5

Microtechnology Process Flows and Equipment Infrastructure

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Executive Summary

Although MST/MEMS is characterized by diversity this chapter managed to define 10 standard processes by which a majority of bulk and surface micromachining devices can be made. The toolset needed for that is relative limited in number, it is a mix of general thin film equipment like CVD equipment , lithography tools etc. and specific MST/MEMS equipment like Deep Reactive Ion Etchers and backside aligners. Those tools are discussed in more detail in the equipment chapter of this roadmap. In this chapter the defined general processes are described supplemented by examples of products made by these processes. A listing of principle equipment is included needed to run the basic processes of bulk and surface micromachining. It is based on the data of 37 micromachining factories in the world. The analyses of the data has demonstrated that the micromachining processes can be structured into 10 different processes, i.e. 10 process flows are able to serve far over 95% of the bulk and surface micromachining products. The 10 different process flow share close to 90% of the same equipment set, and differentiate from each other by mostly 2 to 3 additional processes.

1 Introduction

1.1 Microsystem Technology

From a historical and technological point of view, MST has its roots in the electronics industry. The processing capabilities in this industry were the basis for the development of MST processing. Even now, certain types of MST device use pure semiconductor type processing. However, the field of MST is broadening with an increasing number of processing types being added to the MST toolbox. The field now covers the expanse from electronics and mechanics to optics and chemistry.

1.2 Surface and Bulk Micro-Machining

The chapter bifurcates the Micromachining manufacturing infrastructure into surface manufacturing and bulk manufacturing. This division in manufacturing infrastructure actually correlates well with the way factories differentiae from each other and with the kind of products which are enabled by the manufacturing processes.

Surface micro-machining is processing on the front surface of a wafer, leaving the wafer itself intact. Conventional electronic circuit processing and the SUMMiT V process are examples of intensive high-resolution surface micro-machining. Bulk micro-machining is processing that involves modification of the wafer itself, creating cavities, channels, and through-wafer holes in the silicon. Other methods to build-up micro systems in the thickness direction of the wafer are backside processing, wafer to wafer bonding, high aspect ratio lithography, and electro-plating. The table below shows typical products made with surface and bulk micro-machining and what processing technology is involved.

	Surface micro-machining	Bulk micro-machining (+ bonding, electro-plating,)
Description	Structuring of thin layers at the surface of the wafer front side	Structuring and building-up in the thickness direction of the wafer
Typical product examples	Surface optical moveable mirrors	Pressure sensor
	Low sensitivity acceleration sensor	High sensitivity acceleration sensor
	Gyroscope	Flowsensors
	Optical waveguides	Micro filters
	Micro switches	Fluidic mixer
		Micro pump
		Etc.
Processing technology	Multi-layer polysilicon process	Anisotropic KOH wet etching
	Thin layer patterning of SiN, SiO2 and polysilicon	Deep Reactive Ion Etching of silicon
	Thin layer patterning of metal layers	Silicon on Insulator (SOI) etching
	Sacrificial layer etching	Anodic and Fusion wafer bonding
		High aspect ratio electro-plating

The following pictures show examples of surface and bulk micro-machining.

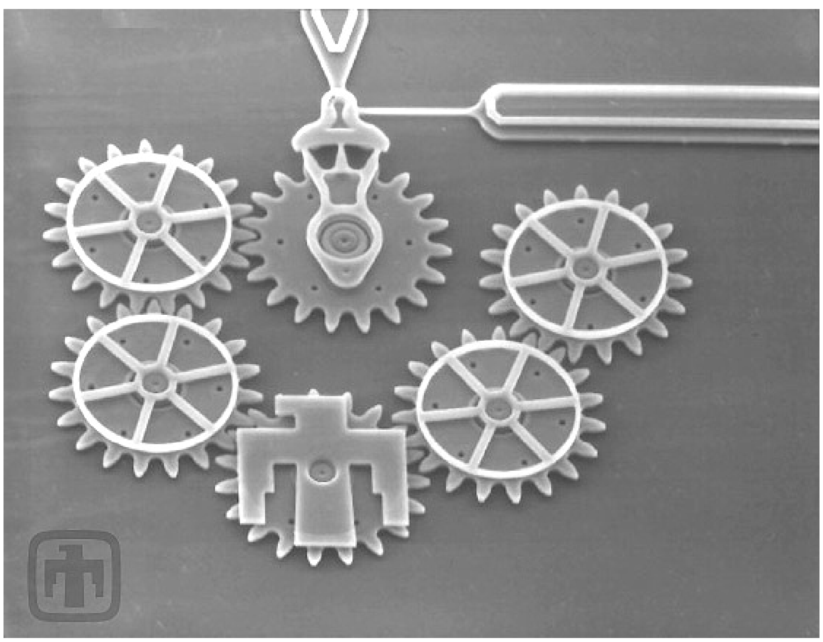


Figure 1 A chain of gearwheels made by Sandia. This is a typical example of surface micro-machining: the structuring is done on top of the surface of the wafer front side. Source: Sandia National Laboratories

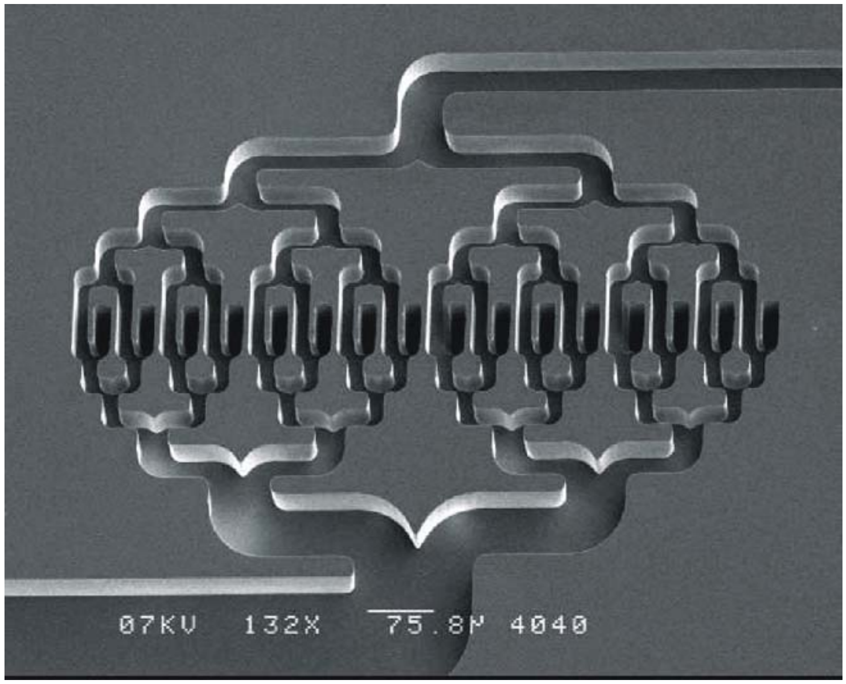


Figure 2 **A fluidic micro-mixer in silicon, manufactured by C2V. The purpose of this device is to mix two fluids very precisely. This is a typical example of bulk micro-machining. The channels are etched 50μm deep into the silicon and the small holes are etched through the wafer with Deep Reactive Ion etching (DRIE). Anodic bonded Pyrex covers the silicon on both sides.**

Figure 3 **A 3-axial force sensor, manufactured by C2V. On-chip strain gauges, very accurately, measure the forces on the triangle in the x, y, and z directions. This device is also a typical example of bulk micro-machining. The silicon bulk is etched with KOH wet etching and Deep Reactive Ion Etching (DRIE).**

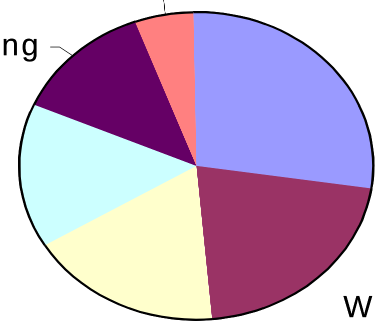


Figure 4 This pie-chart displays the available technologies across thirty seven MST foundries over the world. Surface micro-machining is 14% of the available and used technologies. The rest is bulk micro-machining and other technologies to build-up wafers in the thickness direction.

