Hacking the Stack: From Multilayer PCBs to Shape-Changing Composites

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Most printed circuit boards are made of layers – stacks of copper-coated cores, with insulating sheets sandwiched in-between. The process of making this stack (layup and bonding) is almost always performed in a factory, as a routine step in a highly-mature fabrication process. But a savvy hacker can tweak this formula. If we intercept the boards in the middle of this conventional pipeline — taking command of the layup procedure ourselves — we can insert novel structures that transform standard PCBs into dynamic, compact electro-mechanical devices.

One immediate application is in the development of reprogrammable, shape-changing materials that *scale*. Too often, the electronics that are inserted into these prototypes are treated as an afterthought — the result is a structure that is size-limited by a labor-intensive assembly process. We instead propose integrating actuatable materials directly into the already-established, scalable manufacturing pipeline for electronics, re-conceptualizing these "programmable surfaces" as extra-functional multilayer circuits.

So far, our work in this area has revolved around integrating pneumatic structures (i.e. electrostatic valves) into multilayer PCBs, which has allowed us to create dynamic tactile patterns and simple shape-changing robots. In order to accelerate this experimentation (and allow the wider community to participate), software tools will need to be developed that capture certain abstractions, and render them as design files that can be readily manufactured.

CCS CONCEPTS • Insert your first CCS term here • Insert your second CCS term here • Insert your third CCS term here

Additional Keywords and Phrases: Insert comma delimited author-supplied keyword list, Keyword number 2, Keyword number 3, Keyword number 4

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Building a tangible user interface is (in many respects) much more of a challenge than building a digital one. While a virtual environment can change state at the whims of a user, real-world objects are not so nimble — and so increasingly, researchers have attempted to engineer new structures that bring the dynamism and mutability of software into the physical realm [1].

These actuated structures are often dubbed "programmable surfaces". They sit in a spot between material and machine — not quite robots, but still too gadget-like to be considered a kind of "matter". Most often, they are composed of repeated cells, which can be independently instructed to shrink, bend, or expand [2, 3, 4]. While compelling, a common stumbling block is the issue of scalability, as the multitudes of actuators that comprise these surfaces are usually built and assembled individually [5]. Our work addresses this by leveraging the scalable, PCB layup process.

There's a strong history of "makers" and "hackers" seizing techniques that were once considered factory-exclusive. Years ago, surface-mount assembly was perceived as out-of-reach for hobbyists — surely you needed an industrial reflow oven to sculpt the correct temperature profile for your components. Fearless tinkerers eventually silenced the naysayers, reflowing boards on hotplates and repurposing toaster ovens with surprising effectiveness. These techniques are now commonplace in DIY communities. And while these lower-fidelity methods do have some shortcomings when compared to their industrial cousins, they allow engineers to rapidly develop boards that can later be productionalized with little or no changes to the initial design.

The same can be true of layup and bonding. Early in our experimentation (Figure 3e-3h), we achieved convincing results with inexpensive adhesive sheets and an off-the-shelf heat press. (There are also opportunities here to create physical tools that are more custom-built for this task, yet still more accessible than traditional industrial processes.) This "homebrew" layup procedure allows us to insert unconventional materials that fabrication houses do not currently support — but critically, these layer-driven designs could conceivably be industrialized at a later date. So far, our research [6] in this area has revolved around the insertion of pneumatic structures into multilayer PCBs (Figure 1).

