Lecture 13 - 14

MEMS Materials Selection

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Outline

Lecture 13

MEMS Material Selection - I

MEMS Material Selection Basics

- Materials (and structural configurations and processes) should be selected for applications based on measurable criteria
- It is possible to compare the suitability of materials for a given application according to quantifiable performance metrics based on material properties such as Youngs modulus, density, strength
- Some materials properties are more invariant than others (a) Role of scale, role of manufacturing, microstructure (b) Fiber composite allow flexibility (c) Important to know what you can change - or not!
- Often combinations of material properties
- Material properties group according to class of material
  - Metal, ceramic, polymers
  - Engineered materials (composites, foams)
  - Natural materials (wood, bone, etc)

MEMS Material Selection Basics

- Design of a structural element is specified by three parameters, or groups of parameters (performance indices)
  - Functional requirements (F)
  - Geometry (G)
  - Material Properties (M)
- We can quantify the interdependence if we can specify performance, p, as a function of F, G and M:

$$p = f(F, G, M) \tag{1}$$

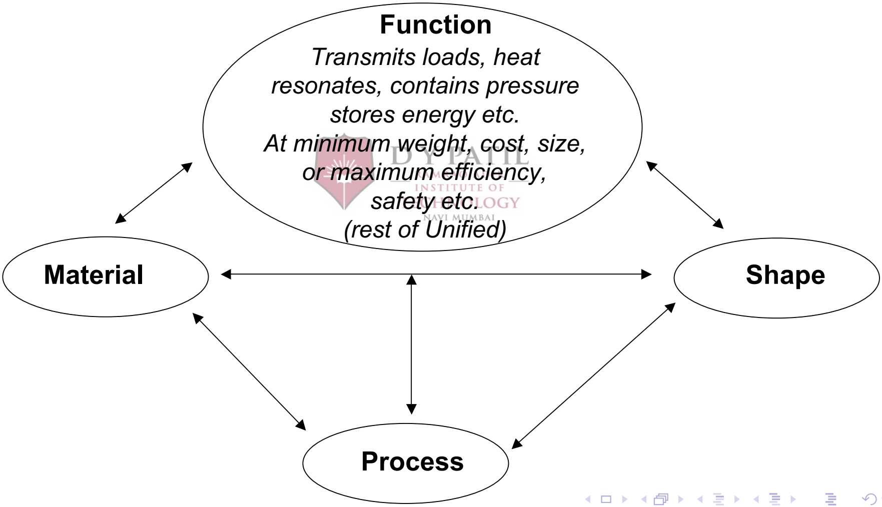
- We can simplify further if the three groups of parameters are separable

$$p = f_1(F)\ .f_2(G)\ .f_3(M) \tag{2}$$

MEMS Material Selection Basics

- Techniques now exist to introduce and integrate a large number of metals, alloys, ceramics, glasses, polymers, and elastomers into microsystems, motivating the need for a rational approach for materials selection in microsystems design.
- First attempt which identified three requirements for materials to be used in MEMS: compatibility with silicon technology, desirable electromechanical properties, and low values of residual stresses.
- MEMS materials are traditionally grouped into four classes: metals and alloys, glasses and ceramics, polymers and elastomers, and composites (combination of materials from different classes).
- Another complimentary classification includes: structural materials are those that constitute load-bearing beams, plates, membranes and other mechanical elements, and transducer materials constitute devices that convert information and energy from one physical domain into another

Central Problem - Interaction of Function, Material, Process and Shape



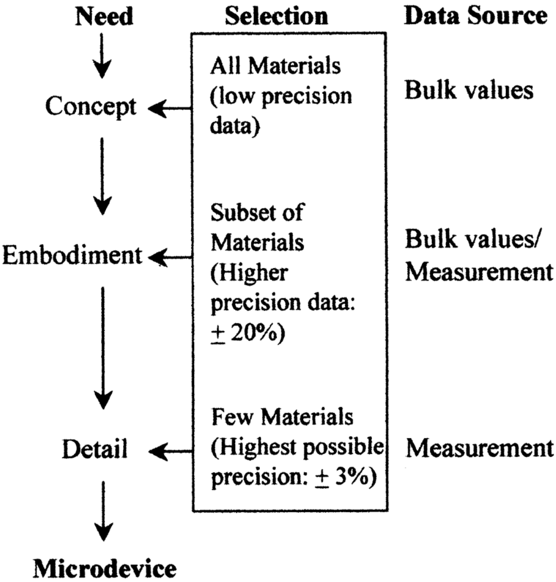
Design process

- The design process can be divided into three stages: concept, embodiment, and detail.
- In the first stage, the designer requires ranges of values for many classes of materials in order to arrive at the device concept. Bulk values can typically be used to make this choice.
- In the next stage, the concept is translated into a class of structures (i.e., embodiment), and the properties of a few materials are required to greater precision (say, 20 to 30
- In this stage, bulk values can be used for many properties within the bounds, although measurements are typically necessary to evaluate residual stresses and intrinsic loss coefficients.
- In the final phase of design, the designer requires the properties of very few materials to very high precision (typically, 3 to 5
- With a few exceptions, most notably the elastic constants of semicond grade single-crystal silicon, measurements are necessary for all properties of all materials at this stage.

