Two Level Metal Process Technology

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OUTLINE

Introduction
Metal Deposition –
  Tools, Uniformity, Surface Roughness, Step Coverage
Metal One Sputter Etch Prior to Metal Two Deposition
Lithography for Metal One and Two
Aluminum Plasma Etch for Metal One and Two
Via Plasma Etch for Intermetal Dielectric
Electrical Test Results, Via Chain with 512 Vias
Conclusions
Summary
INTRODUCTION

The goal of this work is to develop a useful two-layer aluminum metal interconnect technology for our submicron CMOS processes. To do this we had to improve several processes including:

1. Metal Deposition – (For Various Tools)
   1.1 Uniformity
   1.2 Surface Roughness
   1.3 Step Coverage
2. Metal Sputter Etch Prior to Metal Two Deposition
3. Lithography for Metal One and Two
4. Aluminum Plasma Etch for Metal One and Two
5. Via Plasma Etch for Intermetal Dielectric
Two Level Metal

PE4400 SPUTTER / SPUTTER ETCH TOOL
Ave = 11.17K
Min = 8.69K
Max = 12.1K
Non Uniformity = 16.55%
The sputter etch rate was calculated from measured aluminum thickness before and after sputter etch. Measurements were made using 4-point probe thickness technique on the CDE resistivity mapper. The sputter etch rate of aluminum was 18 Å per minute.

Power = 500 watts
Pressure = 5 mTorr
Flow = 20 sccm
Table Rotation = Yes
FLASH EVAPORATOR THICKNESS UNIFORMITY

Ave = 2.03K
Min = 1.90K
Max = 2.18K
Non Uniformity = 6.95%
Thickness 7500Å  
Dep Rate ~300 A/min  
Pressure 5 mT  
Ar Flow 28 sccm  
Time ~ 25 min
CVC601 THICKNESS UNIFORMITY

Ave = 6.03K
Min = 4.73K
Max = 7.68K
Non Uniformity = 23.78%
CDE Resistivity Mapper

Rho = Rhos x t

Tool gives Rho or Rhos depending on recipe used, automatically adjusts correction factors for wafer thickness

\[ t = \frac{\text{Rho}}{\text{Rhos}} \]
EQUATIONS USE BY CDE RESISTIVITY MAPPER

Thickness = \frac{\text{Known Bulk Resistivity}}{\text{Measured Sheet Resistance}}

Bulk Resistivity is assumed to be known

Measured Sheet Resistance = (\pi/\ln2) (V/I)

The CDE Resistivity Mapper can be programmed to automatically convert measured V/I to thickness

Uniformity = (\text{Max}-\text{Min})/(\text{Max}+\text{Min})
MODELING OF BULK RESISTIVITY

Bulk Resistivity is assumed to have a value $= x \exp(y)$

Where the pre exponential value may be different for different film deposition techniques (i.e. evaporation, RF sputtering, DC sputtering, etc.)

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<td>Flash Evaporator</td>
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Note: bulk Aluminum Rho = 270 ohm-Å
VERIFICATION USING THE TENCORE P2
These SEM pictures show typical profiles of aluminum over steps from the CVC601.
SUMMARY FOR DEPOSITION, UNIFORMITY and STEP COVERAGE

1. None of the deposition tools are that great from a thickness uniformity point of view. The best tool we investigated is the Cha Flash Evaporator.
2. The PE 4400 is the only tool that can do sputter etch prior to metal deposition. So we need to use this tool for the 2\textsuperscript{nd} layer of aluminum.
3. The four point probe technique for measuring thickness is a good way to measure uniformity.
4. Step coverage can be a problem so we choose to deposit metal thickness larger than the step height. Our metal thicknesses are 0.75\(\mu\)m for metal one and two.
SURFACE ROUGHNESS

The PE4400 RF sputtering tool has sputter etch capability. There is a lot of heat produced during sputtering in this tool which causes large grain size in the sputtered aluminum. The metal sputtered in this tool can have a white look due to the large grain size. The large grain size and the 1.3 microns of photoresist on top of the aluminum makes it difficult to see alignment marks for the metal two lithography step.