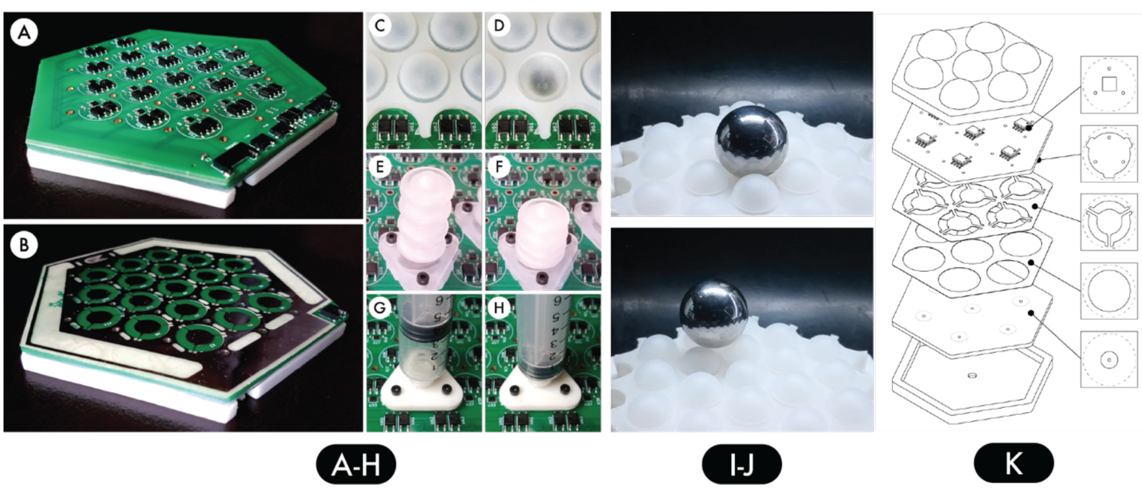

Figure 1: By stacking multiple materials (k), we can create multilayer circuits with embedded pneumatic structures, such as electrostatic valves (a, b). Combined with various transducers (c-h), these valves allow us to build programmable surfaces that can render tactile sensations or move objects (i-j).

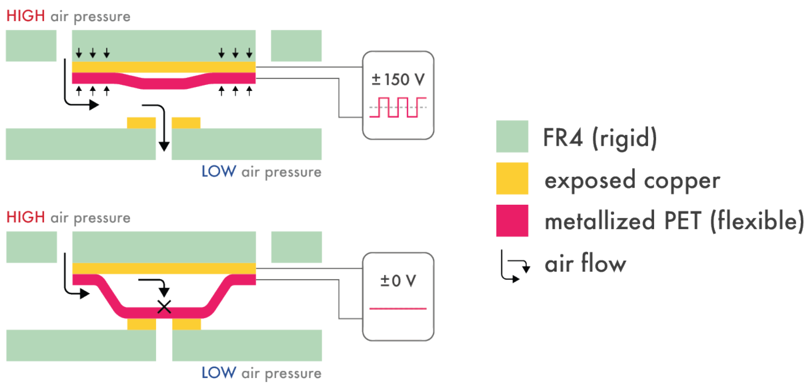

Figure 2: A multilayer circuit board with an embedded electrostatic valve [6].

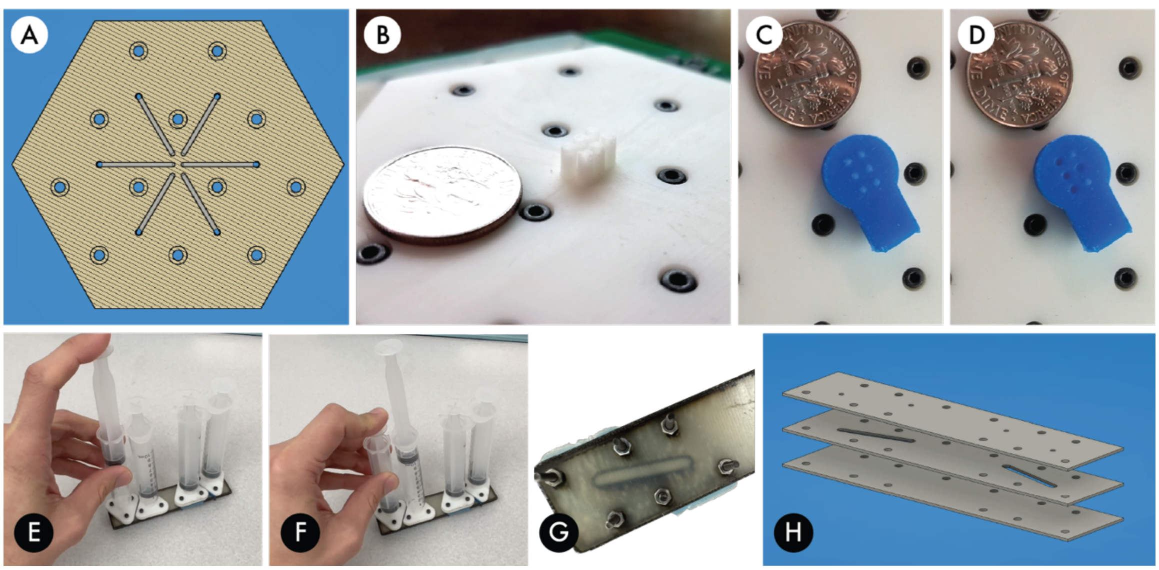

Figure 3: Pneumatic channels can be created using a stacked manifold technique (e-h). A similar method was used in a-d to route pneumatic signals (controlled by our electrostatic valves) to the Braille cell in c-d.

Recently, we introduced a novel design for an electrostatic valve (Figure 2). Going forward, we envision CAD tools where newly standardized patterns such as these can be integrated into the larger process of PCB design. In addition to duplicated patterns, these tools should also support features that can be synthesized from a computational process (hinges for curved geometry, pneumatic routes). This will accelerate the design of scalable, shape-changing interfaces.

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