

Wireless Arterial Flow Stent

Background

A biomedical engineer is intrigued by a statistic in *Circulation* (Thorn et al. 2006), that of the 700,000 Americans suffering a stroke this year, 200,000 cases are recurrent. He has also read that a large percent of the strokes are ischemic (involving a loss of blood supply to the brain) and believed to be caused by an embolism. This fatty plaque buildup (atherosclerosis), may break off in pieces and become lodged downstream in a smaller artery. Reducing or cutting off this blood supply is the embolic “event”. Since roughly 30% of all strokes originate from diseased carotid arteries (Fig. 1), monitoring and restoring adequate blood flow in the region of the artery is the goal of carotid artery disease treatment. For many patients, carotid stenting (Fig. 2) offers a minimally invasive therapy in comparison to carotid endarterectomy (a traditional surgical procedure in which the plaque is removed by opening the artery). Further, stenting can be performed while the patient is awake, reducing recovery time and the risk of complications.

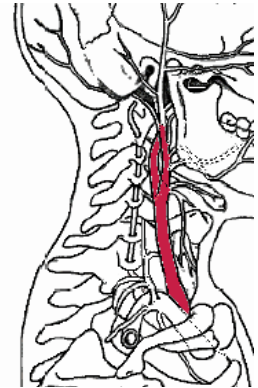


Fig. 1 Carotid artery



Fig. 2 Carotid stent

Restenosis is the return of a blockage (caused by the accumulation of scar tissue) or a re-narrowing of the carotid artery. Since restenosis is likely to occur 6 to 12 months after treatment and may be responsible for some of the recurring strokes mentioned above, an adjunct to disease monitoring would be a method of non-invasive *in vivo* real time arterial blood pressure. The biomedical engineer understands the design challenge involved with such a pressure sensor, as his own animal research studies have involved (less than ideal) vascular cuffs.

The carotid artery is one of the body’s largest blood vessels and the engineer surmises it is more amenable to sensor implants (Fig. 3) than any other artery. In the back of his mind looms the technical challenges in reducing the scale of large vessel technology to his own research projects. Still, the importance of the carotid artery makes it the focus of much research and seems like the best place to start. A literature search quickly brought up recent sensor research at the University of Michigan on arterial flow characterization. Of specific interest was the wireless prototype sensor of DeHennis and Wise (2006) which uses a remotely powered system (Fig. 4). A combination of a monolithic process integration, wireless telemetry, a pressure sensor, and an on-chip antenna suggested the design challenges that DeHennis and Wise had to consider in their research would be worth investigating in more detail.



Fig. 3 Implanted sensor

Just as in the case of animal studies, the designer knew the harsh environment of the human body presents a harsh environments for devices that must be addressed in a successful implant. Obviously, the biological challenge is that the material must be biocompatible. There must not be any corrosion or corrosion byproducts that would be injurious to the host. Further, his coronary research interests placed a “scalability” twist on the situation since coronary arteries are roughly 50% smaller than carotid arteries. All of this motivated the designer to try to better understand MEMS packaging problems and probe the broader application of the University of Michigan technology. Specifically, he wants to understand material selection issues, the packaging of the pressure sensors, and ways to protect the sensor system from the body’s natural defense forces.

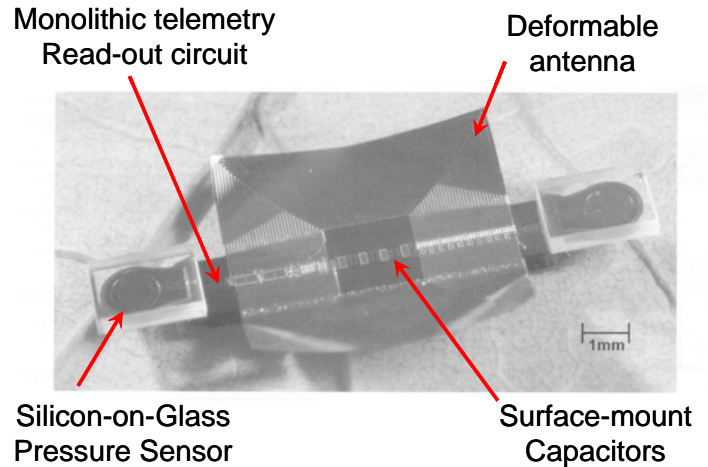


Fig. 4 Wireless arterial flow sensor

Problem Summary

The concept of “restinosis monitoring on demand” presents four basic technical challenges:

