Blog - MEMS New Product Development, Critical Design and Process Steps for Successful Prototypes (Part 1)

David DiPaola, DiPaola Consulting, LLC, www.dceams.com

In the third article of the MEMS new product development blog, critical design and process steps that lead to successful prototypes will be discussed. These items include definition of the customer specification, product research, a solid model, engineering analysis to validate design direction, tolerance stacks, DFMEA, manufacturing assessment and process map. With the modeling and analysis tools available and short loops for both design validation and process development, it is possible and should be expected to have functional prototypes on the first iteration.

Thorough review of the customer specification and an understanding of the application are two of the most critical steps in developing a prototype. Without this knowledge, its a guess on whether the design will be successful meeting the performance objectives with next to zero quality problems. The issues often encountered are the customer specification is poorly defined, it does not exist or there are gaps between customer targets and supplier performance. It is the responsibility of the lead engineer to work with the customer to resolve these issues in the beginning stages of the prototype design to ensure a functional prototype is achieved and is representative of a product that can be optimized for production. Furthermore, this specification creates an agreement between the supplier and customer on expectations and scope. Should either of these change during the project, the deliverables, cost and schedule can be revisited. Expectations and scope include package envelope, application description, initial and performance over life specifications, environmental, mechanical and electrical validation parameters, schedule and quantities for prototype and production. In this process the supplier and customer review each item of the specification and mark it as acceptable as written or needs modification to be met given current knowledge. There can also be area of further research and development before an agreement on the topic can be reached. This entire process is documented and signed by both parties as a formal contract. Then as more is learned about both the product design and application, modifications to the agreement can (and likely will) occur with consent of both parties.

Product research is another area of significant importance to the prototype process. This research has several branches including technology to be used, existing intellectual property, materials, design approaches, analysis techniques, manufacturing processes to support proposed design direction and standard components available to name a few. Product research will also involve reaching out to experts in different fields that will play a role in the product design. This is the initial data collection phase of learning from previous works through reading patents, journal articles, conference proceedings and text books and building a team of qualified professionals. This process is sometimes chaotic and over whelming while wading through mounds of information in search of a viable design path. However, this only lasts for a short period as trends start to form, innovation is birthed and a path is forged.

Parametric, 3D modeling is no longer a luxury but a must have in the design and prototype process. It is essential for visualizing the design, documenting it and analyzing function, geometric properties and potential interferences. However, use of the solid model should not stop there. The documented geometry can be imported through a live link or other means to various other tools such as CNC machining, finite element analysis, tolerance stack analysis, motion visualization, fabric pattern generation prior to stitching, mold flow analysis, electrical simulations, equipment interactions, process development and much more. The solid model should be considered a starting point for a much larger analytical model that is used to describe the fabrication, function and performance of the product and its components. Once the solid model is complete, it is also extremely helpful to make stereolithography (SLA) or 3D printed components that can be felt, observed and often times used for preliminary product testing. For a trivial cost, SLA's can provide a wealth of information prior to prototype and help sell the design to colleagues and customers.

As highlighted in the previous paragraph, engineering analysis is the process used to validate the design and process direction theoretically. The analysis can take the form of a manual hand calculation of deflection to the sophistication of finite element analysis predicting the strain in the diaphragm of a MEMS pressure sensor due to deformation of the surrounding package under thermal conditions. The key to successful analysis is not only proper engineering judgment on parameters and attention to detail in model creation but validation of the analysis through experimentation or other theoretical means. For example, the FEA results of a MEMS diaphragm under large deflection can be compared to other theoretical calculations of a round plate under large deflection that has been validated with experiment. Correlation of the results suggest your model is in the ballpark and can be used to evaluate other parameters such as stress and strain. In this analysis phase, the global model is often comprised of several smaller models using different analytical means that are then tied back together for a prediction of performance. With many live links between several pieces of analytical software and the power of today's computers, this process is becoming more efficient with better overall accuracy.

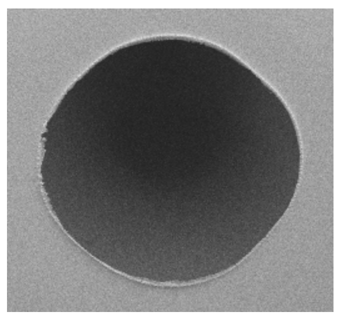
To better illustrate the points above, a case study of a MEMS SOI piezoresistive pressure sensor will be reviewed. This pressure sensor was designed for operating pressures of 1000 - 7000 KPa. Due to the pressure range used, the surface area of the sensor that was bonded to the mating package substrate needed to be maximized while minimizing the overall foot print to increase the number of sensors per wafer. Hence a deep reactive ion etch was used to obtain near vertical sidewalls. A thicker silicon handle wafer was used to provide additional strain isolation from the sensor package while staying within a standard silicon size range for lower cost. The silicon reference cap provided a stable pressure reference on one side of the sensor diaphragm. Its geometry was optimized for handling, processing and dicing.

A solid model was created of the design including the wirebond pads, aluminum traces, interconnects, oxide layers and piezoresistors on the silicon membrane wafer. In addition, the cap and handle wafers were modeled. Although not shown here for proprietary reasons, each layer of the membrane was modeled as though it was fabricated in the foundry. This enabled the development of a process map and flow. Finite element analysis of the diaphragm under proof pressure loads showed that the yield strength of the aluminum traces could be exceeded when in close proximity to the strain gages. This can cause errors in sensor output. Hence doped transition regions were added to keep the aluminum out of this high stress region. A comprehensive model of the piezoresistive Wheatstone bridge was created to select resistor geometry and predict the performance of the sensor under varying pressure and thermal conditions. Strain induced in the gages from applied operating pressure and resulting deflection of the diaphragm was modeled using finite element analysis. A model was also created to determine approximate energy levels needed to dope both the piezoresistors and transition regions. This information was critical in discussions with the foundry in order to design a product that was optimized for manufacture as doping levels and geometry were correlated. Furthermore short process loops were developed at the NIST Nanofab to optimize etch geometry and validate burst strength.

It is important to note that the design of the sense element was designed with constant feedback from the foundry and their preferences for manufacturing. In addition, the sense element and packaging were designed concurrently as there was significant interactions that need to be addressed. Design of the sense element and packaging in series would have resulted in a non optimized design with higher cost. In the end, a full MEMS sensor specification was developed and provided to the foundry for a production quote and schedule. Through working directly with the foundry, optimizing die size and designing a sensor for optimum manufacture, over 60% improvement in cost was achieved over going to a full service MEMS design and fabrication facility.

Figure 1
MEMS SOI Sense Element

Figure 2
DRIE Hole Fabricated at NIST Nanofab



Due to the length of these topics, stay tuned for next months blog for Part 2 of this article. In that segment other critical steps including tolerance stacks, DFMEA, manufacturing assessment and process maps will be reviewed.

Bio:

David DiPaola is Managing Director for DiPaola Consulting a company focused on engineering and management solutions for electromechanical systems, sensors and MEMS products. A 16 year veteran of the field, he has brought many products from concept to production in high volume with outstanding quality. His work in design and process development spans multiple industries including automotive, medical, industrial and consumer electronics. Previously he has held engineering management and technical staff positions at Texas Instruments and Sensata Technologies, authored numerous technical papers and holds 5 patents. To learn more, please visit www.dceams.com.