The above pie chart shows the enabling technologies for MST processing across a large number of foundries. It clearly shows that bulk micro-machining and wafer bonding are the most frequently used processes in MST, followed by surface micromachining.

1.2.1 Typical surface micro-machining related equipment

The analyses of the processes and thereby de facto the equipment of the 37 manufactures provide an extensive list of processes. The objective is to subsequently demonstrate that there is a small and basic group of processes which with on average between 2 and 3 additional processes provide over 95 % of all micromachined based products. The full list of processes and de facto equipment is provided in #2.3

The equipment for surface micro-machining is a subgroup that normally comprises of the following:

- *Wet and dry oxidation*
- *LPCVD* Si_xN_x

- *LPCVD polySi*
- *PECVD* SiO_2 , Si_xN_x , *SiON*
- *Single sided photolithography*
- *Metal deposition*
- *Implantation*
- *Wet isotropic etching of metals,* Si_xN_x *and* SiO_2
- *RIE of polySi,* Si_xN_x *and* SiO_2
- *Sacrificial layer technology like HF-vapor or freeze-drying*
- *APCVD* SiO_2
- *Polyimide application*
- *FHD* SiO_2 *deposition*
- *Flip Chip technology*
- *RIE aluminum*

Most of the equipment and processes mentioned are also used in electronic circuit IC processing.

1.2.2 Typical bulk micro-machining related equipment

The typical equipment used for bulk micro-machining and the building-up of wafers in the thickness direction generally comprises.

- *KOH silicon etching and RCA-cleaning for removal of KOH residues*
- *Silicon Deep RIE with low temperature ICP*
- XeF_2 *isotropic silicon etch*
- *Double sided photolithography*
- *Anodic, fusion and eutectic wafer bonding*
- *Patterning of glass with sand blasting, ultrasonic drilling or etching*

- *Flip chip soldering and alignment machine*
- *Silicon RIE etching of Silicon On Insulator (SOI) wafers and HF-vapor release etch*
- *High aspect ratio lithography*
- *High aspect ratio electro-plating of metals*

Note that processing steps related to photolithography require certain precautions for backside processing. Processing equipment, such as spinners, and hotplates, often require modification to protect the backside of the wafers from physical touching and vacuum suction.

1.2.3 Wafer Size

At present, MST-cleanroom facilities at universities and institutes are in general equipped for processing on 4” wafers. The production type MST-clean rooms are normally equipped for processing on 6” wafers. Both types tend to transfer to processing on larger diameter wafers, although slowly, 6” for universities and institutes and, 8” in the commercial field.

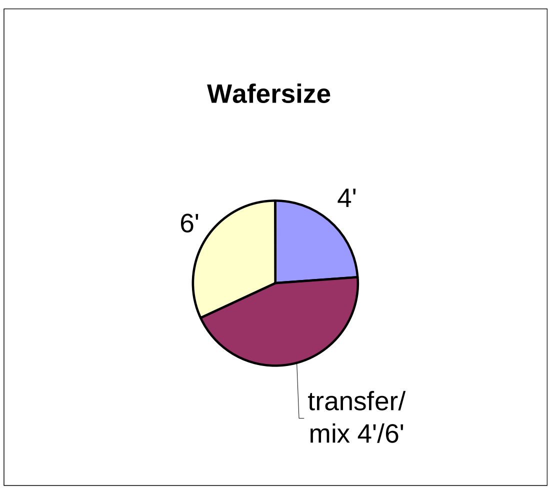


Figure 5. This pie-chart shows the wafer size in MST foundries in the year 2001. Most foundries are transferring to 6” wafer size. Commercial IC foundries dispose of their 6” equipment, in order to transfer to 8” wafer size and larger. Therefore, used 6” equipment becomes available for MST foundries.

2 Listing of MST Process Flows

This chapter gives an overview of products and their manufacturing process flows. Since the goal is to get an overview of what equipment is required, similar manufacturing process flows are grouped into process streams. Each process stream corresponds to a list of required equipment. Additionally, this chapter demonstrates what equipment is essential in a MST cleanroom.

2.1 Most Frequently Used Equipment

Products developed and manufactured, over the years, by C2V are summarized in a matrix. Each product, in this matrix, corresponds with a list of equipment used in its manufacture. The intensity of use for each piece of equipment, in the matrix, is used to formulate the graph below.

The graph demonstrates the most frequently used equipment, a summary of which is as follows (a more detailed list can be found in Appendix B):

- *Wet oxidation*
- *LPCVD stress free Si_xN_x*
- *PECVD SiO_2 , Si_xN_x , SiON*
- *Metal deposition*
- *Wet isotropic etching of metals, Si_xN_x and SiO_2*
- *RIE of Si_xN_x and SiO_2*
- *KOH silicon etching and RCA-cleaning for removal of KOH residues (or TMAHW[1])*
- *Silicon Deep RIE with low temperature ICP*
- *Double sided photolithography*

[1] TMAHW (Tetra Methyl Ammonium Hydroxide in Water) etching is a CMOS compatible alternative to KOH etching. TMAHW allows for a wider selection of materials. The disadvantages are the high costs, lower etch rate, and a slightly lower etch quality.

- *Anodic and fusion wafer bonding*

This list represents the Basic MST toolset for processing MST devices. With this toolset, it is possible to make nearly half of all the MST products that C2V has manufactured so far.