1. Differential pressure measurement,
2. Transmission of signal,
3. Powering of an implantable device, and
4. Minimizing the impact that the measurement device has on the blood flow.

The sensing system itself has several performance requirements:

1. High accuracy
2. Compact size
3. Corrosion resistance
4. Pressure monitoring range of 0.013 to 0.27 MPa (100 to 2000 torr) with response time of less than 1ms.

Device packaging requirements are characterized in Fig. 5, where the rejected, tolerated, and input/outputs are shown. The device must be a sealed MEMS structure and be protected from the body’s environment while the host must be protected from the foreign body. Important aspects of packaging design are corrosion resistance, electrical transparency, and biocompatibility. Working through a few of the critical fabrication steps was thought to be the first step to a better understanding of

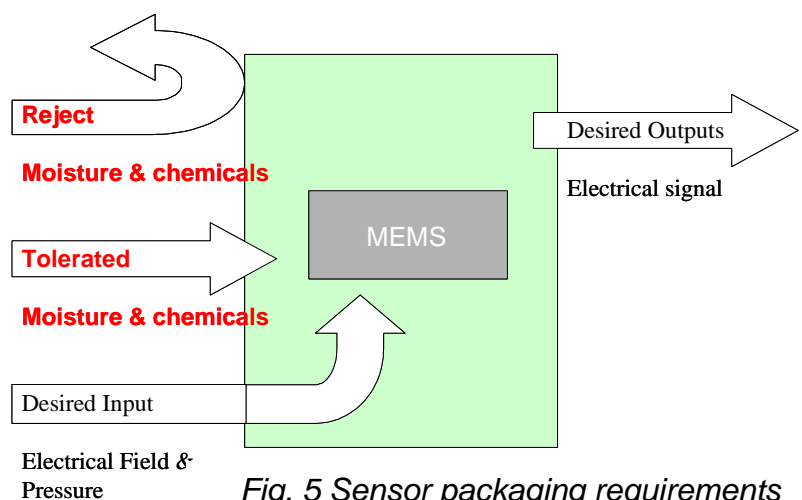


Fig. 5 Sensor packaging requirements

the device design. This would also give the designer a chance to test the new ASM MEMS Materials Database: Packaging.

Figure 6, from the work of DeHennis and Wise (2006), summarizes the seven major sensor system fabrication process steps. Several questions jumped to mind:

1. Why was anodic bonding selected for the polysilicon-to-glass sealing, step (f)? Were other options possible?
2. How did the pressure sensor interface with the complementary metal oxide semiconductor (CMOS)?
3. Assembly of the surface-mount capacitors was the only die-level assembly operation – how was the conductive epoxy selected?
4. What final coatings would provide biocompatibility?

Sample results from an exploration of material and process alternatives are discussed below.

Packaging Database Application

Anodic Bonding Inquiry

Searching on the phrase “glass bonding” provided 29 records. The first nine of the list are shown in Fig. 7. When a search is made in the database, the results are summarized in the left pane. The database is made up of tables having different attributes and the statistics of the search are given. All the tables are visible on the home page of the database. For reference, the top-level categories are provided in Fig. 8.

Process categories dominate the records with the highest relevance, and the Anodic Bonding item (Fig. 9) was selected for further exploration. Of immediate interest are the remarks on the 25-year history of the process. Clearly, the parameters under which a successful bond can be achieved should be well-established. Of some concern to the designer is the moderately high temperature of the process. Noting the database narrative that Anodic Bonding is designated as wafer-level packaging, he expands the Wafer Level Packaging to see what other options exist.

