SILICON MICROMACHINING

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CAMBRIDGE
UNIVERSITY PRESS

PUBLISHED BY THE PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE
The Pitt Building, Trumpington Street, Cambridge CB2 1RP, United Kingdom

CAMBRIDGE UNIVERSITY PRESS
The Edinburgh Building, Cambridge CB2 2RU, UK http://www.cup.cam.ac.uk
40 West 20th Street, New York, NY 10011-4211, USA http://www.cup.org
10 Stamford Road, Oakleigh, Melbourne 3166, Australia

First published 1998

Printed in the United States of America

Typeset in Times Roman 10/12.5 pt. in LaTeX 2_ε [TB]

Library of Congress Cataloging-in-Publication Data
Elwenspoek, M. (Miko), 1948–
Silicon micromachining / M. Elwenspoek, H. Jansen.
p. cm. – (Cambridge studies in semiconductor physics and
microelectronic engineering ; 7)
ISBN 0-521-59054-X (hb)
1. Silicon. 2. Micromachining. 3. Etching. I. Jansen, H.
(Henri) II. Title. III. Series.
TK7871.15.S55E49 1998
621.3815 – dc21 97-43732
CIP

A catalog record for this book is available from the British Library

ISBN 0 521 59054 X hardback

Contents

Preface *page* xiii

1. Introduction **1**
References 4

2. Anisotropic wet chemical etching **5**
2.1 Introduction 5
2.2 Mechanical properties of single crystalline silicon 7
2.3 Crystallographic properties of silicon 9
2.4 Process of etching 11
2.5 Experimental methods 16
2.5.1 Wagon wheel method 16
2.5.2 Etching of spheres 18
2.6 Phenomenological properties of anisotropic etching solutions 23
2.6.1 Introduction 23
2.6.2 KOH solutions 24
2.6.3 EDP solutions 27
2.6.4 TMAH solutions 28
2.7 Micromachining of ⟨100⟩- and ⟨110⟩-oriented silicon wafers 32
2.7.1 Micromachining ⟨001⟩-oriented wafers 32
2.7.2 Micromachining ⟨110⟩-oriented wafers 35
2.8 Etch stop mechanisms 36
2.8.1 Introduction 36
2.8.2 Time etch stop 38
2.8.3 B^+ etch stop 43
2.8.4 Thin films 47
2.8.5 Electrochemical etch stop 49
2.9 Mask materials 51
2.9.1 Introduction 51
2.9.2 Silicon dioxide 52
2.9.3 Silicon nitride 52
2.10 Corner compensation 54
2.10.1 Introduction 54
2.10.2 Fast-etching planes 55
2.10.3 Mask designs for corner compensation 57
2.10.4 Results 61

2.11 Miscellaneous 63
2.11.1 Laser assisted etching 63
2.11.2 Backside protection 64
References 66

3. Chemical physics of wet chemical etching **69**
3.1 Introduction 69
3.2 Crystallography revisited: Atomic structure of surfaces 71
3.3 Surface free energy and step free energy 76
3.4 Thermodynamics 77
3.4.1 Chemical reaction 77
3.4.2 Chemical potential difference 81
3.4.3 The roughening transition 81
3.5 Kinetics 83
3.5.1 Nucleation of etch pits 83
3.5.2 Etch pits formed by screw dislocations 86
3.5.3 Kinetic roughening 88
3.6 Etch rate diagrams 89
3.6.1 Close to the etch rate minimum 89
3.6.2 Form of the minimum 90
3.7 Direct evidence for steps 95
3.8 Summary 98
References 99

4. Wafer bonding **102**
4.1 Introduction 102
4.2 Silicon fusion bonding 102
4.2.1 Description of the process 103
4.2.2 Mechanism of fusion bonding 105
4.2.3 Effect of wafer surface imperfections 108
4.2.4 Bonding of hydrophobic wafers 110
4.2.5 Silicon fusion bonding after chemical mechanical polishing 111
4.3 Anodic bonding 111
4.3.1 Anodic bonding of a silicon wafer to a Pyrex wafer 112
4.3.2 Anodic bonding using a sputtered thin film of Pyrex 115
4.4 Low-temperature bonding 117
References 121

5. Examples and applications **123**
5.1 Introduction 123
5.2 Membranes 123
5.2.1 Pressure sensors 123
5.2.2 Miniature microphones 132
5.2.3 Application of membranes in micro liquid handling devices 134
5.3 Beams 137
References 148

