SIMULATING PRINTHEAD UNIMORPH ACTUATORS AT FUJIFILM DIMATIX

Engineers at FUJIFILM Dimatix have used multiphysics simulation to gather compliance data for improving industrial printhead actuator performance.

By **LEXI CARVER**

THE REACH OF INDUSTRIAL INKJET PRINTERS is truly incredible—from commercial packaging and wide-format graphics to signage, textiles, and even electronic applications, inkjet printing enables the information sharing and communication that surrounds our everyday activities. FUJIFILM Dimatix, a premier producer of commercial inkjet printheads, is now using multiphysics simulation in the development of the MEMS actuators driving their newest ink deposition products.

» PRINTING WITH MICRON-SCALE PIEZOELECTRIC ACTUATION

A PRINCIPAL SCIENTIST on the research team at FUJIFILM Dimatix, Chris Menzel, is studying printhead actuation in order to design FUJIFILM's newest unimorph diaphragm actuators. These actuators are created in a MEMS fabrication process using a high-performance thin-film piezoelectric layer. This layer is a high-quality proprietary sputtered version of lead zirconium titanate (PZT), an electroceramic that changes shape under an applied electric field and is used in many transducers. The PZT is bonded to a silicon membrane and the actuators are then arrayed across the surface of a wafer, with each one corresponding to a tiny jet consisting of flow channels and a nozzle (see Figures 1 and 2). Thousands of these systems are packed tightly together in the printhead.

The components of each jet (the fluidic channels and the actuator) combine to form a resonant fluidic device. Upon electrical stimulation of the PZT by pulses tuned to stimulate the jet's resonance, the actuator deflects and generates acoustic waves within the closely coupled flow channels. The jet design effectively converts the pressure wave into an oscillating flow, which has to overcome the surface tension at the nozzle in order to throw an ink drop. When the resulting fluid momentum is large enough, the droplet is propelled outward and onto a substrate.

The goal of Menzel's design work was to define an actuator and jet flow channels that combine to generate a droplet meeting a target mass at a given

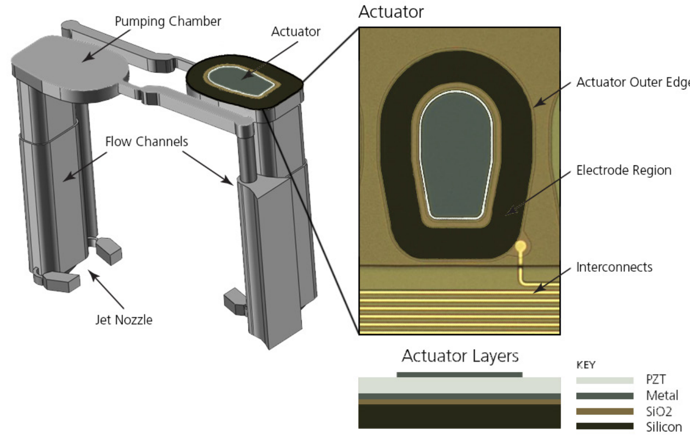

FIGURE 1: The printhead geometry developed by FUJIFILM. Each actuator sits on top of a pumping chamber containing a reservoir full of ink. Below the chamber are flow channels that carry ink to the nozzle.

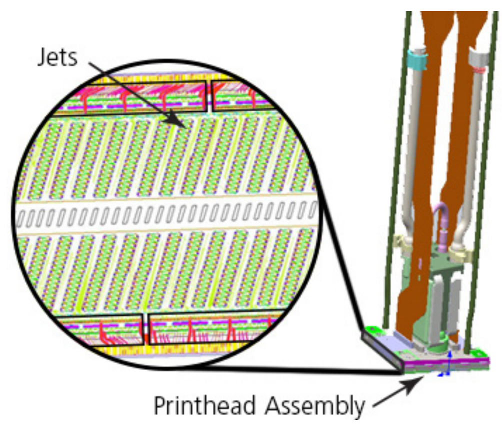

FIGURE 2: Magnification of jets on the wafer and their location in the printhead assembly.

velocity, with a target maximum firing frequency for the available voltage. Implicit in this design process is the need for miniaturization and the associated lower cost. With this in mind, the primary concerns in actuator design are maximizing deflection, minimizing size, and matching the actuator's impedance to the flow channels and the nozzle.