Expanding the entry “Fusion Bonding”, produces the description shown in Fig. 10. Although the initial description suggested that this low temperature process might be an attractive alternative to anodic bonding, some disadvantages of the process are the “exacting surface preparation required” and the idea that “contacting is frequently done in a vacuum.” The question becomes the tradeoff between anodic and fusion bonding. Therefore, a more detailed understanding of the application of the pressure sensor now becomes important. The pressure of the trapped gas in the sealing process and the linearity of the output (to reduce on-board circuitry) are important manufacturing process outcomes. It becomes clear to the

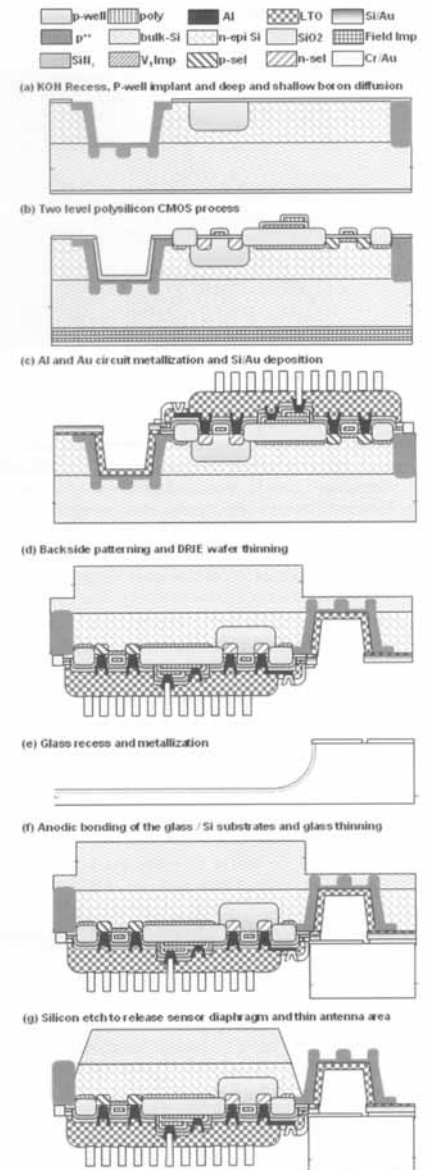


Fig. 6 Fabrication Overview

designer, that in MEMS products, the materials selection and manufacturing process are coupled together more than one might suspect, and that both are intimately linked to subsequent device performance and complexity.

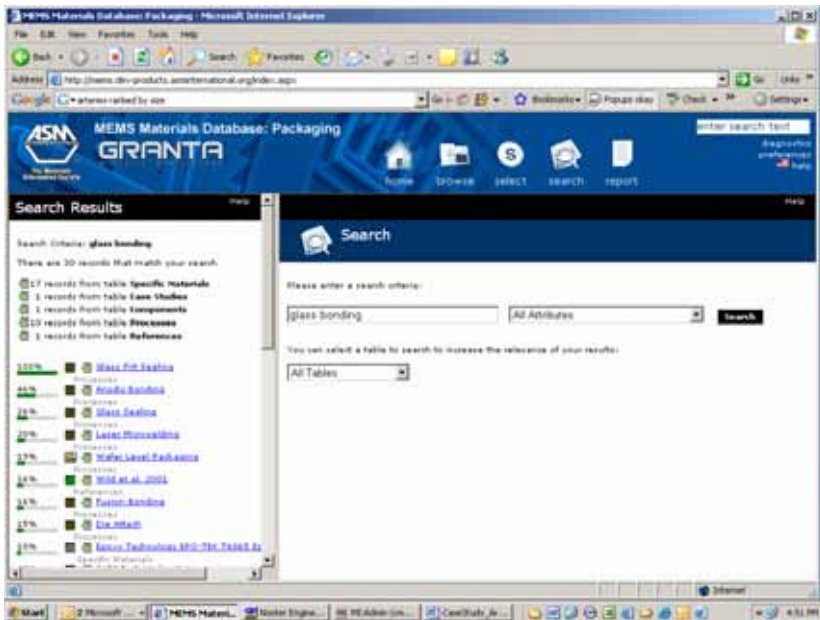


Fig. 7 Search results for “glass bonding”