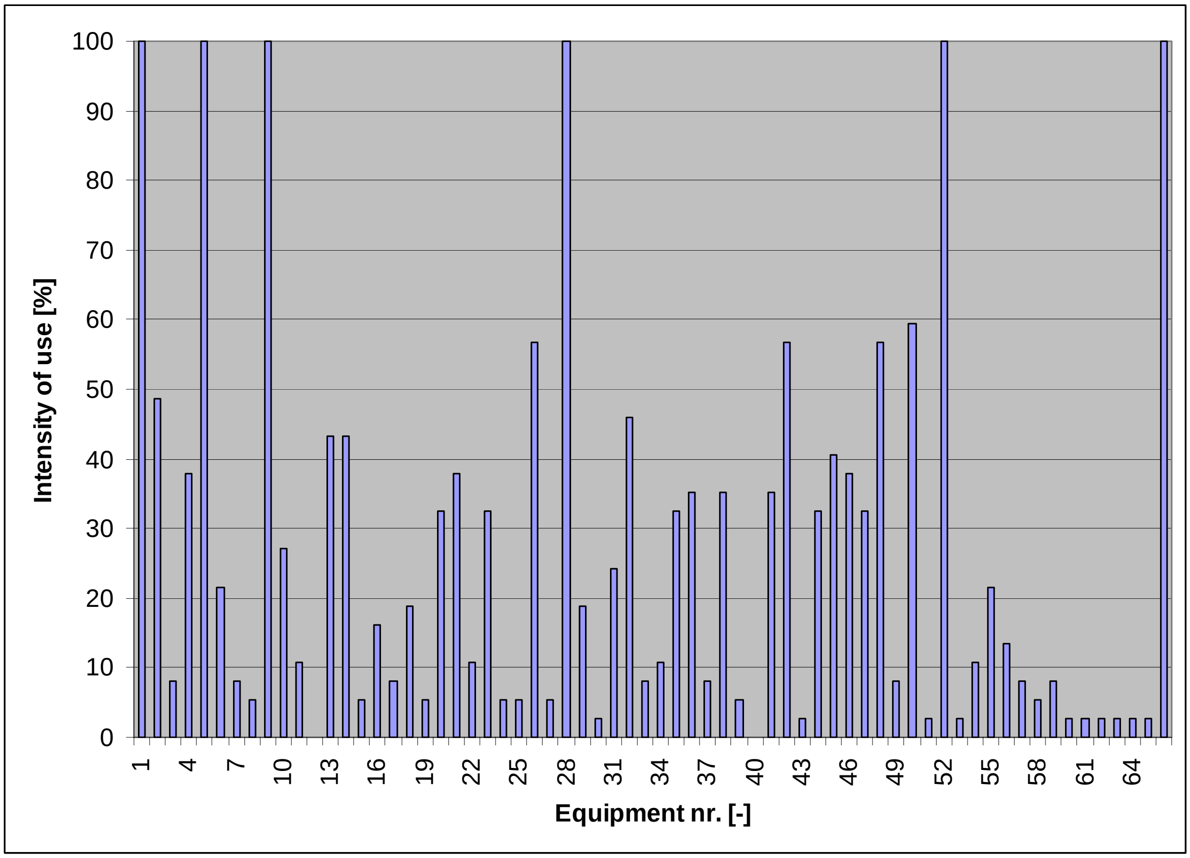


Figure 6 Graph showing intensity of use versus equipment number. The numbers on the X-axis correspond to specific pieces of equipment. The number on the Y-axis is the percentage of process flows in which the specific piece equipment is used.

- *Standard Cleaning*
- *O_2-Plasma cleaning and resist strip*
- *Nitrogen gun*
- *Microscope*
- *Mass measurement*
- *Ellipsometer*

- *Surface profiler*
- *Wafer stack dicing*

2.2 Process Streams

C2V,and many other firms have worked on a large number of devices in the last decade. Every device has its own dedicated manufacturing process. A global view of the relation between products and processes is possible by grouping products with similar processes into 'process streams'. The basis of these process streams are mainly products made by C2V, and relevant products from other MST companies. The intention is for each process stream to correspond with a fixed set of equipment, with similar processes, and with a group of physically similar products. From this overview, it is possible to choose a product group and assess the equipment requirements for creating these products.

Each process stream consists of a characteristic set of process steps or equipment. In the following pages, each process stream describes the main process steps, excluding the most frequently occurring steps: *Cleaning, stripping, inspection, characterization, (double sided) photolithography, low temperature ovens (<400°C), and dicing*

2.2.1 Process Stream 1

Product group: Thermal sensors, micro sieves, and other KOH etched structures

Physical description: Silicon Nitride Membrane devices

This process stream enables the manufacture of many types of devices with different functionality. All related devices contain patterned silicon nitride layers, membranes, or bridges, and wet anisotropically etched (KOH) cavities. Metal deposits on the front and or backside are another option. The equipment for this stream is from the basic set of equipment, as displayed in Appendix B. Some devices in this process stream are well known and still commercially interesting.

Key Equipment: LPCVD and PECVD nitride, KOH, metal deposition and etching, RIE

Products:

- Thermal Conductivity Device (TCD)
- Thermal gas flowsensor
- Thermal fluid flowsensor
- Thin membranes for TEM equipment
- Micro fluidic sieves and other perforated thin membranes
- V-groove glass fiber connector
- Micro needles for medical applications

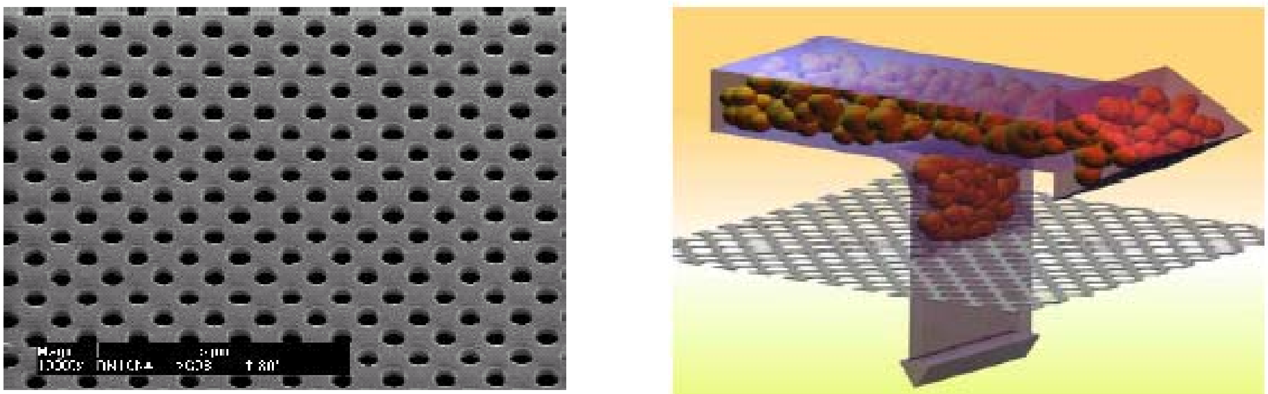


Figure 7 Micro sieve by Aquamarijn and Fluxxion. This micro sieve is a perforated silicon nitride membrane on a silicon chip.

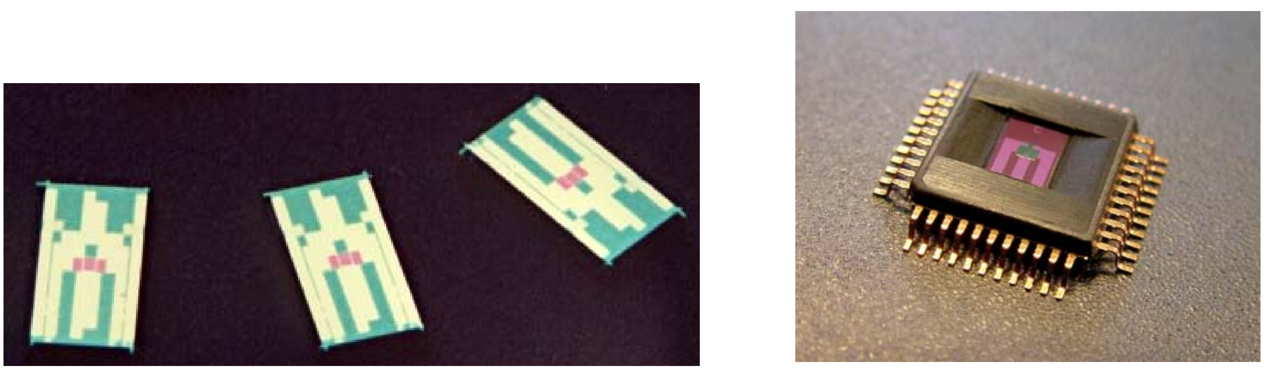


Figure 8 C2V Gas flowsensor chips and an SMD packaged flowsensor chip. The reddish rectangles in the middle of the chips are silicon nitride membranes, made with the help of wafer KOH wet anisotropic etching.