» SIMULATION REVEALS ACTUATOR COMPLIANCE AND OUTPUT

A TWO-STAGE MODELING approach was needed because the actuator performs its function within a jet system. In the first stage, Menzel determined functional parameters for various actuator geometries. He then used these parameters in a complete jet model to determine how the whole system would respond.

"We set up a COMSOL Multiphysics® software simulation to determine the actuator functionality," Menzel said. "Simulations offer an understanding of the relationships between functional parameters and the many layer thicknesses, boundary conditions, and sizes our process can generate. The software's ability to efficiently sweep through a large set of these variables and deliver easy-to-interpret results is of great value. It allows us to easily optimize our total system response, and hence, our product."

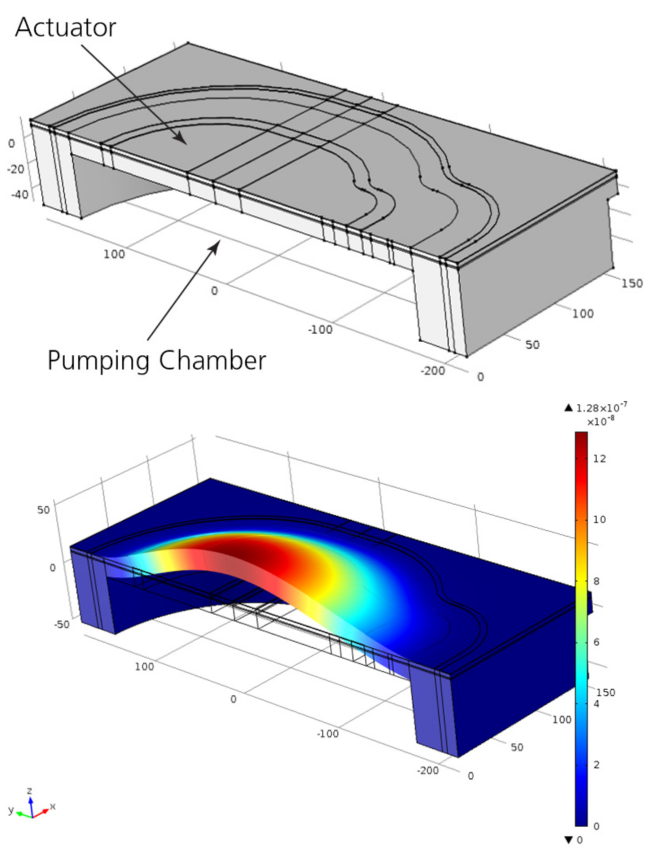

FIGURE 3: Top, Menzel's COMSOL® software model showing half of the actuator geometry with metal, silicon, PZT, electrodes, and pressurized ink chamber. Bottom, simulation results showing the deflection of the actuator.

He modeled half of the actuator geometry along its central axis and included different layers for the silicon, metals, insulators, and PZT (see Figure 3, top). He also included a section of the ink-filled pumping chamber below the actuator and a section of a neighboring flow channel, then performed a simulation to extract the actuator's deflection under a pressure load (known as compliance) and the deflection under a voltage load (known as output) (see Figure 3, bottom). Menzel ran the study over a wide range of actuator geometries. The resulting values were applied to a larger-scale model used for system-level design optimization.

» LOOKING AHEAD TO FASTER, SMALLER PRINTHEADS

THE COMSOL RESULTS led Menzel to an updated design by giving him the information needed to fit a new device to tight specifications and smaller actuator geometries. The multiphysics model revealed valuable information that allowed the engineering team to better understand the ins and outs of their actuator and jet. Modeling remains the starting point for evaluating actuator concepts and product feasibility; the associated reduction in design time is critical to effective and efficient product release. Even higher quality printing will soon be on the market as FUJIFILM Dimatix continues to lead the industry in printhead design, supported by simulation. ◎

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>
> —CHRIS MENZEL, PRINCIPAL SCIENTIST, FUJIFILM DIMATIX

SIMULATING THE PIEZOELECTRIC EFFECT

BY YESWANTH RAO

PIEZOELECTRIC MATERIALS are a family of solids, some natural and some man made, that become electrically polarized as a result of mechanical strain, a phenomenon known as the direct piezoelectric effect. They also exhibit an inverse piezoelectric effect where a mechanical strain results from an applied electric field. Piezoelectric materials are natural transducers that are used in many kinds of sensors and actuators.