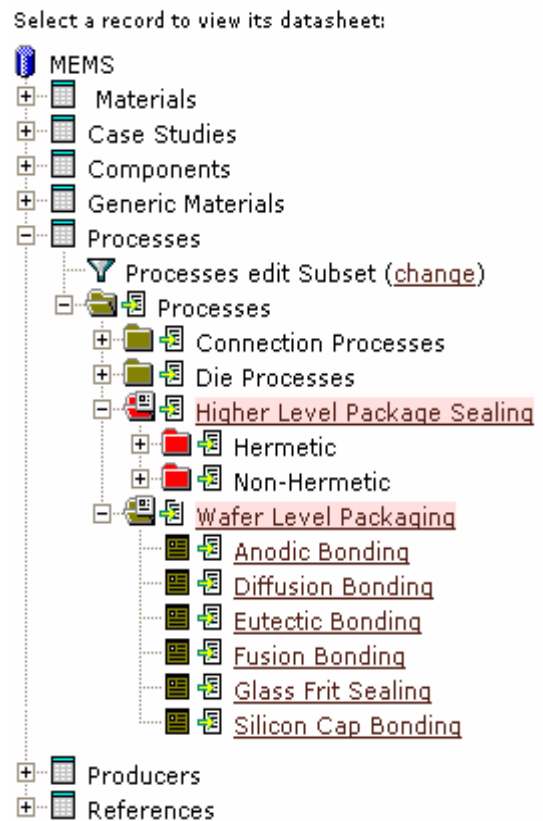


Fig. 8 MEMS top-level categories

ASIM MEMS Materials Database: Packaging
 The Materials Information Society
 Provided by GRANTA

home browse select search report

enter search text
 diagnostics preferences help

Edit Data | Hide Empty Items | Show Summary Datasheet | Search Web | Locate In Tree | Printable Version | Help

Anodic Bonding

MEMS > Processes

Click on a heading to show/hide the section. Sections: Show | Hide

General

Designation: Wafer Level Packaging

Process Description

Anodic bonding is used to connect a silicon die to a glass substrate. It is also called electrostatic bonding, field-assisted bonding, or Mallory bonding. It has a 25-year history of being a reliable hermetic seal for the bonding of silicon to glass.

Two flat clean surfaces are joined by placing them in contact (small compressive pressure of $\approx 3\text{MPa}$ can be applied) and heating to 300-500 deg C. At the bonding temperature, 100-150 Volts direct current is applied, positive to the silicon (anode); negative to the glass (cathode). The growth of the bonded area can be observed. Depending on the size, voltage is applied from a few seconds to 15 minutes (Knowles and van Halbeort 2004).

Silicon can be bonded to silicon by depositing a thin layer of glass (<math><4</math> micrometer) between the silicon layers. This is done by sputtering, evaporating, or spin-on-glass techniques.

Schematics

Schematic 1

Fig. 9 Database description for “Anodic Bonding”



Fusion Bonding

MEMS > Processes

Click on a heading to show/hide the section.

Sections: [Show](#) | [Hide](#)

General

Designation: Wafer Level Packaging

Process Description

Fusion bonding is a direct bonding process also called cold welding. It can be used to build 3-dimensional silicon devices and bulk micromachined packages. Other substrate materials can be fusion welded, such as quartz and silicon to glass. The process relies on having ultraclean and ultraflat surfaces placed in contact with each other. Heat and pressure are not required, but pressure can sometimes be applied. Often, after contact is made, the bond is strengthened ten-fold by annealing.

