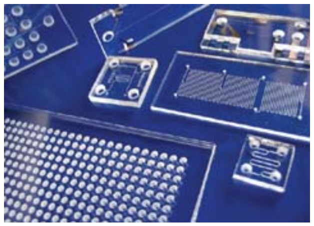
EE 428/528 BioMEMS & Lab-on-a-chip

Lecture 05: BioMEMS Fabrication 01 (Bonding, PolymerMEMS)



Kwang W. Oh, Ph.D., Assistant Professor
SMALL (nanobioSensors and MicroActuators Learning Lab)
Department of Electrical Engineering
University at Buffalo, The State University of New York
215E Bonner Hall, SUNY-Buffalo, Buffalo, NY 14260-1920
Tel: (716) 645-3115 Ext. 1149, Fax: (716) 645-3656
E-mail: kwangoh@buffalo.edu,
http://www.SMALL.buffalo.edu

SMALL for Big Things
nanobioSensors & MicroActuators Learning Lab
University at Buffalo
The State University of New York

[Bonding]

- Bonding techniques are used to join two similar or dissimilar substrates, to create encapsulated structures, and for MEMS device packaging
- Packaging is easy to overlook sometimes but one of the most critical and costly processing step
- Bonding
  - Substrate to substrate bonding or component to substrate bonding
  - Bonding can typically provide hermetic sealing
  - Silicon to silicon bonding
  - Silicon to glass bonding
  - Glass to glass bonding
  - Polymer bonding

SMALL for Big Things
nanobioSensors & MicroActuators Learning Lab
University at Buffalo
The State University of New York

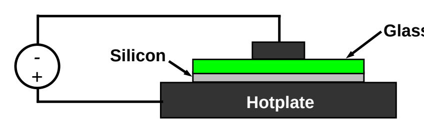
[Bonding]

- Fusion Bonding (Thermal Bonding)
  - Direct bonding method with only heat and pressure required
  - Silicon to Silicon
    - Bonding process occurs between 300-800°C, and annealing at 800-1100°C is used to strengthen the bond
    - Almost no stress and the bond strength is almost identical to the silicon itself
    - (-) High temperature, long processing time
  - Glass to Glass
    - Bonding process occurs around 500-600°C
    - Good bond strength
    - (-) High temperature, long processing time
    - (-) Hard to achieve void-free bonding in a large area, but possible
- Eutectic Bonding
  - Utilizes the formation of eutectic alloys to bond two substrates at a relatively low temperature (typically glass to silicon)
  - Gold-silicon: Bonding occurs at 363°C, which is below the critical point of both glass and silicon
  - Hard to obtain good bonding over a large area

SMALL for Big Things
nanobioSensors & MicroActuators Learning Lab
University at Buffalo
The State University of New York

[Bonding]

- Anodic Bonding
  - Glass to silicon bonding at a relatively low temperature compared to fusion bonding
  - High electric field (400-700V range) at 350-450°C required
  - Sodium-rich glass: Corning #7740 (Pyrex™) or Borofloat™ (Schott Glass)
  - Fast and reliable hermetic sealing at low cost, simple equipment
  - (-) High voltage requirement

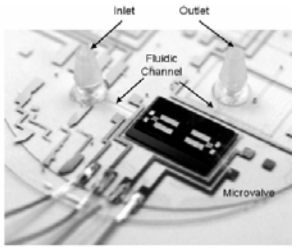


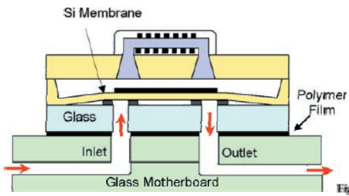
[Bonding]

- **Bonding with Intermediate Layer**
  - To overcome high-temp requirement of typical fusion bonding
  - To bond two different materials that are hard to bond
  - Choose intermediate layer that can be thermally bonded at low temperature (typically below 200ºC)
  - Sputtered glass, vapor-deposited glass, spin-on glass, spin-on or deposited polymer, deposited epoxy, electroplated metal

[Bonding]

- **Spin-coated Fluorocarbon Polymer as an Intermediate Layer**
  - Spin-coated polymer can be patterned using dry etching (RIE)
  - Bonding occurs at 160ºC with slight pressure
  - Achieve bonding only in desired areas
  - Useful when certain areas of the substrate have to be free of intermediate polymer layers





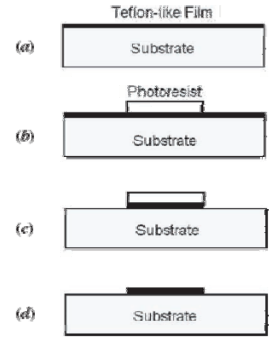


Figure 2. The fabrication process of the Teflon like film cross pattern: (a) spin-coat the film; (b) spin-coat the photoresist and lithography; (c) etch the film using oxygen plasma; (d) remove the photoresist.