Large grain size aluminum contributes to photoresist adhesion problems and the plasma etch seems to be more isotropic.
Al Thickness = 7225Å
Sputtered at 900 watts

Veeco Wyco
RMS Surface Roughness = 37 nm

Metal two looks white instead of shiny silver due to large grain size

Photograph of alignment keys with no photoresist
## PE4400 SETTINGS AND SOME RESULTS

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<th>Space</th>
<th>Pressure mT</th>
<th>Flow sccm</th>
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<th>Deposition Rate Å/min</th>
<th>Total Thickness Å</th>
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Goal is 7500 Å Al thickness and surface roughness <10nm RMS
10nm RMS = 283Å peak-to-peak
VEECO WYCO NT1100 OPTICAL PROFILOMETER

Used to measure RMS surface roughness
**SURFACE ROUGHNESS DATA**

**Bare Silicon Wafer**

- \(~5\text{nm RMS}\)

**Aluminum CVC 601 – 6800Å**

- \(~15\text{nm RMS}\)

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**Rochester Microelect**
ALUMINUM SURFACE ROUGHNESS DATA

900W, 20 sccm, 5mT, 90 min, 7225Å

~37nm RMS

400W, 40 sccm, 5mT, 240 min, 9000Å

~7nm RMS
AL DEPOSITED AT 600 WATTS TO THICKNESS OF 3265Å

600 Watts, Ar Flow 20sccm, 2mT, Table Rotation 100, 60 min
Dep Rate = 3265Å/60min = 54Å/min

Veeco Wyco
RMS Surface Roughness = 17 nm
SUMMARY - FOR SPUTTERING IN PE4400

1. Smoother films can be deposited at lower powers.
2. Thinner films are smoother.
3. To quantify the roughness/smoothness the Veeco Wyco Optical Surface Profilometer is useful.
4. The deposition rate is lower at lower powers.
5. Deposition times become many hours for low power and film thickness approaching 1 micron.
6. Moving the wafers closer to the target increases sputter rate and surface roughness. (The height is as close as possible now “C”)
7. Rough films give problems for lithography and etching.
8. Surface roughness needs to be less than 10nm RMS for successful lithography and plasma etching.
9. Best conditions observed so far are, 300 watts, 5 mT, 40 sccm, to give a deposition rate of 37Å/min and surface roughness of ~11nm RMS for a film thickness of ~7500 Å. after 180 min sputter time.
10. Non uniformity is 22%. Wafers are thinner toward the flat.
LITHOGRAPHY PROBLEMS ON ROUGH ALUMINUM

Rough aluminum makes it hard to see the alignment marks from previous layers. Photoresist adhesion is not as good on rough films. The plasma etch seems to be more isotropic.
i-Line Stepper $\lambda = 365$ nm
NA = 0.52, $\sigma = 0.6$
Resolution = $0.7 \lambda / NA = \sim 0.5$ µm
20 x 20 mm Field Size
Depth of focus = $k_2 \lambda / (NA)^2 = 0.8$ µm
Overlay $\sim 0.1$ µm
Metal two looks white instead of shiny silver due to large grain size.

Veeco Wyco
RMS Surface Roughness = 37 nm

Photograph of alignment keys with no photoresist.
TECHNIQUE TO REMOVE METAL TWO OVER ALIGNMENT MARKS ON TWO DIE

Stepper job F081SUBCMOS_Z
Use plain piece of glass for mask

Blade positions in Shot File
Bu = -6mm
Bd = -8mm
Bl = -8mm
Br = 8mm

Skip shots all except two die
Row 6 column 2 and Row 6 Column 8

Use: COATMTL.RCP and DEVMTL.RCP recipes on the SSI track for thicker resist coatings and better step coverage
We did a wet etch of the aluminum, rinsed and did a spin/rinse/dry. In those two spots on the wafer we could see the alignment marks as shown below.