2.2.2 Process Stream 2

Product group: Complex fluidic devices and resonating sensors

Physical description: Stacked silicon chips with complex internal structures

This process stream enables the manufacture of a range of complex high precision devices mostly for the industrial market. These are mostly fluidic devices and resonating sensors. Additional equipment to the basic set are a Deep Reactive Ion Etcher, fusion wafer bonding equipment, and in some cases HF-vapor etching equipment. These devices are difficult to make and relatively new.

Key equipment: Wet oxidation, LPCVD SiN, Deep RIE, HF-vapor, fusion bonding, KOH, implantation and annealing, metal deposition and etching, stack dicing

Products:

- Fluidic micro pump
- Industrial resonating pressure sensor
- Micro nozzle device for medical application
- Micro nozzle device for printing application
- Resonating fluid flowsensor
- Coriolis mass flow sensor

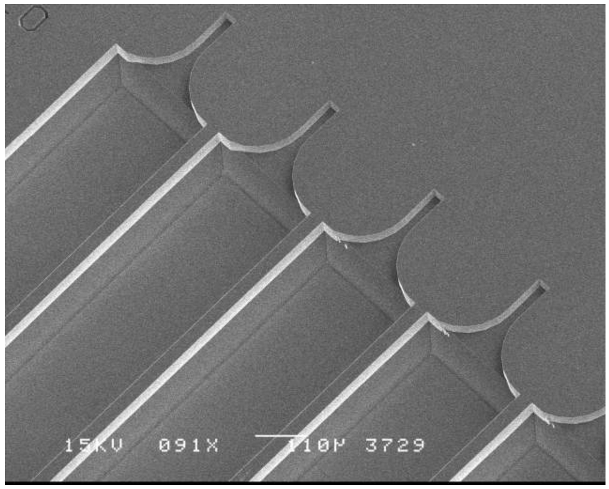


Figure 9 Nozzles for inkjet printers, manufactured by C2V. This picture shows the interior structure of a nozzle chip. At the end of the fabrication process, a thin silicon sheet is fusion bonded on to the nozzles and they are opened by dicing through the end part.

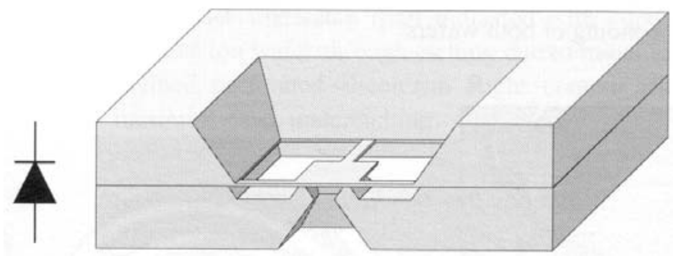


Figure 10 This is a passive fluidic check valve for gas or fluid built from silicon, the structures are etched with KOH and RIE. This valve is from the Transducers Science and Technology group of the University of Twente.

2.2.3 Process Stream 3

Product group: Fluidic devices and planar mirrors

Physical description: Stacked silicon and glass wafers with internal cavities

This process stream makes it possible to manufacture a variety of fluidic devices that are interesting for Bio-MEMS, fluid and gas analysis, and other chemical applications. Production of most of these devices requires only the basic MST toolset. For some devices, it is necessary to use glass patterning, like powder blasting, ultrasonic drilling, glass molding, or glass etching. This process stream is very similar to process stream 2, with the exception that it uses anodic glass bonding instead of silicon fusion bonding. In the experience of C2V, it is commonly preferred to make both complex and accurate devices out of silicon alone. This combination, within process stream 2, contains electronic related processes, like implantation and metallization, which are not present in process stream 3.

Key equipment: Wet oxidation, LPVCD SiN, KOH, Deep RIE, anodic bonding, glass patterning, stack dicing

Products:

- Capillary connector
- Fluidic mixer
- Micro-fluidic channel plates
- Micro valve for gas analysis and pneumatics
- Optical communication devices with moveable planar mirrors

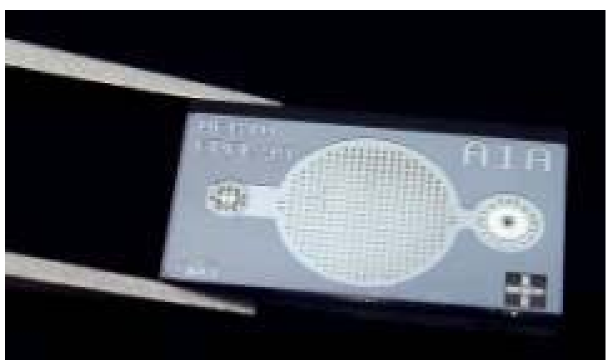


Figure 11A silicon micro pump, made from silicon and Pyrex glass, by Debiotech.

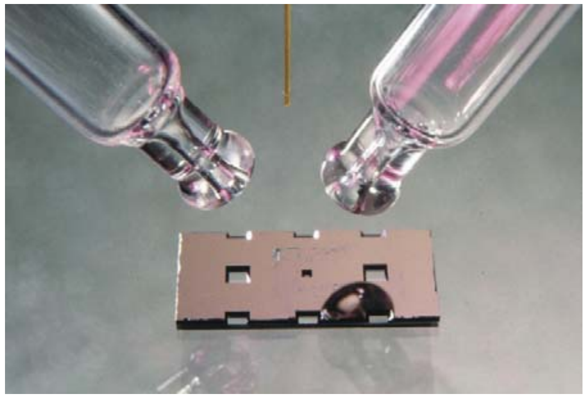


Figure 12A fluid electrophoresis injector chip, manufactured by C2V. The capillary is the output and the glass tubes are the inputs. The chip is built from silicon and glass.

2.2.4 Process Stream 4

Product group: Piëzo resistive sensors

Physical description: Silicon sensor chip with membrane or beams and glass carrier

This type of device originates from the early days of MST and is widely produced in large quantities by commercial MST foundries. Piëzo-resistive pressure sensors and acceleration sensors are widely used in the automotive and aerospace industries.

Key equipment: LPCVD and PECVD oxide/nitride, polySi (bulk Si possible as well), implantation and annealing, metal deposition, etching and annealing, RIE, KOH, anodic bonding, stack dicing

Products:

- Force sensors
- Pressure sensors
- Acceleration sensors

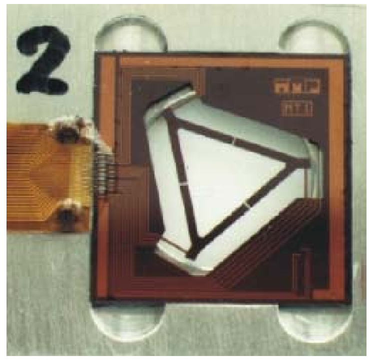


Figure 13A piëzo resistive force sensor for measuring in 3 directions. This is a TMP/C2V product.

