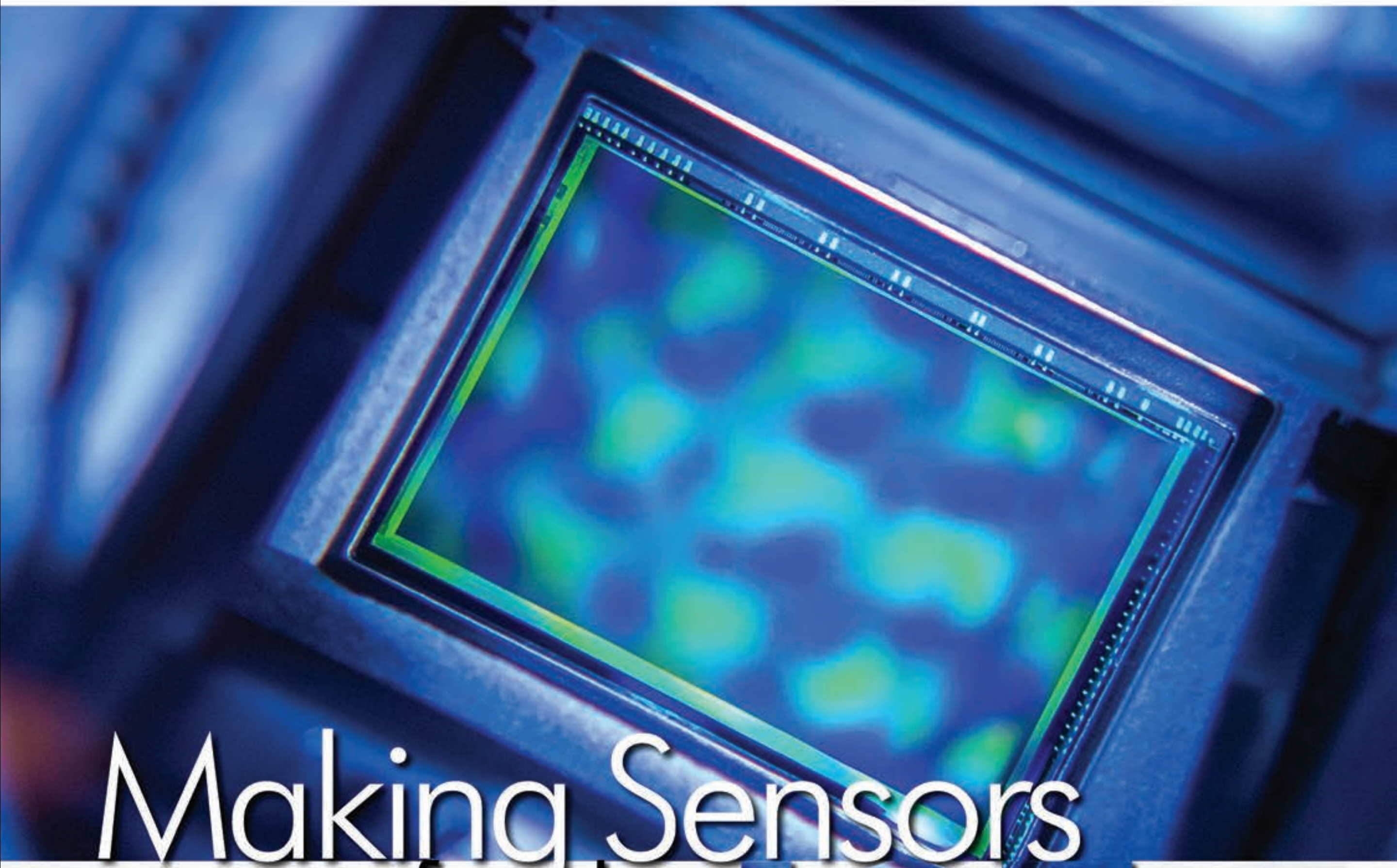

Making Sensors for the IoT

MEMS TECHNOLOGY IS A CRITICAL ELEMENT IN MANY OF THE SENSORS THAT WILL GENERATE THE DATA TO DRIVE VALUE FROM THE IoT. AN EXPERIENCED MEMS DEVELOPER DESCRIBES SOME OF THE ISSUES INVOLVED IN CREATING RELIABLE MEMS AND PROVIDES SOME BEST SIMULATION PRACTICES TO ASSIST IN THEIR DESIGN.

