Microelectronic Assembly of Chemical Sensors for Medical Applications

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MINIATURIZED CHEMICAL SENSORS for medical applications are an attractive technology as they can provide real-time, non-invasive human health information. New science related to chemical sensing techniques continues to emerge, and an existing semiconductor supply chain can be leveraged to develop new products to meet market demands, though, the integration of new science with existing techniques is not without challenges. In order to properly leverage the backend of the semiconductor supply chain—microelectronic assembly—it is important not to overlook the compatibility challenges that can be encountered when integrating novel materials and fabrication methods with standard microelectronic assembly processes. These challenges can be successfully addressed with proven new product development strategies.

Background

A chemical sensor is a device that creates a measurable output when exposed to a specific concentration of a certain molecule. The molecule of interest, sometimes known as the analyte, can be in either gas-phase or liquid-phase. The analyte can be a gas measured in gas, a gas measured in liquid, or a biological composition (e.g., glucose, protein) measured in liquid. Often it is required to measure the existence of an analyte at less than one thousand parts per million per sample. Some of the measurement methods that have been developed include amperometric, resistive, colorimetric, and optical techniques. The sensor needs a reactive material that will respond to the analyte with enough magnitude to produce a measurable change in output. These novel materials can be metal oxides, polymers, nano particles, biological materials, or any combination of these.

Chemical sensors can be used to measure a variety of physiological parameters. They are used in clinical applications but are more commonly known for wellness and monitoring applications. For example, galvanic skin response can be used to measure human emotion. This process has historically been used in lie detector testing, but wearable consumer products use it as a mood analyzer that can be shared with friends. Physiological stress levels in American warfighters can be measured using chemical sensors that evaluate their cognition level in real time, which allows for better decision making with mission-critical personnel. New lab-on-a-chip devices support unmet needs for point-of-care diagnostics which are low cost and provide fast response time. The full potential of breath sensing is unrealized yet, but has the potential to bring a new paradigm to health care. All of these applications benefit from non-invasive, real-time measurements using a chemical sensor.

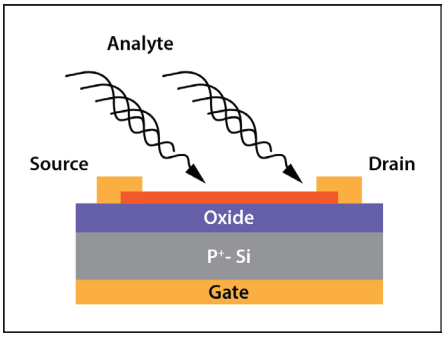

Figure 1. Features of a chemical sensor.

The technical requirements for the chemical sensor are driven by four performance attributes – sensitivity, selectivity, response time, and storage. Once the science is developed, it is important that the design for manufacturability includes these requirements. Sensitivity is achieved when the sensor needs to measure in the proper range in a repeatable and reproducible manner, for instance 5-25 parts per billion for an asthma breath sensor. Selectivity refers to the avoidance of interference or parasitics that can lead to false detection levels. Interference can come from moisture or temperature fluctuations, but may also come from a measured response of an aberrant material or from an unexpected concentration of materials in the environment. Response time is important for measuring dynamic situations, and can be finessed to fit the circumstances. The information coming from the sensor relies on the rate of reaction, which must be characterized. A single-use sensor is one straight-forward path to managing response time, but is impractical when the application requires ongoing measurements, such as a continuous glucose sensor. Sensitive reactive sensor materials require highly inert storage conditions. Typically the sensors need to be protected from thermal exposure and moisture to avoid unintended reaction, but they may also require hermetically sealing and submersion in an inert substance such as nitrogen or deionized water, during storage in order to maintain their efficacy before use.

Assembly Challenges

The novel materials used for chemical sensors can be deposited using a variety of manufacturing techniques. Wafer level processes are the most cost-effective, but activation of the material or surface tends to take place during microelectronic assembly processes. The deposition methods for the active sensor material include physical vapor deposition, photo definable polymers, dispense/dip, screen printing, and selective chemical processing. The economies of scale drive the deposition of the active sensor material to the wafer level – which makes sense – but it aggravates the manufacturing processes for microelectronic assembly. Therefore, a balance needs to be found which often leads to the introduction of a non-traditional, semiconductor process between the wafer foundry and the microelectronic assembly house.