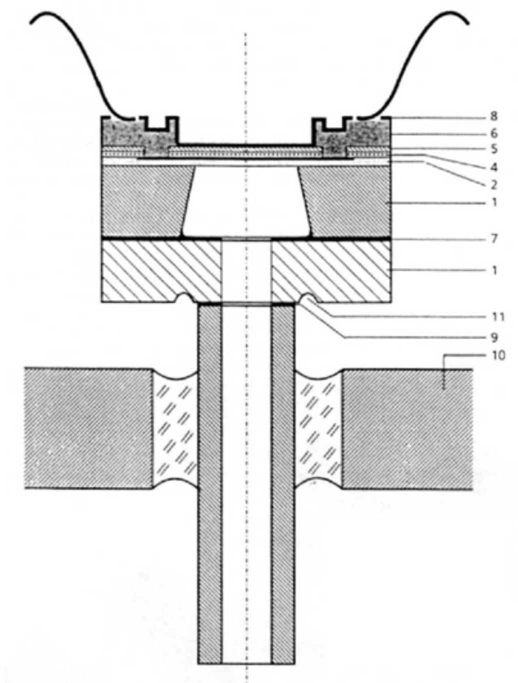


Figure 14Schematic cross-section of a piëzo resistive pressure sensor from Siemens

1 Silicon substrate

2 Silicon epi-layer

3 P-doped resistor

4 Silicon oxide

5 LPCVD silicon nitride

6 Metal electrical contact

7 Interfacing layer

8 PECVD silicon nitride

9 Au/Sn solder joint

10 Header

2.2.5 Process Stream 5

Product group: FHD and SiON optical devices

Physical description: Stacked Oxide or Oxi-nitride layers with metal tracks

These devices are primarily for the communication industry. Recently, this market has collapsed, but will probably be an important market again in the future. Some big players are already in this market. Processing is very critical to meet optical specifications. SiON- and FHD-oxide processing require special equipment dedicated to this purpose alone. The keywords are "Continuous stable processing".

Key equipment: Optical FHD or PECVD SiON, SiO_2 and SiN, RIE, metal deposition and etching, angle dicing

Products:

- VOA
- AWG
- Ring resonators
- Power taps
- Optical sensors

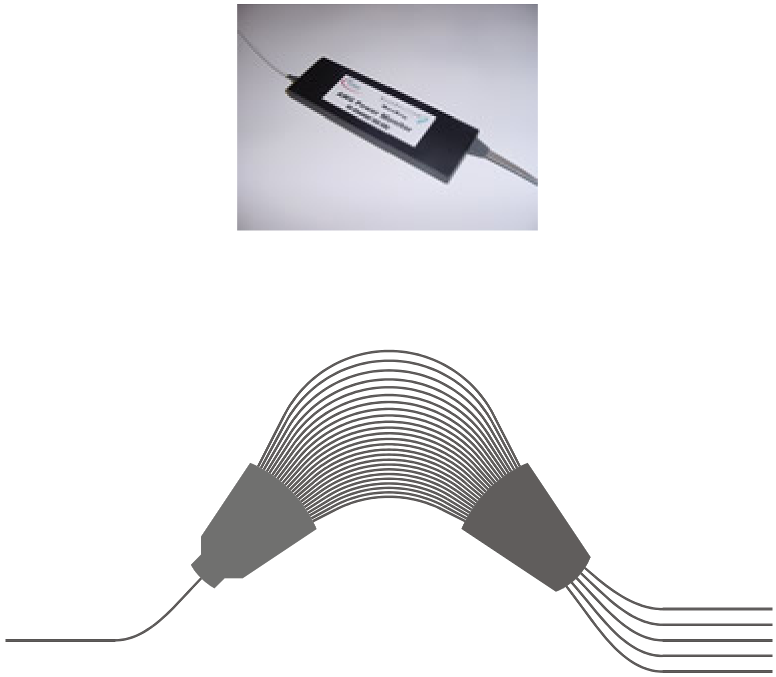


Figure 15 Planar Arrayed Waveguide (AWG) design and a packaged AWG

2.2.6 Process Stream 6

Product group: FET based sensors

Physical description: Modified MOSFET process with Ion sensitive gate

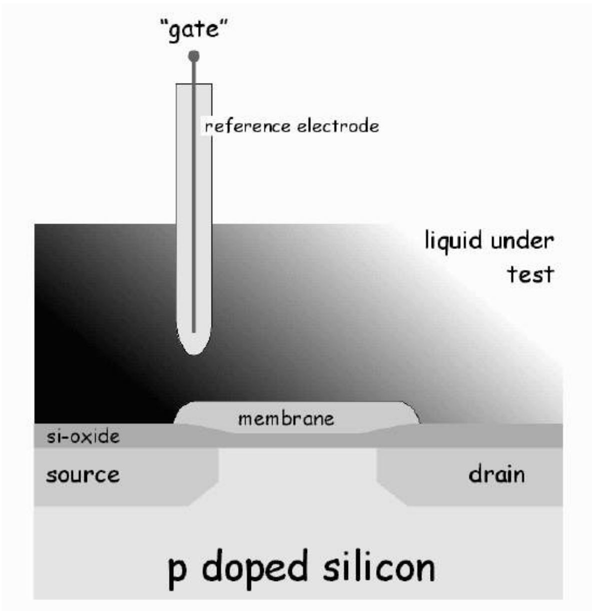
ISFETs and ChemFETs are for chemical fluid analysis in BioMEMS, and medical and laboratory applications. The basis of this group of devices is the MOSFET transistor. Process modification replaces the metal gate with an ion-sensitive layer such as chemically treated polySiloxane. Although the process is well known, it is not easy to achieve stable FET sensors. Implantation or other doping equipment, high temperature annealing ovens, dry oxidation and equipment to create chemical sensitive layers are required in addition to the basic set of MST tools.

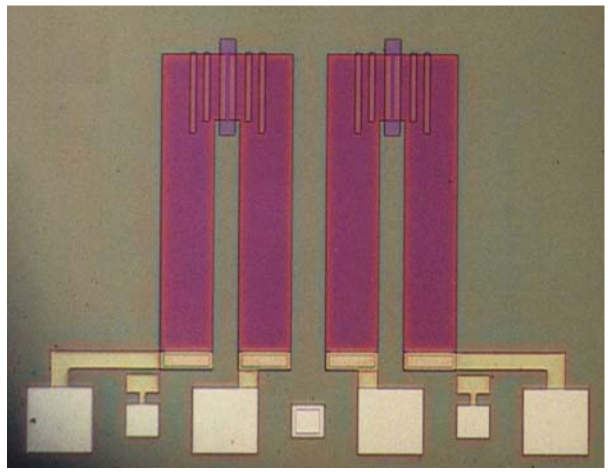
Key equipment: Implantation and annealing, RIE, wet and dry oxidation, polySiloxane, PECVD SiO_2 and SiN, metal deposition and etching, polyimide application and annealing

Products:

- ISFET
- ChemFET

Figure 15 On the left, a schematic cross-section of an ISFET and a reference





electrode in liquid. On the right, a top view photo of two ISFETs, manufactured by C2V.

2.2.7 Process Stream 7

Product group: Electrostatic actuators for optical applications

Physical description: Free hanging silicon structures etched in Silicon On Insulator (SOI) with electrical contacts

These devices are dedicated to the optical telecom industry, but the process might be useful for other applications as well. The process stream provides a way to make mirrors, shutters, and electrostatic actuating comb drives. The special processes in this stream are HF-vapor for release of fragile structures and flip chip technology for mechanical and electrical connection of the devices to an optical board.