6. Surface micromachining **151**
6.1 Introduction 151
6.2 Basic fabrication issues for surface micromachining 151
6.2.1 The basic idea 152
6.2.2 Properties of thin film materials 153
6.2.3 Sacrificial layer etching in HF solutions 157
6.2.4 Stiction 158
6.3 Applications 160
6.3.1 Combdrives 160
6.3.2 Manipulators and x-y stages 162
6.3.3 Microgrippers 164
6.3.4 Rotating micromotors 167
6.3.5 Resonators and sensors 173
References 177

7. Isotropic wet chemical etching of silicon **181**
7.1 Etchants and etching diagrams 181
7.2 Diffusion and stirring 183
7.3 Mask materials 183
7.4 Anodic HF etching 183
7.4.1 Introduction 183
7.4.2 Electrochemical etching mechanism 183
7.4.3 Geometry control of etched structures 185
7.4.4 Low-doped selective anodic HF etching 187
References 191

8. Introduction into dry plasma etching in microtechnology **193**
8.1 Microtechnology 193
8.2 Plasmas 194
8.3 Etching 197
8.4 Outline 198
References 199

9. Why plasmas? **200**
9.1 Vapor etching 201
9.2 Wet etching 201
9.2.1 Freeze drying 201
9.2.2 Photoresist-assisted releasing 202
9.2.3 Surface modification 202
9.3 Dry etching 202
9.3.1 Photon beam etching 202
9.3.2 Neutral (beam) etching 203
9.3.3 Plasma etching 204
References 205

10. What is plasma etching? **206**
10.1 Principle of plasma etching 209

10.2 Physical model 212
10.2.1 Particle velocity, mean kinetic energy, and temperature 213
10.2.2 Pressure, flux, and rate of effusion 216
10.2.3 Entropy 217
10.2.4 Probability of collision and mean free path 218
10.2.5 Elastic collisions 220
10.2.6 Inelastic collisions 220
10.2.7 Plasma density 224
10.2.8 Debye length 224
10.2.9 Plasma parameter 226
10.2.10 Plasma oscillations 226
10.2.11 Plasma-to-floating potential 226
10.2.12 Examples 228
10.3 Chemical model 232
10.3.1 Thermodynamic language 233
10.3.2 Reversible thermodynamics 236
10.3.3 Steady state thermodynamics 258
10.4 Electrical equivalent circuit 264
10.4.1 Discharge unit 265
10.4.2 Rf power supply and matching unit 265
10.4.3 VSWR measuring unit 265
10.4.4 Self-bias potential 266
References 267

11. Plasma system configurations **268**
11.1 Chemistry 269
11.2 Frequency 269
11.3 Electrode arrangement 270
11.4 Load capacity and technique 271
11.5 Plasma-sample distance 271
11.5.1 Contact plasma etching 272
11.5.2 Remote plasma etching 274
11.6 Operating pressure 276
11.7 Type of etching species 276
11.7.1 Radical etching (RE) or plasma etching (PE) 277
11.7.2 Ion beam assisted radical etching (IBARE) or reactive ion etching (RIE) 277
11.7.3 Ion beam etching 279
References 279

12. Contact plasma etching **280**
12.1 Etch directionality in IBARE 280
12.1.1 Ion-induced IBARE 280
12.1.2 Ion-inhibitor IBARE 281
12.2 Pure plasma chemistries 282
12.2.1 Hydrogen based 282
12.2.2 Fluorine based 282