[Bonding]

- **Important Factors affecting Bonding**
  - Clean substrate
  - Flat substrate
  - Smooth substrate

- **Bonding Result Inspection**
  - Visual inspection
  - Infrared inspection } Inspect uniformity
  - Razorblade testing
  - Peel test } Bond strength test

[Bonding] Polymer Bonding

- One of the major challenge in plastic microfabrication
- Various application-specific materials mean different bonding methods/processing conditions for each material
- Bonding has to occur at low temperature due to the low glass transition point of most plastic materials
- Adhesive bonding, thermal bonding, ultrasonic welding, solvent bonding, intermediate layer bonding

[Bonding] Polymer Bonding

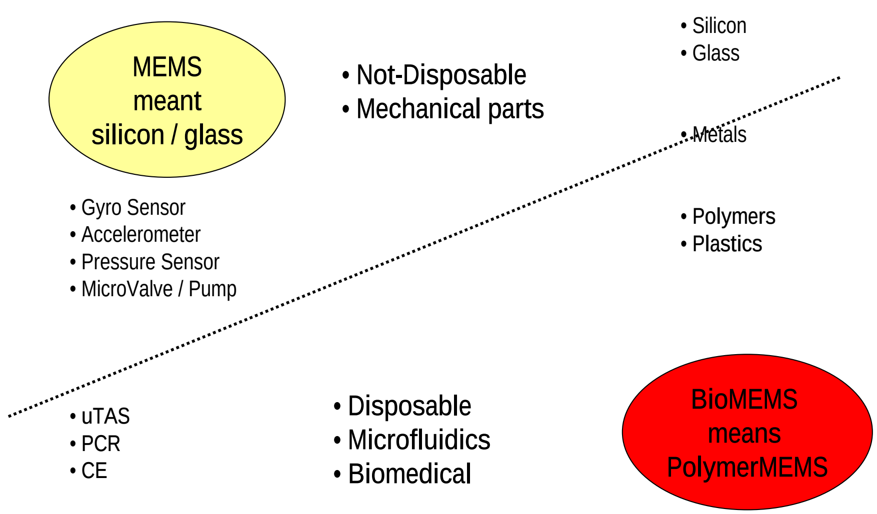
- Thermal Bonding
  - When parts to be joined are made from the same material
  - Can be achieve without adhesive or intermediate layer
  - Temperature slightly above the glass transition point of the plastic + slight pressure
  - (-) Heat can deform the plastic parts => Localized heating through embedded electrodes can overcome this problem
  - (-) Only flat parts can be bonded
- Ultrasonic Welding
  - Utilize high-frequency sound energy (20 kHZ) to either soften or melt thermoplastic at the interface between same types of materials
  - Fast bonding time (typically 2 seconds)
  - Low cost, energy efficient

[PolymerMEMS] Substrates: Silicon, Glass, Polymer

- Si
  - Conventional micro/nanofabrication
  - Applications
    - Microelectronic devices (PN junction, MOS)
    - Optical devices (CCD, photodiode, photodetector)
    - MEMS devices (Pressure sensor, ink-jet nozzle, DMD)
- Glass
  - Conventional micro/nanofabrication
    - Etching
      - Microfluidic channel etching (easy anisotropic etching by HF)
    - Bonding
      - Anodic bonding (Si-to-Glass)
      - Thermal bonding (Glass-to-Glass)
  - Applications
    - Optical devices
    - Microfluidic devices
    - Sealing chamber/cover
- Polymer
  - Advantages
    - Disposability
    - Bio-compatibility
    - Mass-production
    - Good optical property
  - Disadvantages
    - Non-conventional micro/nanofab
    - Surface modification
    - Difficult bonding process
  - Applications
    - BioMEMS devices
      - PC, PMMA
    - Rapid prototyping devices
      - PDMS
    - Packaging

¶ http://www.aero.org/publications/helvajian/helvajian-2.html

[PolymerMEMS] BioMEMS means PolymerMEMS



[PolymerMEMS] Plastic for MEMS

- Polymer
  - Polymer consists of long chains of smaller molecules (monomers) that are the basic building blocks of polymers, e.g. plastic, DNA
  - Plastic:
    - Polymer that can be formed by a thermo mechanical process
    - Plastic typically contains additives that impact their properties
- Advantages of Plastic in Bio-MEMS
  - Low material cost and easy fabrication steps => Disposable
  - Wide range of materials for specific bio/chemical application already exist, e.g. surface charge, molecular adsorption, optical properties, glass transition temperature
    - Glass transition temperature: temperature at which the polymer begins to soften (much lower then melting point): T_g
  - Biocompatibility of plastic

[PolymerMEMS] Why Polymer?

