Multiphysics Simulation
Using Directly Coupled-Field Element Technology

The 22x family of elements allows users to solve coupled-physics problems in one solution pass with a single model.

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For an increasing number of applications, simulation of individual physics is not adequate for evaluating designs under real-world conditions, where engineers must account for the effects of multiple coupled-physics. ANSYS, Inc. provides two proven solution techniques to solve coupled-physics problems. The first is the ANSYS Multi-field solver (available with ANSYS Multiphysics software or with multiple physics product combinations), which performs sequential iterations between the physics disciplines until the solution converges. The second technique is to use directly coupled-field elements (available in ANSYS Multiphysics software) that solve for multiple physics in a single solution pass.

Coupled-field elements in ANSYS Multiphysics version 11.0 software handle a variety of analyses, including thermal–structural coupling, piezoelectricity, piezoresistivity, the piezocaloric effect, the Coriolis effect, electroelasticity, thermal–electric coupling and thermal–electric–structural coupling. The technology is useful in the design of a range of products such as electronic components, microelectro-

mechanical systems, sensors, transducers, piezoelectric gyroscopes, accelerometers and thermoelectric coolers.

The ANSYS 22x family of directly coupled-field elements (PLANE223, SOLID226 and SOLID227) allow users to solve 2-D and 3-D coupled-physics problems by employing a single finite element model with the appropriate coupled-physics options set within the element itself. The coupled-field elements support up to five degrees of freedom per node, including displacement, temperature and voltage. Users can turn on or turn off these degrees of freedom depending on their application. This ability to select the appropriate degrees of freedom allows the flexibility to solve many different types of coupled-field problems.

The coupled-field elements calculate the appropriate element matrices (matrix coupling) or element load vectors (load vector coupling) to account for the interaction between the different physics disciplines. For linear problems, coupled-field interaction is calculated in one solution iteration when using matrix coupling. Nonlinear
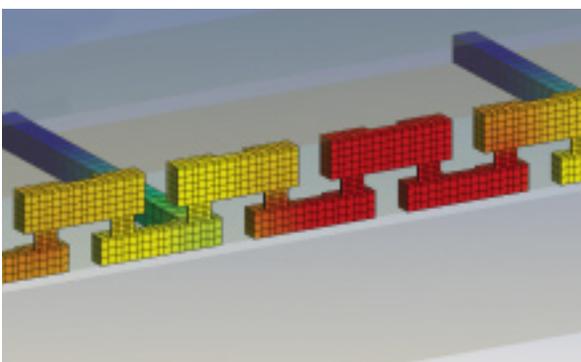
ANSYS Multiphysics coupled-field elements are used to study thermoelectric effects for IC circuits, as seen in this section of an IC's metallization structure.