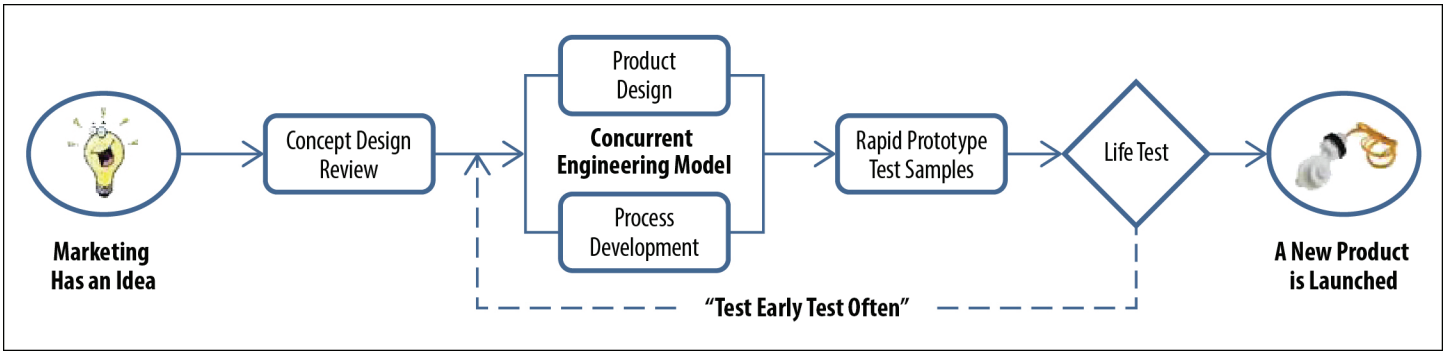

Figure 2. Concurrent engineering flow.

The biggest challenge is that the material(s) used to functionalize a chemical sensor can lose their required properties if not properly protected before the intended use. They are designed to be reactive and sensitive and can easily be compromised by environmental conditions during manufacturing processes. Some common contaminants present during microelectronic assembly operations are moisture, heat, solvents, and light. Some combination of these factors is unavoidable, and drives the development of non-traditional processes.

This presents a challenging situation for new product development where standard processes create conflicting interests with new designs. A test early, test often approach used with concurrent engineering can be used to evaluate design elements in a manner so that processes can be quickly understood. Targeted, early testing shortens the overall development cycle and uncovers weaknesses by testing fundamental design and process assumptions. Concurrent engineering creates synergy between design and process engineering teams by superimposing process development with design activities. This streamlines the development process which significantly reduces the number of iterations required to launch a product.

Microelectronic assembly involves several primary processes: wafer dicing, die attach, wire bonding, and encapsulation. These processes must be balanced with the requirements of the chemical sensor that is being manufactured. The most apparent, streamlined approach involves applying the novel sensor material during the wafer manufacturing. However, this is not always a feasible

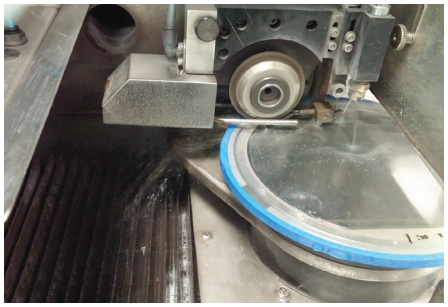

Figure 3. Typical wafer dicing environment.

option due to process compatibility during microelectronic assembly.

Wafer dicing using a sawing process requires significant exposure to water. The water is used to cool the blade while it is in operation, as well as to remove debris from the surface of the wafer. Some sensor materials cannot withstand contact with water or the mechanical force it creates. One option is to coat the wafer with resist or wax before dicing. This requires an additional cleaning step after dicing and also exposes the chemical sensing material to the coating material. Dry, laser dicing is another option, but it requires strict design rules that need to be addressed before manufacturing wafers.