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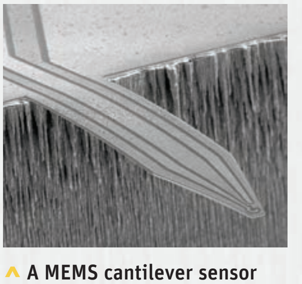
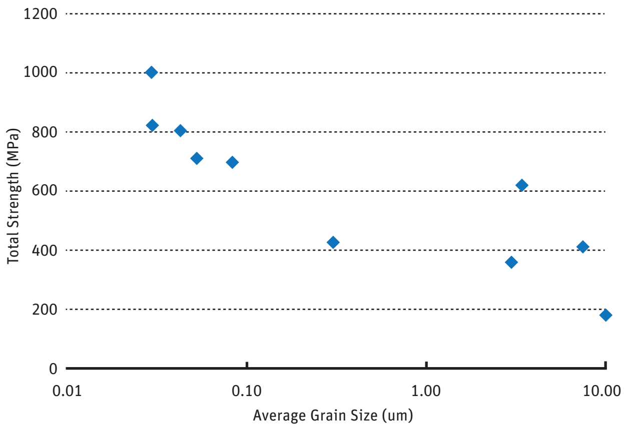
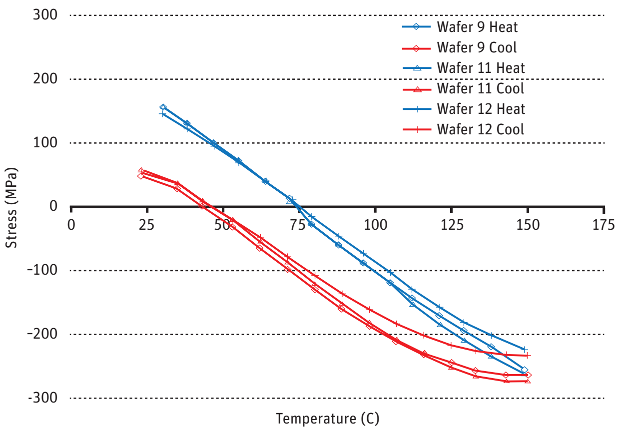
Microelectromechanical systems (MEMS) is a manufacturing technology that can be used to create many different types of sensors — temperature, motion, pressure, sound, etc. — on silicon wafers. MEMS sensors serve as the eyes and ears of today's smart connected products by acquiring information from the environment, such as the air pressure of an automobile tire or the motion of your body to record your steps. It is anticipated that MEMS sensors will experience a rapid growth curve as the Internet of Things (IoT) makes it possible to capture the information from billions of MEMS sensors and



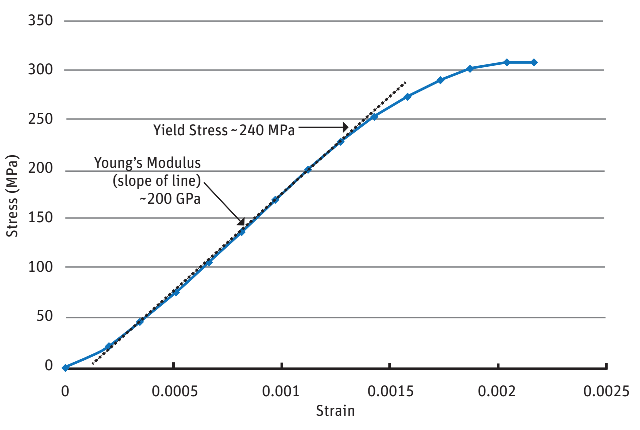
A MEMS cantilever sensor designed and prototyped by AMFitzgerald



^ MEMS material properties are recipe- and tool-dependent.



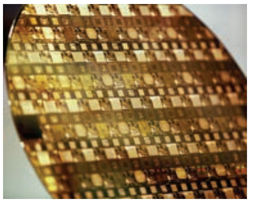
^ Thermal cycling caused a 100 MPa change in residual stress due to plastic deformation of the metal film.



^ Modulus can be estimated from wafer-level film stress data over a temperature range.

utilize this data to intelligently control devices to improve efficiency, quality, health, safety and the environment.

But despite the fact that MEMS are made on a silicon wafer, MEMS development is considerably less rapid and more difficult than conventional integrated circuits (ICs), largely due to a lack of established design practices and the limitations of some current simulation methods. Fortunately, it's possible to work around these challenges using practices such as parametric analysis to understand the impact of uncertain material properties, and to integrate test results with simulation to calibrate boundary conditions. Using these and other techniques makes it possible to achieve useful simulation results that can reduce the number of fabrication (fab) rounds and bring MEMS devices to market in considerably less time and expense than is required using the traditional build and test approach.



MEMS DEVELOPMENT CHALLENGES

The semiconductor manufacturing industry has developed process design kits (PDKs) consisting of standard cell libraries, design rules, simulation models and layout information for producing ICs with a specific technology in a particular foundry. The industry has also benefited from a wide range of well-validated design and process simulation tools. As a result, a company bringing an IC to market can be fairly certain that, if they follow the PDK guidelines and simulate early and often, the resulting device will perform as expected and be manufactured without major difficulty.

But the wide variation in geometry and materials among MEMS devices has, so far at least, forestalled the development of PDKs and prevented simulation from reaching the same level of maturity as it has for ICs. The result is that developers of MEMS devices are never quite sure what they are going to get until they receive samples from the foundry. Unfortunately, the minimum cost for a development batch of ten 150 mm wafers, including recurring costs only, is well over $100,000, and the lead time is a minimum of eight to 12 weeks. Escalating, unknowable development costs have led to the premature closure of some MEMS companies, and to investor caution about the entire industry.