We modified the stepper job F081SUBCMOS_M2 so that it used the two die with no metal two for alignment and exposed the wafer using the M2 photomask.
PHOTOS OF WAFER AFTER PHOTO FOR METAL 2

Metal Two
6µm x 24µm Via Chain Links

Excellent alignment, zero overlay error

Metal Two
100µm x 100µm Pads

100X

10X
SUMMARY-CONCLUSION PHOTO ON ROUGH AL

1. The Canon stepper can be used to image on rough aluminum.
2. Alignment marks can be made visible by etching the aluminum off of selected die and creating a stepper job to use the alignment marks in only those die for alignment.
3. Resolution and overlay is acceptable.
4. Resist adhesion may not be as good as with smooth films.
5. Best solution is to deposit smooth aluminum.
**PROBLEMS ETCHING ROUGH ALUMINUM**

1. Plasma etching using the LAM 4600 undercuts the photoresist significantly.
2. Smooth metal works fine, see metal one, rough metal seems to etch isotropically (may be a resist adhesion issue)
3. Wafer non-uniformity of 22% causes some areas to not etch completely. Over etch is needed to completely etch everywhere.
4. The etch needs to be anisotropic.
PROBLEMS WITH ALUMINUM ETCH OF METAL 2

Metal 1

Metal 2
AFTER METAL ETCH AND RESIST STRIP
M2 lines run vertical, M1 lines run horizontal, both 0.75μm Thick

6µm M2 lines with photoresist

Resist removed show M2 lines are actually 1.3µm
M2 lines run vertical, M1 lines run horizontal, both 0.75µm Thick

6µm M2 lines with photoresist

Resist removed show M2 lines are actually 1.3µm

Note: M1 lines look good, M2 look over etched
OPTICAL LINE WIDTH MEASUREMENTS
ALUMINUM ETCH USING LAM4600

LAM4600

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Microelectronic Engineering
LAM 4600 ALUMINUM ETCHER

Plasma Chemistry

Cl2 – Reduces Pure Aluminum
BCl3 – Etches native Aluminum Oxide
    - Increases Physical Sputtering
N2 – Dilute and Carrier for the chemistry
Chloroform – Helps Anisotropy and reduces Photoresist damage
Recipe: Number 122122

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Rate ~50Å/s

Gianni Franceschinis, May 2005
### LAM4600 Anisotropic Aluminum Etch

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F puddle, December 2009

Rochester Institute of Technology
Microelectronic Engineering

Channel | B
---------|--------
Delay    | 130
Normalize| 10 s
Norm Val | 5670
Trigger  | 105%
Slope    | +
## Two Level Metal

### LAM4600 ANISOTROPIC ALUMINUM ETCH

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Fuller, May 2010

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### LAM4600 ANISOTROPIC ALUMINUM ETCH

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Rate ~38Å/s

Thickness = 7500Å

Various tool modifications resulted in different etch rates for different years

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Fuller April 2013 – 200s
Fuller, January 2012 -300s
Fuller, March 2011 -230s

Channel | B
---|---
Delay | 130
Normalize | 10 s
Norm Val | 5670
Trigger | 105%
Slope | +

Endpoint (not used)
RESULTS FROM NEW ALUMINUM PLASMA ETCH

Photoresist on Metal Two

Photoresist Removed
**Problem:** Photoresist is hardened (and chemically changed) in Chlorine RIE during Aluminum etch and ashing is ineffective in removing the resist.

**Solution:** Use a Solvent based photoresist stripper process. (similar to Baselinc CMOS process at U of California at Berkeley)

Picture of aluminum wafers post chlorine RIE and after ashing. Note resist remaining on aluminum. Even very long ashing (60 min.) does not remove residue.

Germain Fenger
Pictures on left show resist residue after ashing. Pictures on right show effectiveness of ACT 935 solvent strip process.

From: [ACT-CMI Data Sheet]
RESIST REMOVAL AFTER PE4600 PLASMA ETCH

Observations:
A solvent based photoresist stripper followed by a plasma ash is effective at removing Chlorine “burned resist”

Recommendations:
PRS2000 at 90C for 10 min
Rinse 5 min. / SRD
Follow up with 6” Factory ash on the Branson Asher

No photoresist was found on wafers

Germain Fenger
SUMMARY – CONCLUSION PLASMA ETCH OF AL

1. Smooth metal is necessary for good plasma etching.
2. Aluminum film non-uniformity of less than 10% is needed to give best results.
3. A new plasma etch recipe that is more anisotropic was created and shown to work for wafers with non-uniformity of ~22%.
4. The vias were plasma etched.
5. Resist strip using solvent strip followed by oxygen plasma strip is effective after chlorine plasma etch of aluminum.
SPECIAL RCA CLEAN PRIOR TO METAL ONE

Prior to Metal One Only / Sputter etch Prior to Metal Two

APM

NH₄OH - 1 part
H₂O₂ - 3 parts
H₂O - 15 parts
70°C, 15 min.