Key equipment: Oxidation, Deep RIE, HF-vapor, metal deposition, and etching, flip chip technology

Products:

- Optical cross-connect
- MEMS Variable Optical Attenuator with moveable shutter

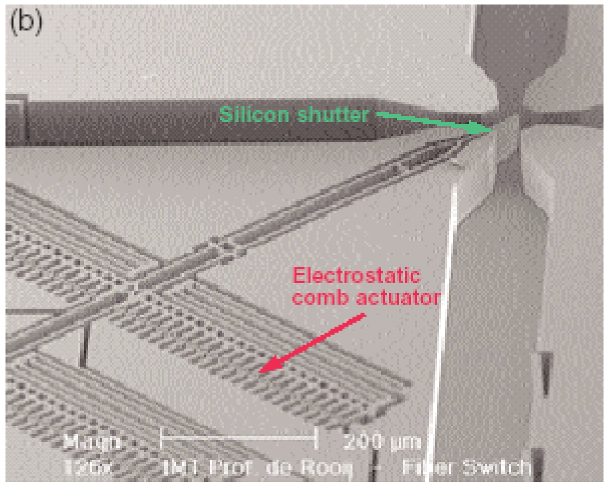


Figure 16 The optical shutter from Sercalo, based on SOI etching. The optical glass fibers insert into the four cavities.

2.2.8 Process stream 8

Product group: Silicon optical and fluidic boards

Physical description: Structured silicon boards with optional glass sealing, metal tracks, and contacts.

These boards are for assembly of optical or fluidic components by means of flip chip soldering. Optical components could be lenses, mirrors, optical detectors, lasers, and fibers. Fluidic components could be fluidic resistors, capacitors, flow sensors, pressure sensors, temperature sensors, ISFETs, etc.

Key equipment: LPCVD SiN, PECVD SiN and SiO_2, metal deposition and etching, flip chip technology, anodic bonding, KOH, Deep RIE, RIE

Products:

- Silicon boards for free field optics
- Silicon-glass fluidic channel plates

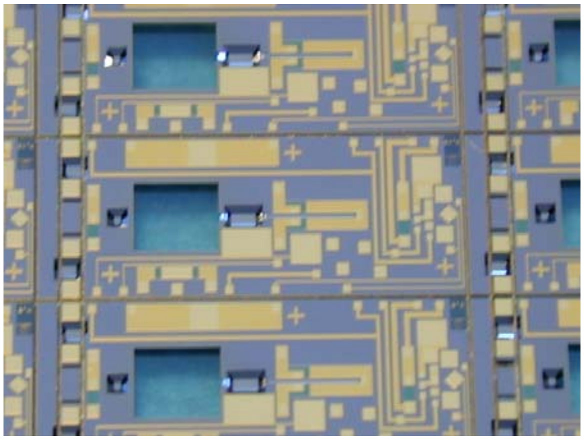


Figure 17 A silicon board for assembly of optical components, manufactured by C2V.

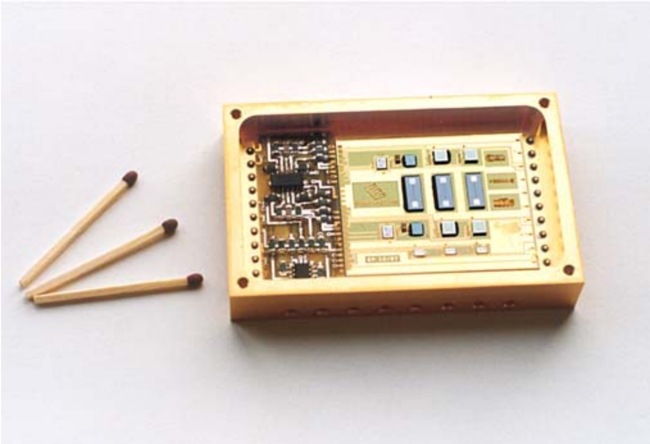


Figure 18 A silicon-glass board with assembled fluidic components and interfacing electronics. This is a demonstrator product that is manufactured in the EuroPractice MC4 cluster project.

2.2.9 Process Stream 9

Product group: RF MEMS devices

Physical description: Electro-plated electro-mechanical structures in vacuum bonded cavities

This is a relatively new family of devices, intended for the electronic telecom market. Many companies, including big players like Philips and Samsung are aiming for this market and developing components that meet the stringent specifications demanded. Electro-plated metal is the base material of choice, because high conductivity is required for this application. Vacuum encapsulation is also required in order to increase speed, to create high quality resonance, and to avoid environmental influences on the devices. In combination with the requirements for low parasitic capacitances and external electrical contact, there are still some technical challenges to meet in this product area.

Key equipment: Electro-plating, wet etching, PECVD SiO_2, dedicated vacuum bonding[2]

Products:

- Inductors
- Adjustable capacitors
- Micro switches
- Micro antennae
- Resonators
- μlines

[2] It should be noted that for complicated products also Chemical Mechanical Polishing (CMP) is often used

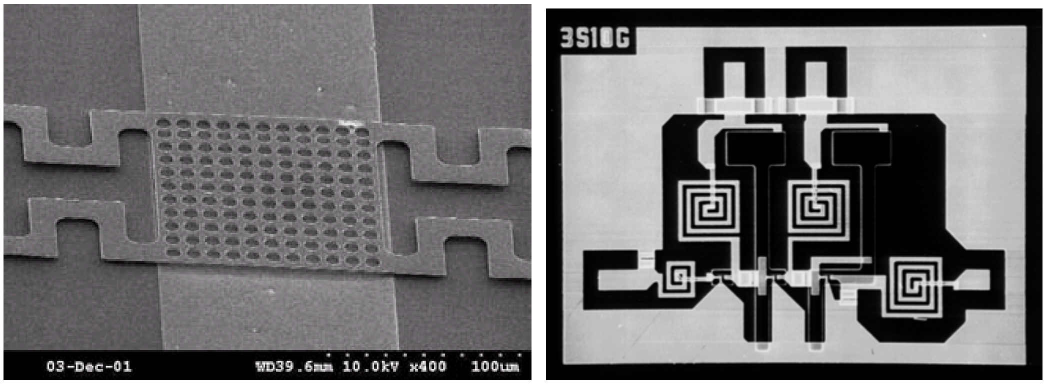


Figure 19 On the left, an RF micro switch and on the right, a chip with four coils in RF MEMS technology. Pictures are found on the internet.

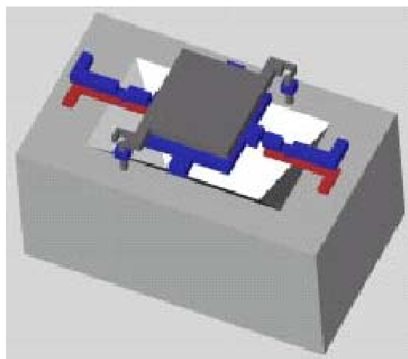


Figure 20 A 3D representation of a tunable capacitor for RF applications. This picture is found on the internet.

2.2.10 Process Stream 10

Product group: Gyroscopes, acceleration sensors, micro-machines, moveable planar mirrors, beam resonators, etc.