One of the biggest obstacles in simulating MEMS is determining the material properties of thin films. The tensile strength of a thin film is highly dependent on the deposition recipe, and can even vary widely among different manufacturing tools using the same recipe. Another challenge with thin films is that metals and dielectrics are generally deposited onto silicon at a very high temperature. In regions where the deposition layer and substrate have different coefficients of thermal expansion, residual stresses are generated in the film when the wafer cools back to ambient temperature. This residual stress often varies at different steps in the process as the wafer undergoes temperature changes. It can result in bowing, buckling or cracking of the MEMS structures, so this stress needs to be accommodated within the simulation model.

Simulation Reduces Uncertainty and Risks in MEMS Design and Manufacturing
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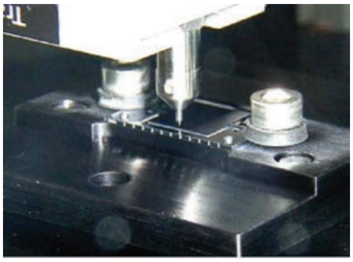
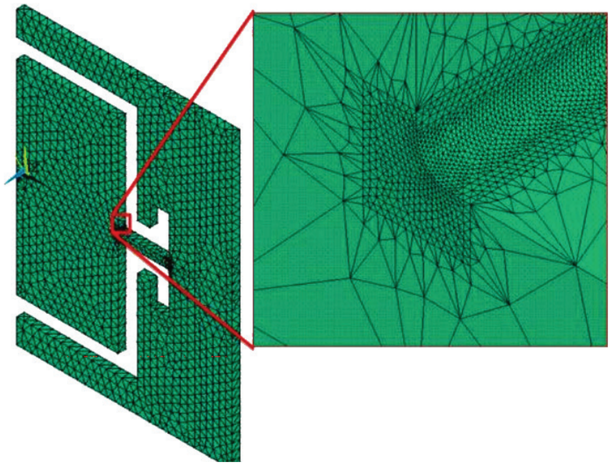
SIMULATION OVERCOMES MATERIAL PROPERTIES UNCERTAINTIES

Uncertainties in material properties can be addressed by using parametric simulation to determine the effects of material property variability on device performance. Tools within ANSYS Mechanical software allow engineers to quickly evaluate the effects of varying material properties, along with design parameters, to save spins in the fab. A typical approach is to start with the textbook material properties, then vary the geometry of the structure while holding the elastic modulus constant. The next step is to hold the geometry constant and vary the modulus. Simulation helps you to make smart design choices that reduce sensitivity to material properties. If you find that your design is overly sensitive to material properties, you can perform wafer-level and device-level measurements to gather empirical data to improve simulation accuracy. For example, a KLA-Tencor Flexus stress measurement system can scan the wafer to determine thin film stress as a function of temperature, which in turn can be used to estimate modulus.

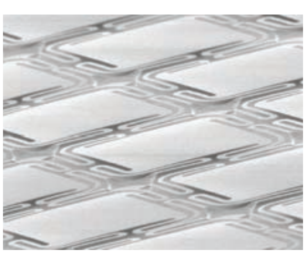


^ Measurements showed that the original MEMS model's boundary conditions were too stiff.



^ Force-displacement measurements were used to correct the finite element model.

While ductile materials such as metals fail at a well-defined limit, predicting the load limit of brittle materials used in MEMS is more difficult. Crystalline microstructures fail at surfaces, so their strength is a function of the size and location of the surface flaws that are created during the etching process. Details such as etch tool type and operating parameters can lead to significant differences in surface strength and device fracture probability. AMFitzgerald invented a method to estimate device fracture probability that uses empirical data and custom ANSYS APDL scripts. The solution is to first build test structures using different process parameters to statistically characterize the influence of the manufacturing process on surface strength. Next, create a finite element model of the proposed or existing microstructure in ANSYS Mechanical and simulate the stresses in the microstructure device under applied load. Finally, in the post-processor, combine the results of the load simulation with surface strength information to predict failure locations and load limits. Based on this information, engineers can revise the device design or process, or proceed directly to manufacturing.



"Simulation can *save hundreds of thousands* of dollars in fabrication and testing and months of *redesign time*."

SIMULATION AND PHYSICAL TEST INTEGRATION HELPS UNDERSTAND BOUNDARY CONDITIONS

Obtaining accurate results from simulation requires using accurate model boundary conditions. For a thin film structure deposited onto a silicon substrate, an analogous macro-level structure would use a fixed boundary condition at the film–substrate interface. However, thin film structures are not as stiff as macro structures. The solution is to perform force versus displacement measurements to determine the stiffness of the structure, which can then be fed back into the model.

Simulation of MEMS is much more challenging than ICs because their material properties and boundary conditions are not nearly as well defined. With some effort, you can work around these challenges and reap the benefits of simulation. Simulation is much less expensive than processing test wafers in the fab, so you will be able to evaluate many more design and manufacturing options early in the design process and bring better products to market in less time. Simulation can easily save hundreds of thousands of dollars in fabrication and testing and months of redesign time. Investing in the development of accurate models for your technology will always benefit your future products. ^