DI water rinse, 5 min.

H₂O - 50
HF - 1
60 sec.

HPM

HCL - 1 part
H₂O₂ - 3 parts
H₂O - 15 parts
70°C, 15 min.

DI water rinse, 5 min.

DI water rinse, 5 min.

DI water rinse, 5 min.

Clean includes 50:1 HF Dip twice once after each bath to remove chemically grown oxide
### Two Level Metal

**VAN DER PAUWS AND CBKR’s**

<table>
<thead>
<tr>
<th>NWELL</th>
<th>PWELL</th>
<th>N+</th>
<th>P+</th>
<th>N-POLY M1</th>
<th>P-POLY M2</th>
</tr>
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<tbody>
<tr>
<td>2µm M1toPoly</td>
<td>2µm M1toP+</td>
<td>4µm M1toPoly</td>
<td>4µm M1toP+</td>
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<tr>
<td>2µm M1toM2</td>
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<td>2µm M1toP+</td>
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<td>4µm M1toN+</td>
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</tbody>
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SERPENTINES, COMBS, AND VIA CHAINS

To evaluate metal1, metal2, CC and Via layer quality.

Via Chain has 512 Vias
DRYTEK QUAD ETCH RECIPE FOR CC AND VIA

Recipe Name: FACCUT
Chamber 3
Power 200W
Pressure 100 mTorr
Gas 1 CHF3 50 sccm
Gas 2 CF4 10 sccm
Gas 3 Ar 100 sccm
Gas 4 O2 0 sccm
(could be changed to N2)

US Patent 5935877 - Etch process for forming contacts over titanium silicide

TEOS Etch Rate 494 Å/min
Annealed TEOS 450 Å/min
Photoresist Etch Rate: 117 Å/min
Thermal Oxide Etch Rate: 441 Å/min
Silicon Etch Rate 82 Å/min
TiSi2 Etch Rate 1 Å/min
CONTACT CUT ETCH RECIPE

Theory: The CHF3 and CF4 provide the F radicals that do the etching of the silicon dioxide, SiO2. The high voltage RF power creates a plasma and the gasses in the chamber are broken into radicals and ions. The F radical combines with Si to make SiF4 which is volatile and is removed by pumping. The O2 in the oxide is released and also removed by pumping. The C and H can be removed as CO, CO2, H2 or other volatile combinations. The C and H can also form hydrocarbon polymers that can coat the chamber and wafer surfaces. The Ar can be ionized in the plasma and at low pressures can be accelerated toward the wafer surface without many collisions giving some vertical ion bombardment on the horizontal surfaces. If everything is correct (wafer temperature, pressure, amounts of polymer formed, energy of Ar bombardment, etc.) the SiO2 should be etched, polymer should be formed on the horizontal and vertical surfaces but the Ar bombardment on the horizontal surfaces should remove the polymer there. The O2 (O radicals) released also help remove polymer. Once the SiO2 is etched and the underlying Si is reached there is less O2 around and the removal of polymer on the horizontal surfaces is not adequate thus the removal rate of the Si is reduced. The etch rate of SiO2 should be 4 or 5 times the etch rate of the underlying Si. The chamber should be cleaned in an O2 plasma after each wafer is etched.

US Patent 5935877 - Etch process for forming contacts over Titanium Silicide
PICTURES OF M1-M2 VIA CHAIN
SEM OF 6µm LINES / 2X2µm VIAS
F081201

M1-M2 Via chain with 512 Vias and total resistance of 118 ohms or 0.231 ohms per contact
A two layer aluminum metal process has been developed and has been shown to work. New processes for CC and Via etch, Metal Deposition, Sputter Etch, Lithography, Metal Plasma Etch, Resist Removal and Cleans were developed.
ACKNOWLEDGEMENTS

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Chris Shea
Germain Fenger
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Thank You !!
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