Supporting Information

[Design guidelines](#)

For direct bonding of silicon substrates, a roughness of less than 100 nanometers with a bow of less than 5 micrometers across a 100 millimeter (4 in.) wafer is desired. Annealing at 1200 deg C will increase the strength an order of magnitude (Schmidt 1998).

Technical notes

An intermediate silicon oxide layer may be formed between layers of silicon. Infrared microscopy can be used to monitor the quality of the bond.

Advantages

There is no thermal stress due to the coefficient of thermal expansion mismatch when bonding identical materials and the bond is stable at high temperature. Fusion bonding is also used for bonding dissimilar substances, where the difference of the coefficient of thermal expansion will exist.

[Disadvantages](#)

A clean room and very exacting surface preparation are required. Contacting is often done in a vacuum. For high bond strength, annealing at a high temperature (800-1200 deg C) is required. If annealing is not being performed in a vacuum, and hermetic cavities are being annealed, the effect of changes in internal pressure must be considered. Oxygen can be adsorbed resulting in lower pressure. Residual gas can also increase pressure with temperature, stressing components (Schmidt 1998).

Fig. 10 Database description for "Fusion Bonding"

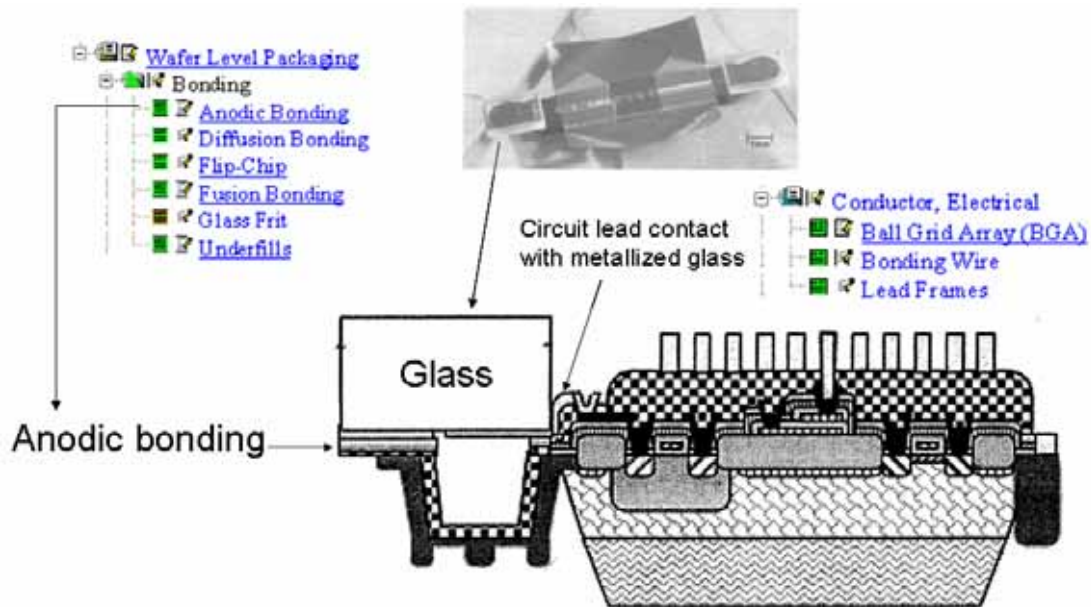


Fig. 11 Glass bonding and circuit lead placement

Pressure Sensor – CMOS Interface.

In Fig. 6, step (g) the glass recess and metallization step provides the other half of the capacitor plate needed for this pressure sensor (Fig. 11). The link between the pressure sensor and the CMOS circuitry is through the Cr/Au deposition. In the database, conventional packaging electrical conductor options (Fig. 12) are presented. These categories are supplemented by a general narrative on “Fundamental Considerations”, which points out that many considerations go into packaging at the wafer level. In the present case, conventional leads would be disruptive to the wafer processing steps and would not satisfy the device requirements of size and conformity. Wafer-level packaging is becoming increasingly necessary as devices become increasingly smaller. For this device to be considered for coronary applications, the size reduction requirements would certainly call for more wafer-level packaging, not less!

