Overview

• About AM Fitzgerald and Tegal
• Motivation for this study
  – Deep reactive ion etch (DRIE)
  – Brittle material properties
• Fracture strength of three DRIE recipes
• Practical application of strength data
Mission

We turn your ideas into silicon.
Fully integrated services: concept to foundry

- Complete design and project management
- Feasibility and cost analysis
- Design optimization using simulation
- Process development on 100 mm or 150 mm wafers
  - Prototype fabrication with own staff engineers at UC Berkeley’s Microlab
- Test system development
- Packaging, system integration
- Technology transfer to foundries for production
Tegal ICP Product Range... From R&D to mass production

Contact Paul Werbaneth: (707) 765-5608
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Tegal 4200
- Cluster Platform: 1 to 4 PM
- 2 Vacuum cassettes

Tegal 3200
- Cluster Platform: 1 to 3 PM
- Single Vacuum cassette

Tegal 200
- Single Cassette

Tegal 110
- Manual Single Wfr

100 % Process Compatibility
Motivation for this study

- Many MEMS devices are fabricated by DRIE

- Trench sidewall roughness is a function of DRIE recipe

- Smoother surfaces typically exhibit higher fracture strengths

- How does fracture strength vary with DRIE recipe (sidewall scallop size)?
Deep Reactive Ion Etch (DRIE) and MEMS

- Fundamental etch process for fabricating vertical sidewalls, high-aspect ratio structures
  - MEMS
    - Gyroscopes
    - Accelerometers
    - Microphones
    - Etc.
  - 3D structures
    - Through silicon vias (TSV)
    - Electrical isolation trenches

Source: Chipworks
Bosch SMB380 3-axis accelerometer

Tegal DRIE for TSV application
The Bosch DRIE Process

A cyclic process alternating between etch and passivation

- SF$_6$ Plasma
- C$_4$F$_8$ Plasma
- Si
- Mask
- F + ions
- SiF$_4$
- -CF$_2$-
- Scalloping
Two types of DRIE surface features

- The cyclic nature of the Bosch process forms an undulating etched sidewall

- Mask edge roughness transferred during silicon etch, forming vertical ridges
  - a.k.a “micro-masking”
Scallop depth vs. etch rate (for ~ 25% open area)
Brittle material behavior

- Ductile materials (metals) fail at yield strength
  - Well-defined limit

- Brittle materials (silicon, glass) have a fracture toughness
  - Strength is a function of flaw distribution (size, location)
  - DRIE creates surface flaws!

- MEMS structural reliability depends on etched surface properties
Theoretical stress-flaw size relationship for silicon

Fracture toughness of silicon, $K_{IC}$
Measure the fracture strength of three different etch recipes.

Scallop depth =
- 150 nm
- 1500 nm
- 3500 nm
Three different etch recipes: close-up view

150 nm

Shallower scallops, but more apexes

1500 nm

Which flaws are most significant?

3500 nm
Fourth surface type: the result of poor resist prep

- Resist eroded; hard mask revealed
- Sidewall micromasking
- Corner Erosion
Measuring surface strength: four-point bend specimens

Simple but ideal test:

- Uniform maximum stress develops on beam outer surface
- Strength calculated analytically from measured fracture load
- No need for inspection or modeling of each individual specimen
  - Cost-effective
  - Efficient

\[ \text{max stress at surface constant within area} \]
\[ A_0 = \frac{Ld}{2} \]

Follows ASTM D 6272-02
Test specimen fabrication

- Test specimens etched using the different DRIE recipes
  - Through-wafer etch of a double-polished wafer

- Design allows easy handling and testing in macro-scale apparatus

DRIE-etched silicon test beams

\[ L = 8 \, \text{mm}, \, b = 300 \, \mu\text{m}, \, d = 310 \, \mu\text{m} \]
Test apparatus

- Specially-designed test fixtures mounted to Instron 5542
- 90° rotation of specimen allows selection of either polished or etched surface
- Measure load to fracture
Results: Fracture strength distribution vs. DRIE recipe

Weibull analysis follows ASTM C 1239-07
Observations

- Polished surface ~ 2x stronger than etched surfaces
- 40% difference in characteristic strength across three recipes
- Mask preparation influences surface strength
  - Resist recipe AND etch recipe are important
- Etch recipes have statistically distinct Weibull parameters
  - “Figures of Merit” for process control monitoring
Application of Fracture Strength Data
# Applications for fracture strength data

| Foundry/Etch Tool Selection | Compare fracture strengths across recipes, etch tools, foundries  
Make informed purchase decisions |
|-------------------------------|------------------------------------------------------------------|
| Cost Savings                  | Informed etch recipe selection to optimize wafer throughput without sacrificing reliability  
Reduce development time  
Improve yield |
| Quality Control               | Monitor etch process stability  
Across-wafer uniformity  
Diagnose in-process fracture failures  
Improve mechanical reliability |
| Design                        | Reliability simulation, fracture prediction  
Performance improvements  
Size reduction |
AMFitzgerald Fracture Prediction Methodology

- Identifies where and when a device is most likely to break
- Informed design
- Reduction of time to market: fewer design, fab, test cycles required
- Process IP stays secure: fabrication and fracture of test specimens is all that’s needed
Summary

• Fracture strength varied by 40% across recipes tested

• Mask preparation influences surface strength
  – Resist recipe AND etch recipe are important

• The methods used here have broad applicability to recipe/tool/foundry selection, quality control and design

• Contact Alissa Fitzgerald (amf@amfitzgerald.com)
  – Information on test services and fracture prediction
  – A copy of the slides
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