12.2.3 Chlorine based 283
12.2.4 Bromine based 283
12.2.5 Oxygen based 284
12.3 Mixed plasma chemistries 284
12.3.1 Mixed molecules 284
12.3.2 Mixed gases 284
12.4 Multistep plasma chemistries 288
12.5 Plasma parameters/influences 288
12.5.1 Doping 288
12.5.2 Temperature 290
12.5.3 Reactor materials 290
12.5.4 Reactor cleanliness 291
12.5.5 Loading 291
12.6 Mask materials/influences 292
12.6.1 Etchability 292
12.6.2 Film formation 293
12.6.3 Catalytic reactions 293
12.6.4 Selectivity 293
12.6.5 Materials 294
12.6.6 Conductivity 295
12.6.7 Temperature 295
12.7 Problems and solutions 296
12.7.1 Uniformity 296
12.7.2 Roughness 296
12.7.3 ARDE 297
12.7.4 RIE damage 299
12.8 Data acquisition 299
12.8.1 Fundamental models 300
12.8.2 Design-of-experiment models 300
12.8.3 Black surface methodology 303
12.9 End point detection and plasma diagnostics 308
12.9.1 Laser interferometry/reflectance and ellipsometry 308
12.9.2 Spectroscopy 308
12.9.3 Probes 309
12.10 Current trends 309
12.10.1 Magnetron ion etching (MIE) 309
12.10.2 Electron cyclotron resonance (ECR) 310
12.10.3 Inductively coupled plasma (ICP) 310
12.10.4 Pulsed plasma 310
12.10.5 Cryogenic cooling 311
12.10.6 Clustering 311
12.10.7 Others 312
References 312

13. Remote plasma etching 314
13.1 Review of vacuum etching 314
13.2 Etch apparatus 316

	13.2.1	The vacuum system	316
	13.2.2	The ion source	316
	13.2.3	The substrate holder	317
	13.2.4	The heater	317
13.3	Review of thermally assisted ion beam etching		317
13.4	Etch mechanism		317
	13.4.1	Photon source	318
	13.4.2	Conduction	319
	13.4.3	Radiation	320
	13.4.4	Sublimation	320
13.5	Grass		322
13.6	Experimental		324
13.7	Results and applications		325
	References		329
14.	**High aspect ratio trench etching**		**331**
14.1	Qualitative analysis		332
	14.1.1	IBARE setting	333
	14.1.2	Equipment parameters	333
	14.1.3	Plasma characteristics	333
	14.1.4	Trench-forming mechanisms	336
	14.1.5	HART effects	338
14.2	Equipment and experimental		338
	14.2.1	Plasmafab 310/340	338
	14.2.2	Plasmalab 100	338
	14.2.3	Experimental	339
14.3	HARTs		339
	14.3.1	Tilting	339
	14.3.2	Bowing	340
	14.3.3	TADTOP	341
	14.3.4	RIE lag due to ions	341
	14.3.5	RIE lag due to radical depletion or reflection	342
	14.3.6	Micrograss	343
	14.3.7	Bottling	345
14.4	Quantitative analysis of RIE lag		345
	14.4.1	Problem description	347
	14.4.2	Ion beam assisted radical etching	347
	14.4.3	Literature	350
	14.4.4	Inhibitor depletion in a trench	351
	14.4.5	Radical depletion in a trench	352
	14.4.6	Ion depletion in a trench	356
	14.4.7	Ion/solid interactions	369
	14.4.8	Experimental	370
14.5	Conclusions		377
	References		380

15. Moulding of microstructures **382**
15.1 Dry etching 383
15.2 Electroplating 383
15.3 Embossing 384
15.4 Dry etching with photoresist as a mask 385
References 387

16. Fabrication of movable microstructures **388**
16.1 SCREAM 388
16.2 SIMPLE 389
16.3 BSM-ORMS 390
16.3.1 BSM-SCS 391
16.3.2 BSM-SOI 392
16.3.3 BSM-SISI 394
16.3.4 Conclusion 395
References 396

Index 399

1

Introduction

Etching and bonding of silicon are basic technologies in micro systems technology (MST). MST is currently developing very fast, partially due to the large financial backing which is put into its development by governments and companies.

The promises of MST are formidable. The main promise stems from the fact that MST is based on batch fabrication derived from integrated circuit technology. It is anticipated that MST will undergo an evolution similar to integrated circuit (IC) technology, with new inexpensive products that will in part revolutionize our lives. The ideas on the potential of MST range from devices which are nowadays found in nearly all automobiles (pressure sensors and accelerometers) to sensors for flow, temperature, force, position, magnetic fields, chemicals, light, IR-radiation, etc.; either inexpensive or with unmet performance. In our view, the next generation of devices will use micropumps, flow sensors, micromixers, microsieves, microreactors, etc. for dosing in medicine, biology, chemical, and biochemical analysis systems with applications in environmental monitoring, medicine, process control, and chemical analysis in general.

