Memstar SM

Micromachined Solutions For Optical Networks

Silicon Micromachining Reference Chart

Definitions

MEMS (MOEMS): Micro (Opto) Electro Mechanical System

LIGA (Lithographie, Galvanik und Abformung): High aspect ratio process for fabricating microstructures through lithography, electroforming, and injection molding. It requires the use of high intensity source of X-Rays. (Synchrotron). Typically used for the fabrication of stamping molds.

MUMPs™ : Multi-User MEMS Process (a dual layer poly-Si process)

SUMMiT™ : Sandia's Ultra-Planar MEMS Technology

DRIE Bosch Process : Fluorine based chemistry developed by Robert Bosch GmbH, that allows deep anisotropic etch aspect ratios at relatively high etch rates, by using alternating etch and side-wall passivation steps.

Etching Parameters: Etch Rate, Bias (or Undercut), Tolerance, Anisotropy, Selectivity, Over Etch, Feature Size Control, Loading Effects.

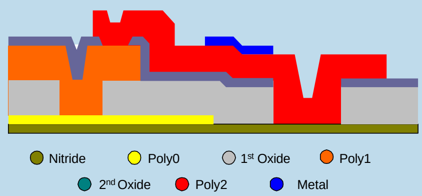
Etch Aspect Ratio: Ratio of the Etch Depth to the Feature Width.

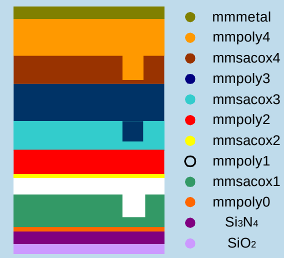
Release : Removal of sacrificial oxides at the end of the fabrication process and aimed at allowing motion of the structure.

Stiction : Unwanted bonding of interface surfaces caused by the drying gradual drying of residual water.

Drying : Usually super-critical CO2 drying aimed at sublimating the water at the interfaces thus avoiding stiction.

Silicon Surface Micromachining





MUMPs™ Process [4]

(Subject to Variations)

Film	Function	Thickness	Residual Stress	Sheet Resistance
		Å	Mpa	ohm/sq
Nitride	Isolation	6,000	90	N/A
Poly0	Ground	5,000	-25	30
Oxide1	Sacrificial	20,000	N/A	N/A
Poly1	Structural	20,000	-10	10
Oxide2	Sacrificial	7,500	N/A	N/A
Poly2	Structural	15,000	-10	20
Metal	Contact	5,200	50	0.06

SUMMiT™ Process [5]

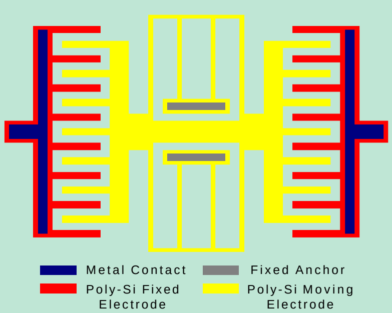
(Subject to Variations)

Layers	Function	Thickness Å	Sheet Resistance ohm/sq
mmpoly0	Ground	2,937	29.4
mmpoly1	Structural	10,010	18.5
mmpoly2	Structural	15,120	20.5
mmpoly3	Structural	22,821	8.1
sacox1	Dimple & Sacrificial	20,083	
sacox2	Sacrificial	5,020	
sacox3	Dimple & Sacrificial	20,000	
Thermal Oxide		6,282	
Nitride	Isolation	8,162	

Common Si Wet Etches [1]

Etchant (Diluent)	Typical Compositions	Temp °C	Etch Rate (mm/min)	Anisotropic (100 / (111) Etch Rate Ratio	Dopant Dependence	Masking Films (etch rate of mask)
HF	10 ml, 30 ml, 80 ml	22	0.7-3.0	1:1	< 10^{17} cm^{-3} n or p reduces etch rate by about 150	SiO_2 (300 Å/min)
$HN0_3$	25 ml, 50 ml, 25 ml	22	40	1:1	no dependence	Si_3N_4
(water, CH_3COOH)	9 ml, 75 ml, 30 ml	22	7	1:1	----	SiO_2 (700 Å/min)
Ethylene Diamine, Pyrocatechol (water)	750 ml, 120 g, 100 ml	115	0.75	35:1	>7 x 10^{19} cm's boron reduces etch rate by about 50	SiO_2 (2Å/min) Si_3N_4 (1Å/min) Au,Cr,Ag,Cu,Ta
	750 ml, 120g, 240 ml	115	1.25	35:1		
KOH (water, isopropyl)	44 g, 100 ml	85	1.4	400:1	> 10^{20} cm^{-3} boron reduces etch rate by about 20	Si_3N_4 $Si0_2$ (14 Å/min)
	50 g, 100 ml	50	1.0	400:1		
H2N4 (water, isopropyl)	100 ml 100 ml	100	2.0	----	no dependence	SiO_2 Al
NaOH (water)	10 g 100 ml	65	0.25-1.0	----	>3 x 10_{20} cm^{-3} boron reduces etch rate bay about 10	Si_3N_4 SiO_2 (7 Å/min)