Fundamental Considerations
MEMS > Components

Click on a heading to show/hide the section. Sections: [Show](#) | [Hide](#)

General

[Description](#)

The primary design considerations for integrated circuit (IC) packages are environmental protection, electrical power and signal connections, and heat dissipation. These are also considerations for MEMS packaging, but since the device must usually interact with the environment, the package cannot provide isolation from the environment. The dual needs of protection and exposure often dictates that the device or parts of the MEMS system be packaged at the wafer level, while other applications are suited to packaging at a higher level. Packaging material needs are not solely determined by the final application. Manufacturing methods, test methods, and repairability options will also drive the packaging design.

The packaging types are categorized as wafer level and higher level, hermetic, near-hermetic, and nonhermetic. The method of interconnection is also used to describe the package. Wafer level packaging is gaining popularity, especially for large quantity designs. Sensors that are monitoring fluids or monitoring the external environment are nonhermetic. Because gas can be transmitted through polymers, plastic packages are considered nonhermetic. Coatings can be applied to make cavities near-hermetic.

MEMS devices often contain cavities to provide clearance for moving mechanical parts. They may either be gas filled or they may be a vacuum depending whether mechanical damping is desirable. If the package is hermetically sealed, the design must address pressure differentials. Packages can be differentiated as being cavity type or noncavity type.

The internal environment within the cavity affects the MEMS device itself. Getters are used to absorb unwanted gasses. While the first impulse may be the elimination of all moisture, some humidity may improve the performance of MEMS devices with moving wear parts as humidity provides lubrication.

The components that comprise the MEMS system and the manufacturing processes are interrelated. Processing temperatures affect component material selection. Stresses incurred in manufacturing can affect reliability. The interface and interaction between the MEMS package and its external environment is a major driver for material selection and package design. Conditions during manufacture, shipping, storage, nonoperating, and operating conditions must be addressed. Steady state and cyclic conditions must be specified in detail to ensure reliable functionality over the device equipment.

Fig. 12 Fundamental Considerations in MEMS Component Table

Help
Search Results

Search Criteria: **monolithic**

There are 2 records that match your search

1 records from table **Case Studies**
 1 records from table **References**

100% ■ [Allan 2007](#)
 References

8% ■ [Wireless Arterial Stent](#)
 Case Studies

Allan 2007
 MEMS > References

Click on a heading to show/hide the section.

Reference	
Author(s)	R. Allan
Title	Mainstream MEMS: Monolithic or Hybrid?
Bibliographic details	
SmallTimes, Vol 7 (Issue 1), January/February 2007, p 11-12	
Online source	Online Article
Date created	March 30 2007

Fig. 13 Search result showing online link

Die-Level Assembly

The circuit-lead discussion increased the designer's awareness of the term "monolithic" and he begins to wonder if there are additional sources of information on this subject. A database search of "monolithic" (Fig. 13) quickly brought to his attention two references to explain design implications further. One was an article in Small Times that is only a click away (click underlined [Online Article](#)). The other referred to a case study in the ASM Packaging database itself. After a brief scan of the other case study, the idea was clear that MEMS designers were successfully increasing their use of wafer-level packaging as the current work is consistent with that trend.

In the present work, the epoxy is needed to attach the surface mount capacitors to the device (Fig. 14 and recall Fig. 4) and this process is accomplished manually.

