**TECHNICAL BRIEF** FLEXIBLE CIRCUITS

# Micron-scale Flex Circuits Solve Miniaturization Challenges

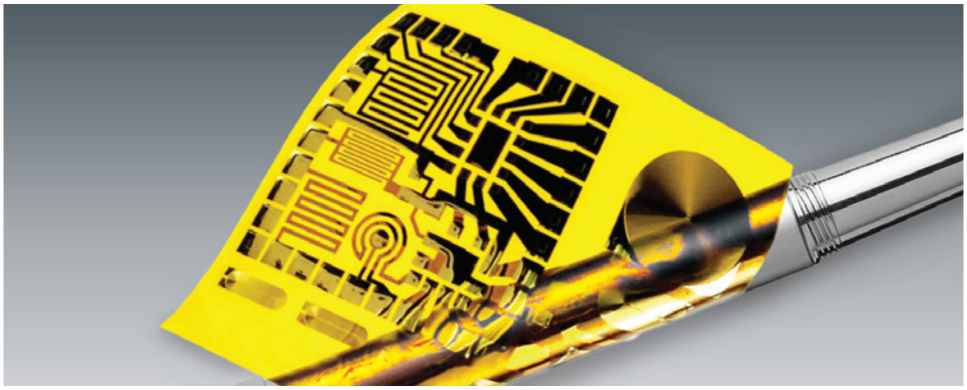
“It needs to be tiny in size. The circuits need to be dense and precise. And it needs to bend to fit.”

When that call comes in there are only a few companies in the world who can handle it. In fact, the circuits often have feature sizes ranging from three to ten microns and can consist of six or more layers. At Metrigraphics, we call them ultra-miniature flex circuits and they often need to hold up under extreme conditions such as in military and aerospace applications, and perform in such critical environments as human body implants.

METRIGRAPHICS®

## Unique Circuit-Design Challenges

Bend radius, structural loads and environment play an important role in many ultra-miniature circuit applications. Here a Metrigraphics flex circuit wrapped around a pencil demonstrates the ability to achieve a small radius of curvature — especially important in medical devices. Small circuits often must be rolled and inserted into a catheter, for example, to attach a test device to connecting cables.



*Flex-circuit products include:*

- Single-layer flex
- Multi-layer flex
- Coils
- Sensor components
- Electrodes (neuro-stimulation)

*Single-layer and multilayer applications include:*

- In-vitro diagnostics
- Invasive and non-invasive medical devices
- Tracking devices
- Data-feedback devices

### How is a Flex Circuit Made?

Metrigraphics' flex circuits are made using a combination of additive photolithographic, electroforming and proprietary technologies. The circuits consist of one or more very thin layers, each of which consists of sputtered metal, or thicker-plated metal such as gold or copper, on a polyimide substrate.

An additive process creates circuit lines by sputtering a positively charged metal to a negatively charged base. Then, if needed, plating can build up conductive traces of precise height and width. The base may be either a conductive material or non-conductive polyimide to which a metallic layer was applied. Using photolithography, a photoresist "stencil" is then applied on top of this conductive layer. The plated metal is attracted to and bonds with the conductive layer only where the non-conductive photoresist has left it exposed.

If the circuit is to be multilayer then a new polyimide layer is applied on top of this first layer's circuit elements to support a new metalization layer. Metal is then sputtered (and/or plated) on top of this new polyimide — and this cycle continues until all circuit layers are added. The polyimide layers separating the circuit layers range in thickness from 10 microns up to 100 microns and possibly more. Thinner layers make for a more flexible circuit. However, the trade-off is that thinner polyimide offers less electrical impedance, so there is a greater likelihood of crosstalk between layers.

Typically openings need to be created in the polyimide layers to allow for electrical connections (plated vias) between layers or for contact pads. These openings are imaged using photolithography or, alternatively, are drilled with a laser if the holes are too small to be imaged.

A glass mandrel supports the base during circuit manufacturing and then is separated from the finished circuit when manufacturing is done. Finally, the individual circuits — which are nested together during production — also need to be separated from each other.

Nesting is, in fact, a key factor in the cost of flex-circuit manufacturing. Ultra-miniature circuits are not volume-produced one at a time but instead are produced in sheets of material, with each sheet typically containing hundreds of individual devices. Following fabrication, those devices are then laser-cut from the sheets much like a cookie cutter cuts out individual cookies from sheets of dough. Although this cutting step comes at the end of the production cycle, the nesting process itself starts very early. The more circuits that can be produced per sheet the lower the cost per unit — and so a major factor driving that cost is the size and shape of the device. The smaller and more uniform the shape, the more devices that can be nested and the lower the cost of each device — so device size and shape are issues to be considered during the upstream circuit design.