Comb Drive Resonator [2]



$$F = \varepsilon_o V^2 \left(\frac{t}{g}\right)$$

$$K = 2Et\left(\frac{w}{l}\right)^3$$

$$f = \frac{1}{2\pi}\sqrt{\frac{K}{M}}$$

$$x = \frac{F}{K}$$

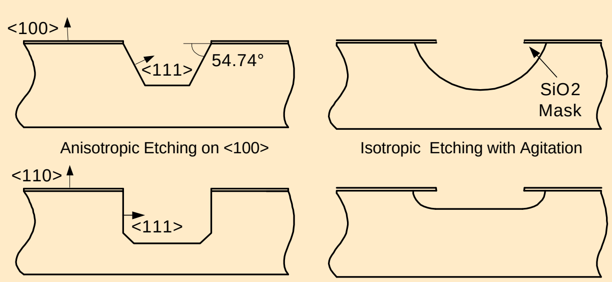
if t/w >1 then E = E/(1-v^2)

F: Single Finger Force
e_o: Free Space Permitivitty
V: Applied Voltage
t : Beam Thickness
g : Comb Finger Gap

K: Suspension Stiffness
E: Young's Modulus
v: Poisson's Ratio

x: Displacement

Silicon Wet Etching [1]



Anisotropic Etching on <100>

Isotropic Etching with Agitation

Anisotropic Etching on <110>

Isotropic Etching without Agitation

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Wet Etchants for Non-Crystalline Films [2]

SiO_2 (Silicon Dioxide)	28 ml HF + 170 ml H_20 + 113 g NH_4F ("Buffered HF Etch (BHF)") 15 ml HF + 10 ml $HN0_3$ + 300 ml H_20 ("P-etch") 1 ml BHF + 7 ml H_20	1000-2500 Å/min. @ 25°C 128 Å/min. @ 25°C 800 Å/min.
BSG (Borosilicate Glass)	1 ml HF+ 100 ml $HN0_3$ + 100 ml H_20 ("R-etch")	300 Å/min. for 9 mole% B_20_3 50 Å/min. for Si02
	4.4 ml HF+ 100 ml $HN0_3$ + 100 ml H_20 ("S-etch")	750 Å/min. for 9 mole% B_20_3 135 Å/min. for $Si0_2$
PSG (Phosphosilicate Glass)	28 ml HF + 170 ml H_20 + 113 g NH_4F 15 ml HF + 10 ml $HN0_3$ + 300 ml H_20 1 ml BHF + 7 ml H_20	5500 Å/min. for 8 mole% P_2O_5 3.4 µm/min. for 16 mole% P_2O_5 800 Å/min.
Poly-Si	6 ml HF + 100 ml $HN0_3$ + 40 ml H_20 1 ml HF + 26 ml $HN0_3$ + 33ml CH_3COOH	8000 Å/min, smooth edges 1500 Å/min.
SIPOS (Semi-insulating poly-Si)	1 ml HF+ 6 ml H_20 + 10ml NH_4F (40%)	2000 Å/min. for 20% 0_2
Al	1 ml HCl + 2 ml H_20 4 ml H_3PO_4 + 1 ml $HN0_3$ + 4 ml CH_3COOH + 1 ml H_20 16-19 ml H_3PO4 +1 ml $HN0_3$ + 0-4 ml H20 0.1 mol K_2Br40_7 + 0.51 mol KOH + 0.6 mol $K_3Fe(CN)_6$	80°C, fine line 350 Å/min., fine line 1500-2400 Å/min 1 µm/min., pH 13.6
Au	3 ml HCL + 1 ml HN03 ("Aqua Regia") 4 g KI + 1g I_2 + 40 ml H20	25-50 µm/min 0.5-1 µm/min., resist mask
Cr	1 ml HCl + 1 ml glycerine 1 ml HCl + 9 ml saturated $CeS0_4$ solution 1 ml (1 g NaOH in 2 ml HBO) + 3 ml (1 g $K_3Fe(CN)_6$ in 3 ml H_20)	800 Å/min., need depassivation 800 Å/min., need depassivation 250-100 Å/min., resist mask
W	34 g KH_2PO_4 + 13.4 g KOH + 33 g $K_3Fe(CN)_6$ + H_20 to make 1 liter	1600 Å/min., resist mask

Properties of Silicon

Properties	Unit	
Atomic Density	$Atoms/cm^3$	5.00E+22
Atomic Weight		28.09
Breakdown Field	V/cm	3.00E+05
Density	g/cm^3	2.33
Dielectric Constant	ε_r	11.9
Heat Capacity	J/mol-°K	20.07
Index of Refraction		3.42
Intrinsic Carrier Conc.	cm-3	1.08E+10
Intrinsic Resistivity	Ω-cm	2.30E+05
Knoop Hardness	kg/mm^2	850.00
Linear Coeff Thermal Exp	$\Delta L/L\Delta T$ (°C^{-1})	4.20E-06
Melting Point	°C	1412
Poisson's Ratio <100>		0.28
Specific Heat	J/g-°C	0.70
Thermal Conductivity	W/cm-°C	1.57
Thermal Diffusivity	cm^2/s	0.90
Yield Strength	N/m2	7.00E+09
Young's Modulus	GPa	190