Lecture 14

MEMS Material Selection - II

Design process



Performance index

- Performance index is such a criterion in 'Ashby method', providing a comparison between material candidates for a given design.
- Three things specify the design of structural elements: the functional requirements, the geometry, and the properties of the material.
- The performance of an element is described by an equation of the form as

$$p = f\{(\text{Function}), (\text{Geometry}), (\text{Material})\} \tag{3}$$

or

$$p = f(F, G, M) \tag{4}$$

- p describes some performance aspects of the component: its mass or volume, or cost, or life for example.
- Optimal design is the selection of the material and geometry, maximizing or minimizing p according to its desirability.
- The optimization is subject to constraints, some of which are imposed by the material properties, M.

Performance index

- The three groups of parameters in Eq. (4) are said to be ‘separable’ when the equation can be written as:

$$p = f_1(F).f_2(G).f_3(M) \tag{5}$$

- When the groups are separable, the optimal subset of the materials can be identified without solving the complete design problem, or even knowing all the details of F and G.
- This enables enormous simplification.The performance for all F and G is maximized by maximizing $f_3(M)$, which is called performance index.

Mechanical properties of thin film materials for MEMS

Table 1—Mechanical properties of thin film materials for MEMS

Property Material	Elastic modulus E in GPa			Failure strength σ_f in GPa			Thermal conductivity k W/cm/°C	Coeff. Of thermal expn. α in 10^{-6}/°C	Specific heat C_p J/kg/k	Density ρ Kg/m^3	Fracture toughness K_{IC} MPa(m)$^{1/2}$
	mean value	lower variation	upper variation	mean value	lower variation	upper variation					
Diamond	800	600	1100	8.50	8	10	6.9	1	518	3500	5.9
3H-SiC	400	331	470	7	4	9	3.5	3.3	1340	3200	3.8
Si_3N_4	250	230	290	6.40	5	8	0.19	0.8	170	3100	1.8
SiO2	70	57	92	1	0.8	1.1	0.001	0.55	937	2500	0.8
SCSi (100)	130	115	142	3.40	2	4.3	1.57	2.33	706	2300	1.0
SCSi(110)	168	147	188	7	6	8					
Poly-Si	159	140	169	1.65	1.21	2.8	0.34	2.8	706	2300	1.2
Tungsten	410	NA	NA	0.70	NA	NA	1.78	4.5	135	19300	44
Aluminium	70	47	85	0.17	0.15	0.3	2.36	25	899	2700	20
Nickel	185	168	214	0.40	0.32	0.78	0.899	13	444	8910	95
Copper	120	86	137	0.25	0.12	0.26	3.98	16.6	386	8960	85
Titanium	110	96	115	0.50	0.44	0.79	0.2	8.5	522	4510	70
SU8	3	1.8	4.2	0.04	0.03	0.05	0.002	52	NA	1164	NA
Polyimmide	8	4	15	0.04	0.023	0.07	0.001	20	1100	1420	3.9
PVDF	2.3	1.1	4	0.05	0.048	0.06	0.002	140	1500	1780	3.2
PMMA	2.4	1.8	3.1	0.08	0.048	0.08	0.002	80	1466	1200	NA

Performance index

Table 2—Performance indices

Performance index	Applicability criterion	Applicable device
$\sqrt{\frac{E}{\rho}}$	The highest value maximizes natural frequency	Resonators, CMUT, Gyroscopes
$\left(\frac{\sigma_f}{E}\right)$	A higher value maximizes deflection under specified load for a beam	Accelerometers, switches
$\left(\frac{\sigma_f^{3/2}}{E}\right)$	A higher value maximize deflection under specified load for a plate	CMUT, Microphones
$\left(\frac{k}{\alpha}\right)$	A higher value indicates minimum thermal distortion	Microheaters, thermal actuators
$\left(\frac{\sigma_f}{\rho}\right)$	A higher value indicates maximize inertial force within the limit of failure stress	Micromotors, micropumps and microturbine