Other factors also have an impact on the ultimate success of a flex circuit in meeting its application objectives. Following is an overview:

## Flex-Circuit Success Factors

Ultra-miniature circuits, whether rigid or flex, are highly complex and customized devices, so it makes sense that the design of the fabrication process itself would also be highly complex and customized. That is, in fact, the case and there are a number of factors that help determine whether the circuit can indeed be successfully fabricated to meet its intended objectives.

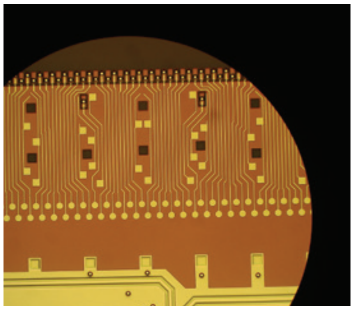
*Key factors include:*

- The circuit's physical characteristics
- Mechanical and environmental requirements
- Quality of fabrication facilities
- Flex micro-circuit manufacturing experience

## Let's Take These One at a Time.

### *Circuit Design Characteristics*

There are always design challenges that must be overcome in fabricating any ultra-miniature circuit. These include line (or trace) density, line width and height, number of layers, and the number and proximity of various features such as coils and vias. As already discussed, the overall size and shape of the device helps determine how many devices can be nested on a single sheet during manufacturing, which is a big cost factor. Where features are located on the board may strongly impact performance factors such as the circuit's ability to flex, its electrical impedance, and whether features can be fabricated as part of the imaging process or have to be cut out with a laser as a separate step — which increases manufacturing cost, complexity and, potentially, risk.



**Circuit Design at a Glance**

Designing a microflex circuit involves designing the actual circuit as well as the manufacturing process needed to produce the circuit at high yield and high volume.

It involves off-the-shelf design tools and methodologies plus creative tailoring of the product and process, such as to achieve an extreme bend radius.

Key variables include:

- Spacing and distribution of circuit elements
- Height and width of circuit lines
- Number of circuit layers
- Thickness of layers
- Location and size of vias for electrical connections between layers
- Thermal conductivity of materials
- Signal cross-talk between layers
- Mechanical stress points
- Stiffness of layers and bonding agents

Ultimately, the best way to overcome physical challenges is to reduce or eliminate them in the first place. That means designing for manufacturability from the start with help from your micro-flex circuit manufacturing partner.

*Mechanical and Environmental Challenges*
How much will the circuit have to bend? How much shock and vibration must it withstand? What about acceleration loads? Is it subject to high humidity or liquid emersion? These and other mechanical and environmental challenges need to be taken into account when deciding the best way to deal with the raw design challenges just discussed. Again, consulting with your fabrication partner early in the design cycle is the best way to avoid expensive rework and wasted parts later — and to ensure the design will work at all.

*Quality of Manufacturing Facilities*
Whether your circuit can meet design requirements, mechanical challenges and environmental hazards has a lot to do with the capabilities of the manufacturing equipment and processes involved in making the circuit. Those capabilities include state-of-the-art systems for computer-aided design, photolithography masking and imaging, the layering of metals at an almost atomic level, advanced laser cutting, and ultra-pure manufacturing equipment and clean rooms. Even a two-micron-size piece of lint can do serious damage to a circuit with features in the five-micron range.

Of course, even the most advanced facilities for producing ultra-miniature flex circuits are of limited value without the next, and perhaps most important, success factor of all:

## Flex micro-circuit manufacturing experience

Advanced skills are required throughout the flex-circuit production cycle — especially when it comes to taking a seemingly impossible flex-circuit application, and not only making it possible but also cost-effective as well. The ability to know what will work and what will not, with virtual certainty, only comes after thousands of successful process designs for hundreds of customers in dozens of industries. It's the ability to tailor a production process that meets all the customer's design, mechanical, environmental, and cost criteria in high volumes at high yield — and to do it all within turnaround times that meet the customer's target market opportunity.

**Circuit Manufacturing at a Glance**

A microflex circuit consists of one or more conductive layers (typically metal) covered by non-conductive polyimide that has openings created using a photolithographic process.

More metal is then plated onto the exposed conductive material underneath, forming the circuit.

Follow these steps:

1. Sputter a very thin layer of metal onto a base mandrel, such as glass.
2. Cover the metal layer with a thin polyimide layer.
3. Sputter a seed layer of metal.
4. Cover the seed layer with a photoresist.
5. Image the circuit line pattern onto the photoresist.
6. Plate additional metal onto the exposed trace lines.
7. Etch seed layer with wet or dry technology.
8. Cover the trace lines with another polyimide layer.
9. If a multilayer circuit sputter the next metal layer and repeat steps 2-8.
10. When done, separate the finished circuit from the mandrel.