Current Flow Direction
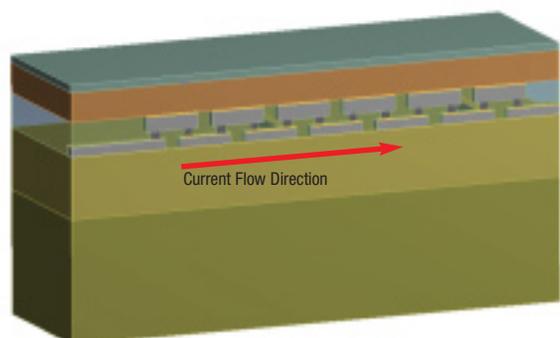
Metallization structure for an integrated circuit; regions of different colors represent different materials that are present.
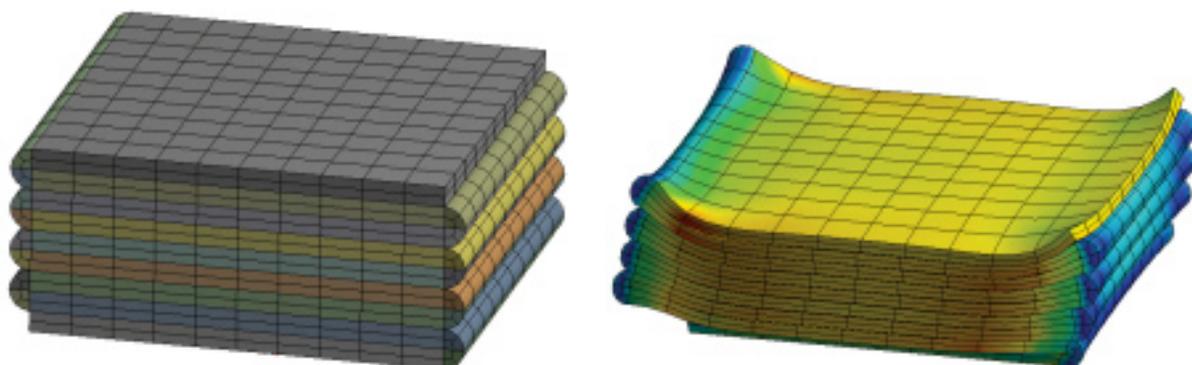
Mesh for a folded dielectric elastomer actuator (left) and contours of deformation (right), which results from electrostatic actuation

problems require an iterative solution employing the Newton-Raphson algorithm for both the matrix and load vector coupling options.

The ANSYS 22x family of elements offers several advantages. First and foremost, it allows for multiple physics solutions otherwise not possible with single physics finite elements. Coupled-field elements simplify the modeling of coupled-field problems by permitting one element type to be used in a single analysis model. This allows users to create a single mesh, apply all boundary conditions to one model and post-process just one set of results. Nonlinear solution convergence is robust, and coupled-physics solutions typically converge automatically without requiring manual intervention. Also, although 22x elements are not natively supported by the ANSYS Workbench platform, they are easily incorporated into this environment through the use of command objects. This enables users to perform many coupled-field solutions directly in the ANSYS Workbench environment and take advantage of functionality such as parametric models, sensitivity studies, design optimization and design of experiments for multiphysics solutions.

In working with coupled-field elements, users should note that, with up to five degrees of freedom per node, models tend to be larger for multiphysics solutions and thus lead to higher storage and memory requirements. Also, because coupling terms are often not symmetric, an unsymmetric equation solver must be used for the coupled-field solution.

Many companies use coupled-field elements to address their multiphysics design challenges. In the development of integrated circuits (ICs), for example, the technology is used in evaluating electromigration: the transport of material caused by the movement of ions in a conductor.

During an overload condition, high current densities and Joule heating can lead to electromigration in the metallization structure of an IC. The metallization structure forms the interconnections for an IC. Thus, electromigration in this component can decrease the reliability of an IC and possibly lead to failure of the circuit. For studying this type of critical problem, a coupled-field element can be used to couple the thermal and electric effects in one analysis model.

By incorporating the temperature dependence of the electrical and thermal properties into the nonlinear simulation, this type of study using coupled-field elements enables engineers to accurately predict temperatures during an overload condition, and thus determine the level of risk to the integrity of the IC.

In another example, coupled-field elements can be used in the evaluation of electroactive polymers, which exhibit a deformation when subjected to an electrostatic field. Often referred to as "artificial muscles," electroactive polymers are gaining increased application as electrostatic actuators and sensors, as well as in the emerging field of micro-robotics in which linear motion is required. One class of electroactive polymers is dielectric elastomers, which can be used as high-voltage insulators or electrostatic actuators.

Electrostatic actuators can be configured as a multi-layer stack, a helical or a folded sheet. In all configurations, the coupled-field elements can be used to solve for the deformation generated by the electrostatic field — a new feature of the coupled-field elements in ANSYS Multiphysics 11.0 software. This capability to perform coupled-field electroelastic analyses provides researchers with valuable data needed in the development of this growing class of products. ■