Looking further into the future, we will have microrobots in a vast number of applications. They will be found in charge coupled device (CCD) cameras for active optimizing of the position of the CCD chip, and transporting and positioning the optic components in CD setups. There will be robots that help physicians in microsurgery, robots that repair and maintain other microsystems, and microrobots that perform fabrication and inspection tasks in microclean rooms. Most of the latter are a few decades away, and – very likely – main future applications of MST are lacking in the list, being as unpredictable as the application of computers for games was twenty years ago.

At present we have to solve a great deal of problems. These problems are associated with the control of the technology; we have to learn how to design microsystems, and we have to develop tools for design, modelling, and simulation of microsystems. We are encountering new aspects of physics and chemistry when scaling down known systems. We have to translate three-dimensional principles, design, and fabrication to planar, say 2.5-dimensional, principles, design, and fabrication.

The microworld is different from the macroworld. The microworld is governed by surface forces such as surface tension and friction. Inertia and weight have meaning in microsystems only in exceptional cases, such as the accelerometer or the resonant sensor, and electrostatic forces and fluid shear forces are large and heavily deform mechanical constructions. Streaming is at extremely small Reynolds numbers, so all fluids appear quite viscous. Surfaces appear very rough, and mechanical constructions are very stiff and strong. In systems of μm size the temperature of the surroundings would manifest itself by violent Brownian motion.

To give an illustrative example, ants are unable to wash their face: they are not strong enough to break through the surface tension of a water droplet. Once inside a water droplet they would drown because they couldn't leave it. They could never maintain a fire, because the flame is too large. They could never read a book: the surface tension of the micropages would forbid ants to open the book. If we were to shrink by using a fantastic machine, as in the movie "The Fantastic Voyage," we would certainly be unable to survive a fight against an ant, just because we are wrongly designed for this scale.

The physics of the microworld and the resulting possibilities for microsystems were anticipated by R. P. Feynman in 1959. The article ("There is plenty room at the bottom") has been reprinted in the *Journal of Microelectromechanical Systems* [1]. Feynman anticipated the important role of photolithography, thin film techniques, high density recording, and electrostatic motors. Twenty years later, Feynman gave a second lecture on the subject, a written version of which can be found in [2].

When designing microsystems, we have to learn how this microworld feels. The designer has to be trained for a new intuition. If one looks at scaling from a phenomenological point of view, one finds some interesting trends. In Fig. 1.1 we show how the price per mass for machines and mechanical components depends on the scale. It is quite evident that small things are relatively more expensive than large things.

Figure 1.2 demonstrates a striking scale effect. The Reynolds number, as defined in the figure, lies on a single line for animals over the whole range between the smallest animals (bacteria) and the largest animals (whales).

The technology for microsystems is rooted in two quite different traditions. One derives from fine mechanics, and the other is based on photolithographic techniques. The latter allows fabrication of structures with finest details in the order of 1 μm and a relative precision of not more than say 1/10,000. The limit of fine mechanics is close to 10 μm; however, the relative precision is one or two orders larger. The most important difference between these

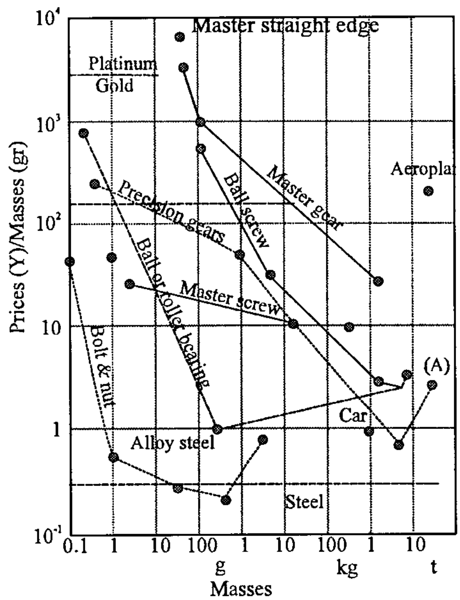

Fig. 1.1. Price per mass of machines as a function of the size (data from Hayashi [3]).

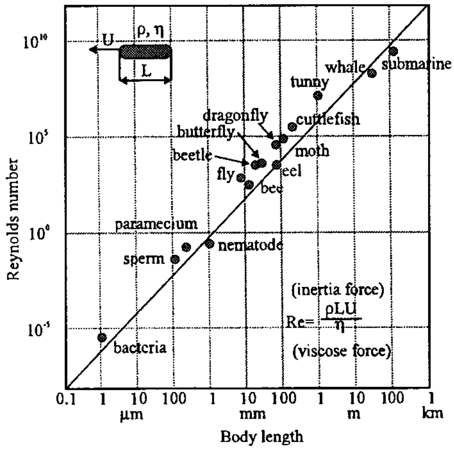

Fig. 1.2. Reynolds number as a function of size (from Hayashi [3]).