The COMSOL Multiphysics® software offers a predefined *Piezoelectric Devices* interface that couples electrostatics and structural mechanics (Figure 1), which are essential for modeling these phenomena.

For accurate modeling, material properties and orientation must be carefully described. The *Piezoelectric Devices* interface allows the user to specify material properties in Stress-Charge or Strain-Charge form (Figure 2), with options for defining material orientation using Euler angles.

Piezoelectric materials are usually one of many components in a device. To capture the true behavior of the device as a whole, it is necessary to model the interactions between the piezoelectric devices and the surrounding materials. The multiphysics modeling capabilities in the COMSOL® software allow the *Piezoelectric Devices* interface to be readily coupled with physics such as pressure acoustics, fluid flow, and structural vibrations (Figure 3). It is also important to describe damping mechanisms that may affect device performance. COMSOL allows users to include mechanical damping, dielectric losses, conduction losses, and piezoelectric coupling losses.

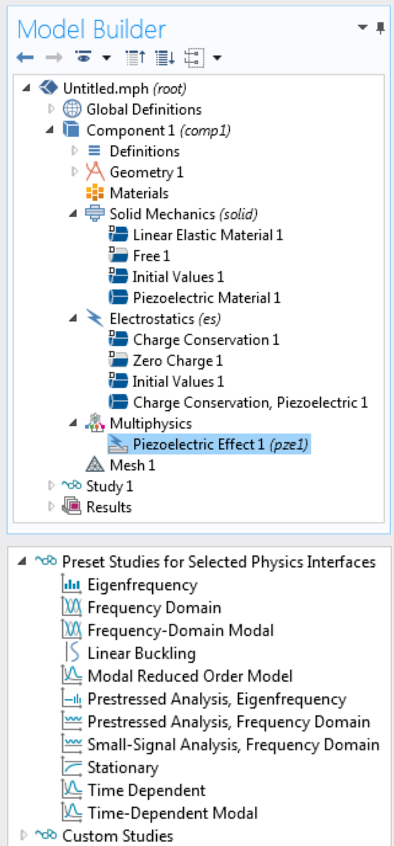

FIGURE 1: COMSOL® software Model Builder showing the setup for simulating the piezoelectric effect (top) and studies available to the user to simulate a piezoelectric application (bottom).

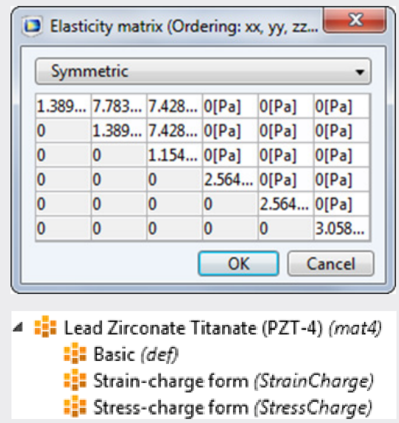

FIGURE 2: Strain-charge form settings showing the elasticity matrix, accessible from the Materials node in the Model Builder.

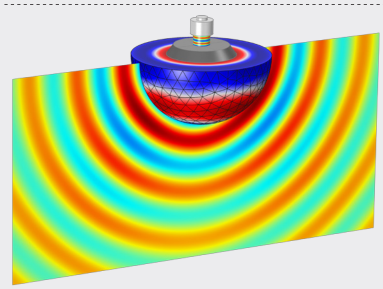

FIGURE 3: Simulation of a piezoelectric tonpilz transducer with results showing the acoustic pressure levels, including the far-field and voltage distribution in the piezoceramic rings. These transducers are used for low-frequency, high-power sound emission.