Many implantable medical devices contain sophisticated electronic circuits. Hermetic packaging is required to provide the implant's electronic circuitry with protection from the harsh environment of the human body. Many issues associated with hermetic packaging are not yet completely understood, nor are any corresponding difficulties completely overcome. The continued miniaturization of future implantable medical devices provides both opportunities and challenges for packaging/materials engineers to improve the existing packaging methods, and to develop new methods. Reliable hermetic micropackaging technologies are the key to a wide utilization of microelectromechanical systems (MEMS) in miniaturized implantable medical devices.

Jiang and Zhou, Implantable Neural Prostheses Springer 2010
Hermetic Bio-Packaging of IMDs

- IMDs contain sophisticated electronics.
- Long-term IMDs are susceptible to damage by body fluids over time.
- Hermetic packaging is required to protect electronics from the harsh environment of the human body.
- Package makes direct contact with the tissue: Biocompatibility is key → Stable material that does not elicit any local or systemic effects.
- Biocompatible materials such as: polymers, glasses, metals, and ceramics.
- Optimal encapsulation method: greatly dependent upon the clinical application and the electronics to be encapsulated.

Traditional IMD Packaging

- Traditional Ti-can packages are large and rigid → Mechanical mismatch, large incision, higher risk of irritation and infection, pronounced foreign body reaction (FBR)
- Bio-packaging: A bi-directional diffusion barrier
  - No diffusion of harmful chemicals into tissue
  - No leaching of body fluids into IMD
- Feedthroughs should also be a bi-directional diffusion barriers
  - at location of feedthroughs: reduce fibrous encapsulation (biofilm) due to FBR
  - small package
  - soft, flexible, textured package: biomimetic
  - Use of functional drug containing coating
- Device should withstand common sterilization techniques (chemical and thermal)
Polymer-Based Packaging

- Polymer encapsulation: Components are compactly arranged and “potted” in a mold with leads or conductive feedthroughs penetrating through the polymeric encapsulation wall.
- Historically been the preferable approach to encapsulation because of its simplicity and relatively low processing temperature.
- Polymers do not provide an impermeable barrier → Moisture ingress will ultimately reach the electronics, and surface ions can allow electric shorting and degradation of the leakage-sensitive circuitry.
- Polymer encapsulation is currently unsuitable for high-density, high-voltage electronics → Research is underway

- Liquid crystal polymers (LCPs) can provide near-hermetic packages in IMDs.

Phase-I: Wafer level chip encapsulation
Creation of a bi-directional diffusion barrier

Phase-II: Sub-system package / interposer
Biocompatible interconnect and embedding of various dies.

Phase III: System package
Global biocompatible interconnect and embedding of various components.
**Metal/Ceramic/Glass Packaging**

- Used in: implantable pacemakers, cardioverter defibrillators, neuromuscular stimulators, and cochlear implants.
- Feedthrough assembly utilizes a ceramic or glass insulator to allow conducting wires to exit without coming in contact with the package.
- Requires that power-receiving coil or RF antenna be placed outside the package to avoid significant loss of power or RF signals, thus requiring additional space.
- Bioceramic and biograde glasses are transparent to EM fields and more suitable for miniaturized IMDs.
- Hermetic seal between similar or dissimilar components: fusion welding methods, such as laser welding, tungsten inert gas welding, and electron-beam welding.

**IMD Packaging Failure Mechanisms**

- Metal-ceramic or metal-glass sealing: High temp. brazing and welding: Mismatch in coefficient of thermal expansion (CTE) → residual stress → cracks and leaks at the interface
- Majority of failures (3 out of 4): Moisture ingress at the interface between two materials, often the feedthroughs, causing open or short circuits.
- Moisture ingress can change the coil Q-factor or resonance frequency.
- Metal packages: Risk of heating due to Eddy currents. \( \Delta T < 2 \, ^\circ \text{C} \)
- Glass and ceramic packages are the most suitable for inductively powered IMDs.