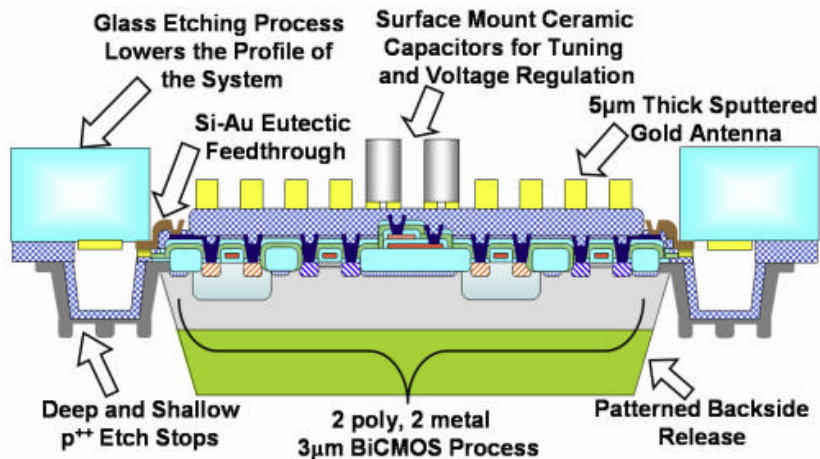


Fig. 14 Process cross-section

A search of the database netted 20 records including 17 specific conductive epoxy materials. This search could also be conducted by entering “conductive epoxy” in the “enter search text” box on the right hand side of the top banner.


Of significant interest in Figure 14 is the integrated antenna. This reduces the need for die-level assembly and such close-coupled design helps reduce the vertical footprint of the device, an important consideration for an implantable device.

Biocompatibility

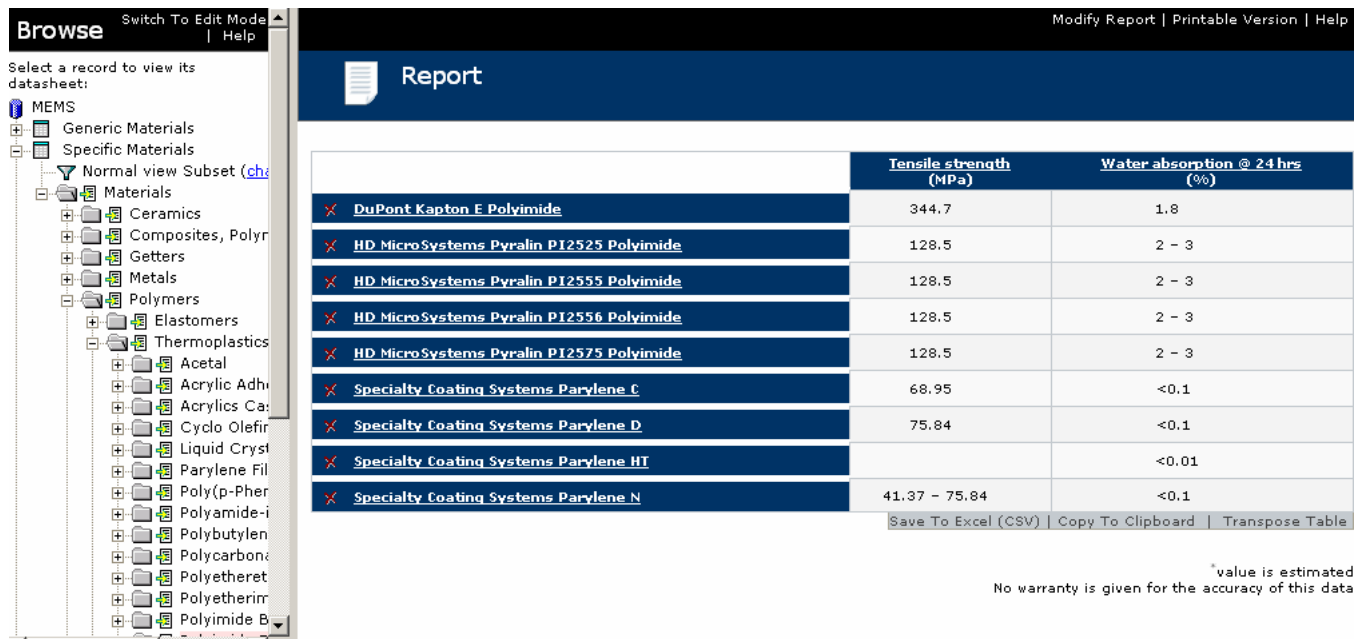
In the fabrication overview schematic, a final coating of the device was not mentioned. The designer decided to check the database for “biomedical coating”. At the time his search was made, three materials, all parylene based, were provided. Picking the first item on the list, Parylene C, produces the material properties description shown partially in Fig. 15. From the display, it is clear that Parylene is categorized within “Specific Materials” as a Polymer, Thermoplastic. He clicked on the “Locate in Tree” to see what other polymers were in the MEMS database hierarchy. Seeing that there are Pyralins as well as Parylenes, he decided to investigate the difference.

