PBS&T

Recipe Development Considerations for Focused Ion Beam Gas Assisted Etching

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GAE Recipe Development: Yield Equation

$$\text{Yield} = \frac{\text{Removed Atoms}}{\text{Incident Ions}} = \frac{AR + AS}{Jt_D}$$

AR (Atoms Reacted) – <u>FAST</u>, parameter-sensitive, <u>not limited by aspect ratio</u>.

AS (Atoms Sputtered) – <u>SLOW, limited by aspect ratio</u>

J - Ion Beam Current Density

t_D – Time of beam dwell within the pixel

GAE Recipe Development: Two Phases of GAE Within Pixel

$$t_D = t_{AR} + t_{AS}$$

For effective GAE

$$t_D \rightarrow t_{AR}\text{, and } t_{AS} \rightarrow 0$$

GAE Recipe Development: Reactive Yield vs. Mill Parameters

Parameter Change And Limit	Pixel Dwell 0.2μSec ↓	Pixel Overlap ~ 0 ↓	Pixel Refresh 1~ 10mSec ↑
Effect on Reactive Yield AR	↑	↑ →	↑ →

GAE Recipe Development: Timing of Pixels within Raster

$$t_{Raster} = t_{Refresh} = \sum_{i=0}^{n} t_{Di}$$

Raster time equivalent to refresh time provides most efficient GAE.

GAE Recipe Development: Gas Refresh Defines Number of Pixels

$$N = \frac{t_{Refresh}}{t_D = 0.2\ \mu Sec}$$

Shortest pixel dwell, available in modern FIB systems, is close to 0.2 µSec.

GAE Recipe Development: Via Size “L” Defines Pixel Distance

$$dX = dY = \frac{L}{(\mathrm{Sqrt}(N) - 1)}$$

Dwell points are desirable on the edges of the via.

GAE Recipe Development: Pixel Distance Defines Beam Size

For uniform orthogonal raster:

$$D_{Beam} = dX = dY$$

- Beam diameter equivalent to pixel distance ensures minimal overlap and maximal yield.
- Corresponding current value is controlled by the FIB system; diffused beam is desirable.

GAE Recipe Development: Numerical Example

2 μm via in Si milled with Cl_2, $t_{Refresh}$ = 1 mSec

N = 1mSec / 0.2 μSec = 5000 pixels for uniform raster

dX = dY = 2μm / (Sqrt(5000) – 1) = ~ 30 nm = ~ beam diameter

- Corresponding beam current depends on FIB system
- Extra refresh time for milling of UHAR vias
- Extra beam current for surface micromachinning

Conclusions

- Starting point recommendations for development of efficient milling recipes are deducted from published research on FIB GAE theory.
- Further experimental and theoretical efforts, focused on milling rate enhancement aspects of FIB GAE, are needed to improve efficiency of FIB in industrial applications.

References

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