High Aspect Ratio Deep Silicon Etching Technologies [7]

Parameters Type	Deep Chemical Etch Wet	Low Density Reactive Ion Etch Dry (Plasma)	High Density Plasma Etch Dry (Plasma)
Etchants	TMAH, KOH	Chlorine or Bromine	Fluorine
Corrosion	No	Yes	No
Mask 1 Mask 2	Std. Photoresist Thin Oxide	Thick Photoresist Hard Oxide	Thin Photoresist Thin Oxide
Mask (Back Side)	Yes	No	No
Precursor Gases	NA	Fluorine or Bromine	Argon
Etch Orientation	Anisotropic	Anisotropic	Anisotropic
Sidewall Profile	Crystal Dependent		~ 90°
Etch Rate	Very Slow	~ 1µm/min	15 µm/min
Aspect Ratio	< 10:1	~ 20:1	< 100:1
Mask Selectivity (Crio T=-120 to -80 °C) (RT= Room Temp)	400:1 <100>/<111> NA NA	 NA NA	> 200:1 (SiO2) RT > 800:1 (Si02) CrioT > 50:1 (Photoresist) RT > 250:1 (Photoresist) CrioT
Depth	~ 10 µm	Wafer	Wafer
Wafer Uniformity			~ +/- 3%
Wafer Throughput	Batch	Discrete	Discrete
Cost	Low	Medium	High
Process Complexity	Low	Medium	High (>20 parameters)

Si Etch Rates on KOH [3]

(Calculated for Eo= 0.60 eV, ko=4500 mm/hr (mol/L) $^{-4.25}$)

%KOH	20ºC	30ºC	40ºC	50ºC	60ºC	70ºC	80ºC	90ºC	100ºC
10	2.2	4.8	10.1	20.1	38	71	126	216	362
15	2.3	5.1	10.6	21.2	40	74	132	228	381
20	2.3	5.1	10.7	21.3	41	75	133	229	383
25	2.3	5	10.4	20.6	39	73	129	222	372
30	2.1	4.7	9.8	19.4	37	68	121	209	350
35	2	4.3	8.9	17.8	34	63	111	192	321
40	1.7	3.8	8	15.9	30	56	99	171	285
45	1.5	3.3	6.9	13.7	26	48	85	147	246
50	1.2	2.7	5.7	11.3	22	40	71	122	204
55	1	2.2	4.5	9	17	31	56	96	161
60	0. 7	1.6	3.4	6.7	13	24	42	72	121

Thermal SiO_2 Etch Rates on KOH [6]

(Eo=0.85 eV, Activation Energy)

%KOH	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C
10	0.4	1.22	3.5	9.2	23	54	123	266	551
15	0.63	1.91	5.4	14.4	36	85	193	416	862
20	0.88	2.66	7.5	20	50	118	268	578	1200
25	1.14	3.46	9.8	26	65	154	348	752	1560
30	1.42	4.32	12.2	32.5	81	193	435	940	1950
35	1.44	4.37	12.4	32.8	82	195	440	949	1970
40	1.33	4.03	11.4	30.3	76	180	406	876	1820
45	1.21	3.67	10.4	27.5	69	163	369	797	1650
50	1.08	3.28	9.3	24.6	62	146	330	713	1480
55	0.95	2.87	8.1	21.6	54	128	289	624	1290
60	0.81	2.45	6.9	18.4	46	109	246	532	1100

Die Finishing Steps

1.- Metallization

Metal	Good	Bad
Al	IC Compatibility	Dissolves in Release Etch
	Long Experience	(Rough and Poor Surfaces)
Au	Silicon Micromachining	Poison to CMOS process
	Metal of Choice	(Minority Lifetime Killer)

2.– Release

HF Etch (Hydrofluoric Acid)	Good Oxide Etch Rate Good Selectivity to poly-Si Attacks aluminum surfaces
BOE (Buffered Oxide Etch)	Slow Oxide Etch Rate Good Selectivity to poly-Si and Aluminum

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3.- Madou, M., Fundamentals of Microfabrication, CRC Press, 1997

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5.- Sandia National Laboratories—Course Notes of Advanced Design Short Course, 2000

6.- Seidel et al, J. Electrochem Soc., **137**, 3612-3626, 1990

7.– Pandhumsoporn,T., "High Etch Rate, deep anisotropic plasma etching of silicon for MEMS fabrication", SPIE Vol. 3328, pp.93-101

About Us

Memstar Corporation is a company dedicated to the development of micromachine and microsystem enabled products for the optical communications industry. Memstar provides fab-less development services for micromachined components and related subsystems. The company leverages proprietary technology covering novel device and packaging concepts, and unique characterization methods. Memstar's design methodology is focused on allowing short development cycles and cost containment.

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