Physical description: Surface micro-machined devices

The basis of this process stream are the capabilities of a standard CMOS foundry. The process stream provides a way to make many types of small planar devices, which are compatible with CMOS processing. Sandia provides the SUMMiT V process, which relates to this type of processing. Fairchild and Analog Devices are companies known to use similar processes.

Key Equipment: LPCVD and PECVD SiN, SiO_2, wet oxidation, polySi, HF-vapor, metal deposition and etching, implantation (generally: CMOS type equipment)

Products:

- Gyroscope
- Acceleration sensor
- Micro gearboxes and micro-machines
- Moveable planar mirrors
- Resonator structures
- Micro relay

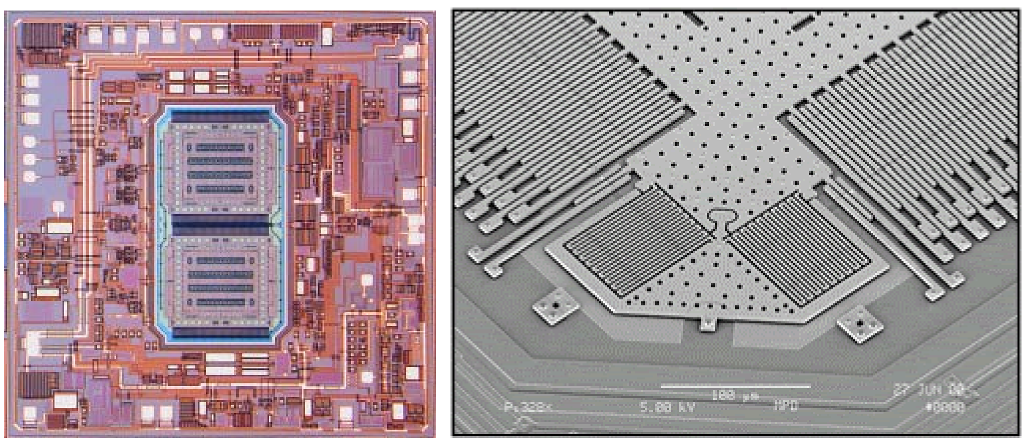


Figure 21. The iMEMS process of Analog Devices. Left side: Gyroscope, right side: Accelerometer

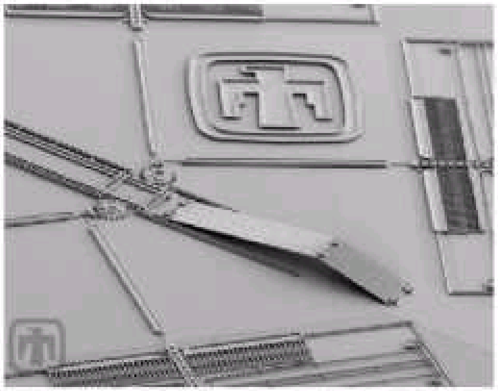
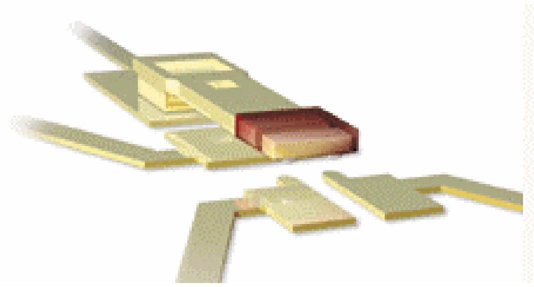



Figure 22A micro-mirror from Sandia and a micro relay from Analog Devices

2.2.11 Other Process Streams

Many MST related process steps are not included in the above described process streams, they are product or product specific and are therefore less often seen. Examples of such process steps are rubber application, TEOS deposition, and PZT deposition.

2.2.11.A Rubber application

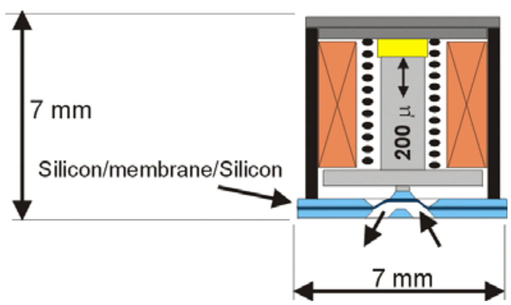
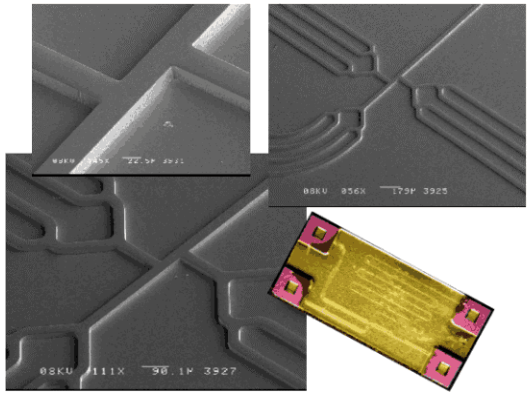


Figure 23C2V uses rubber application for creation of liquid micro valves. A small force can create a large opening of the valve.

2.2.11.B TEOS low stress oxide



SEMs and photo of the micro glass channels

Figure 24 The TEOS low stress oxide process provides a way to create thin glass channels for electrophoresis. The chips are manufactured by C2V.

2.2.11.C PZT: Lead Zirconate Titanate

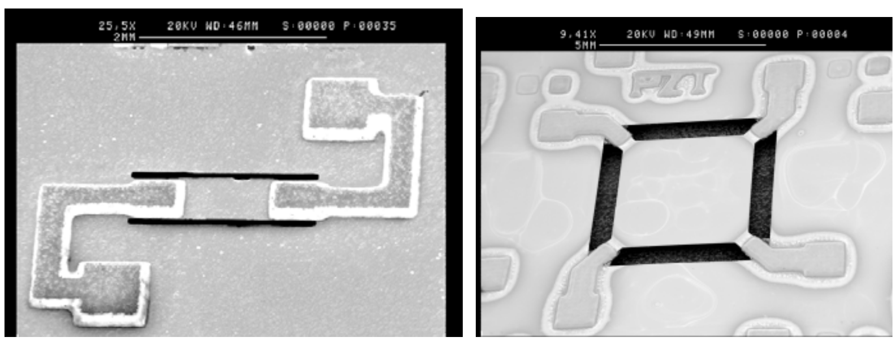


Figure 25PZT is a material for detection and actuation. Left side: resonator beam, right side: acceleration sensor. MEMS application commonly uses thick film paste. These pictures are from USITT's website.

2.2.11.D Pyrex to Pyrex fusion bonding

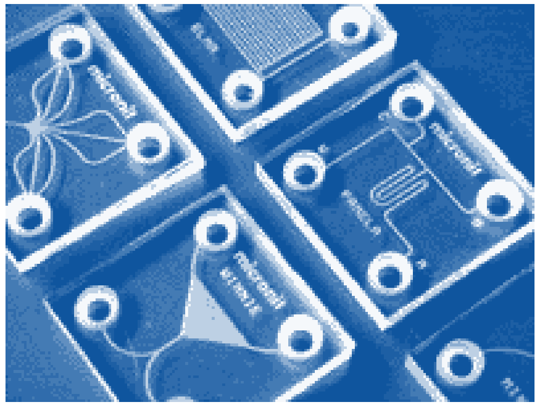


Figure 26There is a process to bond Pyrex wafers to each other. This process is beneficial to make fully transparent fluidic devices that are used for electrophoresis. The picture is taken from the website of Micronit.