Dispensing and thermally curing adhesive is a common process for the die attach step, however some sensor materials may not be compatible with heat

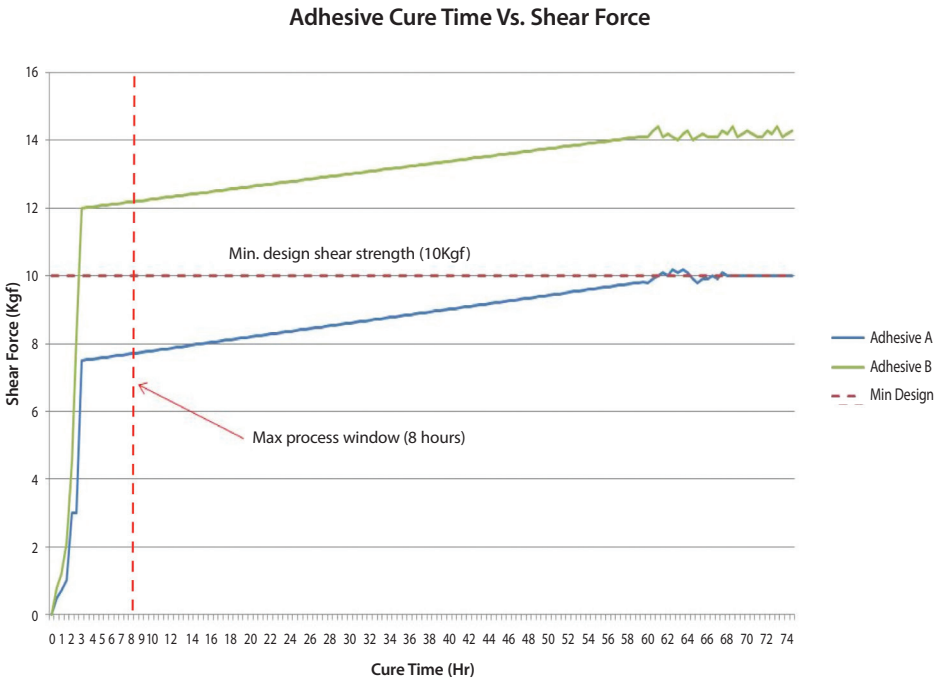

Figure 4. Humidity cure for manufacturing.

cure and the associated solvent exposure. Humidity cure adhesives can be used as an alternative, but adds cycle time to the manufacturing process and management of work in progress (WIP). Another attach option is tape attach, which avoids the thermal process (and the solvent exposure therein) but creates an additionally manufacturing step. Figure 4 shows data from a study that compared two room temperature curable adhesives. The process requirement for die attach at volume production was to meet the minimum design shear force requirement in less than eight hours to avoid excessive work-in-progress (WIP).

Wire bonding noble metals requires heat. Gold wire that is 1 mil in diameter can be bonded with a thermosonic process at 150C. Wire bonding platinum wire is very challenging and needs to be done at higher temperatures. Gold wire bonding can be done at reduced temperatures (80-125C) though the repeatability and reliability would have to be evaluated for the application. Aluminum wire bonding is performed at room temperature, which makes it a viable option to avoid thermal exposure.

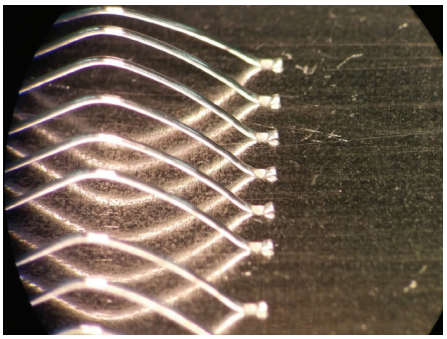

Figure 5. Aluminum wire bonds.

Conclusion

Chemical sensors are an attractive solution for non-invasive, real-time measurements of physiological conditions in both medical and consumer fields. Novel materials can be used to functionalize chemical sensors, but present manufacturing challenges for the existing traditional supply chain. Proven new product development methods, such as early testing and concurrent engineering, can be used to understand the manufacturing challenges early on. Using these strategies, many of the common problem scenarios for microelectronics assembly processes can be addressed to seamlessly incorporate new science and novel materials using established techniques before freezing product design.

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