Specialty Coating Systems Parylene C			
MEMS > Specific Materials			
Click on a heading to show/hide the section. Sections: Show Hi			
General			
Designation	Parylene Film i		
	Datasheet reference	Manufacturer data	
Tradenames	Parylene C i		
Composition			
Composition (summary)	Parylene C is produced from the same monomer as parylene N and is modified only by the substitution of a chlorine atom for one of the aromatic hydrogens. i		
Physical			
Density	1289	kg/m ³	i
	Notes : Properties measured on films, 0.001 - 0.003 in. thick. Test Standard : ASTM D1505		
Carbon dioxide transmission	3.031	cc.mm/m ² .24hr.atm	
	Test Standard : ASTM D1434 Test Temperature : 25 °C		
Nitrogen transmission	0.3937	cc.mm/m ² .24hr.atm	
	Test Standard : ASTM D1434 Test Temperature : 25 °C		

Fig. 15 Parylene Description

Material property comparisons in the database are accomplished with a simple-to-use Record tool. This convenient tool was designed facilitate quick snapshots of material property differences. From the Browse mode, clicking on the  icon adds the material to the comparison list. Figure 16 illustrates a simple case where tensile strength and water absorption are to be compared. (Many other material properties are available for comparison, with just a sample shown below for illustrative purposes. User picks from the entire materials property hierarchy or templates can be used).

Another feature of the system is the ability to export material properties in to a Microsoft Excel format. This facilitates uses for subsequent analysis applications.



	Tensile strength (MPa)	Water absorption @ 24 hrs (%)
× DuPont Kapton E Polyimide	344.7	1.8
× HD MicroSystems Pyralin PI2525 Polyimide	128.5	2 - 3
× HD MicroSystems Pyralin PI2555 Polyimide	128.5	2 - 3
× HD MicroSystems Pyralin PI2556 Polyimide	128.5	2 - 3
× HD MicroSystems Pyralin PI2575 Polyimide	128.5	2 - 3
× Specialty Coating Systems Parylene C	68.95	<0.1
× Specialty Coating Systems Parylene D	75.84	<0.1
× Specialty Coating Systems Parylene HT		<0.01
× Specialty Coating Systems Parylene N	41.37 - 75.84	<0.1

value is estimated
No warranty is given for the accuracy of this data

Fig. 16 Material property comparison chart

Summary

MEMS product design efforts are initially paced by matching the product performance specifications to MEMS device principles (e.g., vibrating beam, mechanical switch, and/or resistive element). Once the phenomenon has been established, the identification of the fabrication process and materials selection occurs concurrently. This wireless arterial flow sensor case involves a significant degree of wafer-level packaging, adding further complexity to the fabrication specification process. A critical packaging issue for the wireless arterial flow sensor involves selecting the proper conformal coating to meet electrical, mechanical, and environmental specifications. Finding the right material is often an iterative learning process, as the present case illustrates.

Expediting access to materials information adds value to the product development process. Second only to the MEMS device identification task, materials selection is the critical path to the manufacturing process, device performance, and product success. The ASM MEMS Materials Database: Packaging, is a materials information resource for the product design community.

More Information:

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A. DeHennis and K. Wise, "A Fully Integrated Multisite Pressure Sensor for Wireless Arterial Flow Characterization," *J. Microelectromech. Syst.*, Vol 15 (Issue 3), June 2006, p 678-685