2.3 Summary of Process Analysis

The information provided indicates what equipment sees most frequent use throughout the different MST processes and in the manufacture of products by C2V. The provision of this equipment is essential to an MST cleanroom. Production of nearly half the number of product types is possible with this Basic MST toolset. The appendix shows the Basic MST toolset. Depending on the manufacturing processes and products desired, processes like implantation and annealing, electro-plating, flip chip technology, rubber application, glass structuring, dry oxidation, chemical mechanical polishing etc., can be added to the list. The process stream descriptions given in the previous paragraphs help in making the choice of what specific pieces of equipment maybe required in addition to the basic MST toolset.

3 Equipment Requirements

3.1 Basic MST Toolset

The toolset shown in the appendix consists of a number of tools that have the highest intensity of use in MST processing. Intensity of use is measured by listing all past processes executed at C2V and counting the number times a tool was needed for a certain process. The tools listed enables to process approximately 50% of all product types listed before.

3.2 Process Streams

- **Process stream 1** is for creation of a large range of products, such as TCDs and thermal flow sensors, membranes, micro sieves, etc with the Basic MST Toolset.

- **Process stream 2** and **process stream 3** enable creation of a large range of competitive products for micro-fluidics, bioMEMS, instrumentation, etc.

- **Process stream 4** is for creation of piëzo resistive sensors. Many commercial foundries in America and Europe provide these types of products using a standard process. American companies such as Sentir, IC-sensors, Silicon microstructures. Sensonor and Siemens/Infineon are located in Europe.

- **Process stream 5** is for planar optical waveguides for the telecom market. It is a rather specialized process stream for this one market. However, at the same time, some larger companies in America such as JDS Uniphase, Intel and Triquint (formerly Agere) are already working on these devices and sometimes provide foundry services.

- **Process stream 6** is for creation of FET based sensors. These sensors measure chemical parameters, like pH and other ion concentrations in liquids. These devices are useful for chemical analysis systems and bioMEMS. Processing is not trivial, since the stability of FETs and chemically active layers is a major concern.

- **Process stream 7** is for the creation of SOI-based electro-static actuator chips with the possibility to flip chip them to a silicon board or another silicon chip. The primary application is telecom, but other applications might be possible.
- **Process stream 8** is for creation of optical and fluidic silicon boards.
- **Process stream 9** is a dedicated process for RF-MEMS devices. The general assumption is that this will soon be a very important market. STMicroelectronics, PHS MEMS, IMT and Coventor are working in this area. So there is a lot of competition in the market.
- **Process stream 10**, as described previously, is the process stream for surface micro-machining.
- **Other process streams** incorporate specific processes that enable to make for example liquid micro valves, thin glass channels, PZT actuators and fluidic devices for electrophoresis.

3.3 Extended Toolset

Implementing additional equipment is a choice generally driven by commercial interest and based on the products or product groups desired. The table below shows the various process streams, with products and corresponding additional equipment. The table should simplify the selection of additional equipment.

The equipment used in the preferred process streams (1, 2, 3, and 8) are glass patterning, ion-implantation and annealing, HF-vapor and flip chip technology equipment. Polyimide, polysiloxane, and chemical active layer deposition, dry oxidation, electro-plating and dedicated vacuum bonding for RF-MEMS are processes used for a number of interesting products. However, polycrystalline silicon processing, optical layer processing, angle dicing, TEOS, PZT and rubber processing are considered less interesting for the Microsystems Cluster.

Process stream	**Products**	**Equipment requirements excluding the Basic MST toolset**
Process stream 1	Thermal sensors, sieves, etc. *Nitride membranes*	No additional equipment
Process stream 2	Complex fluidic devices, etc. *Silicon stacks*	HF-vapor, ion implantation and annealing
Process stream 3	Fluidic devices, planar mirrors *Silicon-glass stacks*	Glass patterning
Process stream 4	Piëzo resistive sensors *Silicon membranes*	Ion implanter, PolySi, ion implantation and annealing
Process stream 5	Planar waveguides *Optical layers with metal*	SiON or FHD oxide, angle dicing
Process stream 6	FET chemical sensors *MOSFET based*	Polysiloxane, polyamide, dry oxidation, implantation
Process stream 7	Electrostatic actuators *SOI structures with metal*	HF-vapor, flip chip technology
Process stream 8	Optical and fluidic boards *Silicon-glass stacks with metal*	Flip chip technology, glass patterning
Process stream 9	RF-MEMS devices *Metal structures in vacuum*	Electro-plating, dedicated vacuum bonding
Process stream 10	Surface micro-machining *PolySi and SiN structures*	PolySi, HF-vapor, ion implantation and annealing
Other process streams	Micro valve, electro-phoretic channels, PZT actuators *Rubber, TEOS, PZT, Pyrex bonding*	Special rubber application, TEOS oxide, PZT paste application

4 Conclusions

For an overview of the processes and product groups possible in MST, ten process streams are identified that encompass most MST applications. The definition of a process stream is a set of process capabilities, with a fixed, specific set of equipment. Some process streams are dedicated to one product group, such as RF-MEMS, Optical waveguides, and piëzo resistive sensors, where as others are applicable to several products groups. This set of process streams is a leading element for equipment suppliers who are producing equipment to enable these processes (see equipment chapter).

5 Appendix A: MST Basic Toolset

Wet cleaning processes

Standard wafer cleaning with NMP or HNO_3

Piranha (HNO_3 and H_2O_2) wafer cleaning for fusion bonding

RCA II (H_2O, HNO_3 and H_2O_2) wafer cleaning for removal of KOH residues

Standard resist-strip with NMP or HNO_3

Quick-dump rinsers or cascade rinsers with de-mineralized clean water

Dry spinners

Dry cleaning processes

O_2 Plasma cleaning (barrel or plate)

O_2 Plasma resist strip (barrel or plate)

High temperature ovens for deposition and annealing

Wet thermal oxidation

LPCVD silicon rich nitride (stress free layers)

PECVD silicon oxide, silicon nitride

Aluminum annealing at 450°C

Metal Deposition

Metal sputtering for fast metallization with step coverage (Al, Au, Pt or Ni, Ti, Cr)

Lithography

Mask generator

Double-sided mask photolithography resist spinner, mask aligner and development stage

Standard positive photo resist soft and hard-bake (90°C and 120°C)

Resist hard-bake for low temperature silicon RIE etch (150°C)

Wet etching

Metal etch (Al, Au, Pt or Ni, Ti, Cr)

1% HF silicon oxide strip

Buffered HF silicon oxide etch

50% HF silicon nitride strip

KOH or TMAHW anisotropic silicon etch

Dry etching

RIE Fluoretcher for Si_xN_x and SiO_2

Silicon Deep RIE

Wafer bonding

Si-Si Fusion Vacuum Bonding

Pyrex-Si Anodic Vacuum Bonding with high voltage

Dicing

Silicon-Pyrex wafer stack dicing

Dicing foil application

Characterization

Surface profiler for step height measurement

Ellipsometer layer thickness measurement

Wafer thickness measurement

Wafer mass measurement

Several microscopes up to 1200x with line width measurement

Scanning electron microscope (SEM)

Fusion wafer bonding inspection with Infra Red camera

Manual or automatic probe station with electrical parameter analyzer

Special

Several Nitrogen guns for Wafer and Tool cleaning

Wire bonder