300	16	10	6.670885
4060	300	16	16	7.787766
4060	700	10	10	6.61927
4060	700	10	16	6.824732
4060	700	16	10	5.803045
4060	700	16	16	6.300478

Eh = 174 ~ 406 MPa

Es = 30 ~ 70 MPa

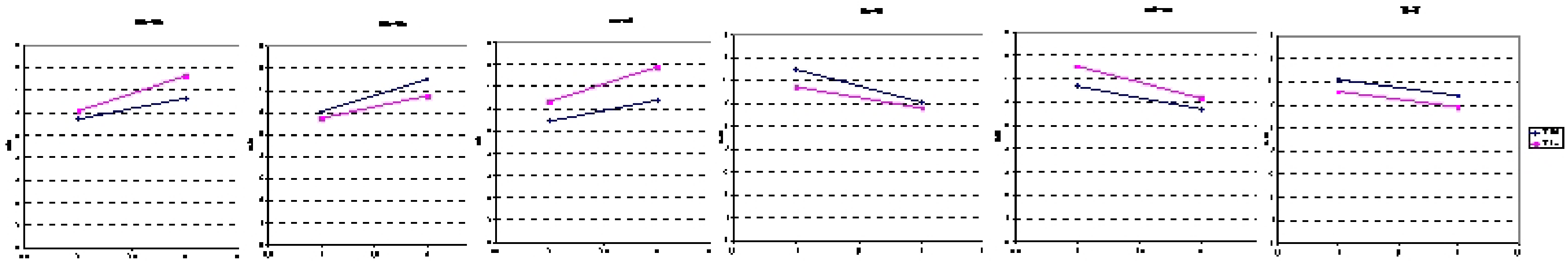
Th = 1 ~ 1.6 mm

Ts = 1 ~ 1.6 mm

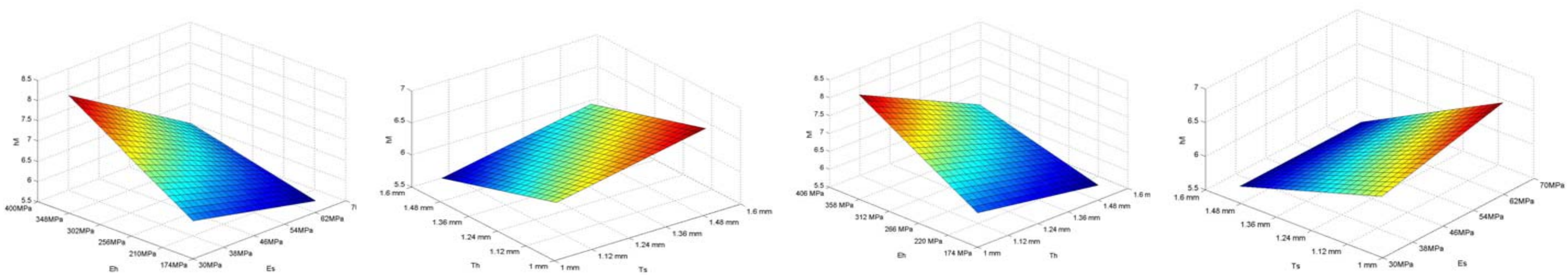


Basic pad design rule from FEM

Interactions between factors :



Response surface model :



Basic design rule for a stacked CMP pad :

The stiffer the hard layer, the bigger the WIDNU

The thicker the hard layer, the smaller the WIDNU

The stiffer the soft layer, the smaller the WIDNU

The thicker the soft layer, the bigger the WIDNU

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Conclusion

- Stress distribution from FEM model shows good correlation with the pattern density based oxide CMP model
- Window size for local contact stress evaluation is dependent on the pattern itself (especially, line space)
- FEM model shows that local contact pressure is dependent upon not only the pattern density but also line width and space
- Pad thickness also has to be considered in CMP modeling along with pad material properties