- PolymerMEMS means MEMS which is using plastics and/or polymers for the concept of micro-total analysis systems or lab-on-a-chip.
- Primary interest of researchers in the field of Microfluidics
  - applications
  - rather than fabrication methods
- Due to the demand for single-use disposable products in
  - clinical diagnostics
  - genetic analysis
- Materials beyond MEMS-based materials
  - Plastics and/or polymers
    - new trends in BioMEMS
  - Si and Glass
    - normal materials in classic MEMS

¶ Ralf-Peter Peters, microParts GmbH, BioMEMS 2000

[PolymerMEMS] Why Polymer?

- Cost
  - Factor 100 and more compared to Si
    - PMMA: 0.2 - 2 cents/cm2
    - Boro-silicate glass (Schott B270): 5 - 15 cents/cm2
    - Boro-float glass (Corning Pyrex): 10 - 20 cents/cm2
    - Silicon: 20 - 50 cents/cm2
- Design Freedom
  - Flexibility
- Interfacing Micro/Macro
  - Can be combined with standard parts
- Coating
  - Variety, flexibility
- Biomedical Application
  - Acceptance

¶ Ralf-Peter Peters, microParts GmbH, BioMEMS 2000, ¶ Holger Becker, Reviw Paper, Electrophoresis 2000, 21, pp.12-26

[PolymerMEMS] Why Polymer?

- Processing
  - Si ≈ Glass >> Plastics (more development needed)
- Bio-Compatibility
  - Plastics (excellent) > Glass > Si
- Transparency
  - Plastics (yes) ≈ Glass >> Si
- Power Dissipation
  - Si > Glass > Plastics (poor)
- On-Chip Detection
  - Si > Plastics (possible with hybrids) ≈ Glass
- Cost
  - Plastics (cheap) > Glass > Si

¶ Piotr Grodzinski, uFluidics Lab, Motorola, BioMEMS 2000

[PolymerMEMS] Polymer Materials

- Thermoplastic Polymers
  - Unlinked or weakly linked chain molecules
  - Above Tg, become plastic and can be molded into specific shapes, and retain after cooling below Tg
  - Example: PC, PMMA
- Duroplastic Polymers (or Thermoset Polymers)
  - Strongly cross-linked
  - They are harder and more brittle than thermoplastic materials and soften only very little before the temp reaches their decomposition temp
  - Example: Teflon
- Elastomeric Polymers
  - Very weakly cross-linked polymer chains
  - Molecular chains can be stretched with an external force, but relax and return to their original state without an external force
  - Do not melt before reaching their decomposition temp.
  - Example: PDMS

[PolymerMEMS] Polymer Materials

- PC (PolyCarbonate)
  - For optical devices such as compact disks and eye lenses
- PMMA (PolyMethylMethAcrylate)
  - Well known from the generation of micro-optical devices
  - Favorite polymer for the fabrication of microfluidic structures
  - Implantable grade PMMA is used in intraocular lenses and orthopaedic cement
- PDMS (PolyDiMethylSiloxane)
  - Silicone rubber (Sylgard, Dow Corning)
  - Biomedical grade silicones are popularly used in breast implants and the medical world to carry gases and solutions.
- Polymers / Plastics
  - Other polymers: Polyimide, SU-8, Liquid Crystal Polymer (LCP), Parylene, Teflon and Cytop, Biodegradable Polymers
  - MEMS (Micro-Electro-Mechanical Systems) does not always mean silicon, it could be polymers / plastics

[PolymerMEMS] Processing

Master Fabrication
- X-ray Lithography
- e-beam Lithography
- UV Lithography
- Excimer Laser Machining
- Mechanical Microfab.
- Si Micromachining
- Fabrication of a Mold Insert by Electroplating

→

Plastic Replication
- Injection Molding
- Hot Embossing
- Casting (Soft Lithography)

Other Direct Plastic Fabrication
- Machining
- Laser Micromachining
- Stereolithography (SLA)

→

Post Processing
- Metallization
- Surface Modification (Plasma treatments or plasma coating for adapting wetting behavior)
- Bonding (ultrasonic welding, lamination, gluing or laser welding)
- Assembly

[PolymerMEMS] Fabrication Technology