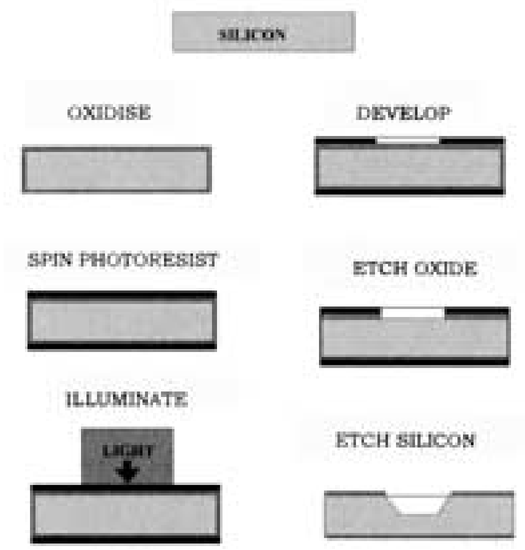

Fig. 1.3. Basic photolithographic process.

techniques is that the latter technology is suitable for batch processes but is restricted to projections of a two-dimensional structure in three dimensions.

This book concentrates on the latter. In Fig. 1.3 we show the basic photolithographic process. We see how "three-dimensional" structures are realized by using a two-dimensional structure. This "three-dimensional" structure is not truly three dimensional: we will always see that the structures derive from a pattern in a plane. In some way or other (Fig. 1.3) we only get projections. We cannot make screws and nuts, but they would not be of much help: we have no systems to assemble microsystems.

Here is one of the challenges for the microengineer: to design microsystems that need not be assembled part by part, but that come out of the production process assembled. We cannot make microcomponents and thereafter assemble them: we have to design microsystems. Microtechnology does not only restrict the design possibilities, but also offers new design

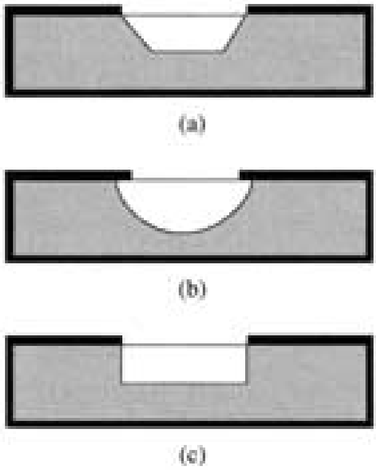

Fig. 1.4. Possibilities for etching. (a) and (c) anisotropic etching, (b) isotropic etching.

principles. We can fabricate microbridges with a thickness of 1μm and a length of 1 cm. In a macroworld this would correspond to a bridge of 1 km length and 10 cm thick!

In Fig. 1.4 the various possibilities for etching are indicated. All shapes shown can be realized by both dry and wet etching. However, wet chemical anisotropic etching is restricted to crystallographic orientations, while dry etching is not. Dry etching is therefore more flexible than wet etching, but the process is more difficult to control and the equipment is much more expensive.

Engineers who do their work in MST are faced with the fact that MST is a multidisciplinary field. In the optimal situation, the engineer must be trained in basic physics and chemistry in order to be able to understand design and modelling of the microdevices and systems. He needs to know quite a lot about mechanical engineering, in particular, strength of materials, theory of elasticity, and tribology. He needs the typical skills of an electrical engineer with respect to systems thinking, and he must be able to use the various simulation tools, such as finite elements and SPICE. He must be aquainted with the fundamentals of optics and magnetics. He will find that each application will have its own difficulties. For example, an application in the medical field demands that the engineer be able to communicate with the physician; an application in space travel again demands a totally different knowledge and background.

All this cannot be combined in a single person. Research in MST is only possible in teams in which physicists, chemists, and electrical and mechanical engineers co-operate. We believe however that the high degree of interdisciplinary demands in the long term that engineers are trained not in a single discipline, but start from one discipline to gain knowledge and skills from other disciplines as well. Therefore, it is necessary to design new curriculum in MST.

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