Elastic Interconnections For Stretchable Electronics

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Today, most electronic appliances are rigid, or at most mechanically flexible. Future applications, however, will require electronics that are both flexible and stretchable and that offer maximum user comfort.

At the TFCG Microsystems lab, associated with the IMEC Research Center, scientists are involved in several long-term projects that aim to make this comfortable circuitry available. Recently, they have made headway in creating elastic interconnections that stretch to twice their length without losing their conductivity. Combined with flexible components, these interconnections promise to create a completely new field of user-friendly applications.

In the not so distant future, say beyond 2010, researchers envisage ambient-intelligent electronics. These will consist of embedded, unobtrusive devices that will allow people to carry out activities, tasks and rituals in an unhampered, natural way. The applications will be highly responsive, personalised and embedded in the user's environment so that they are almost unnoticeable. Possibilities are, for example, sensors integrated into clothing, worn unobtrusively over the user's skin, or even implanted. The components that make up this environment will be extremely compact and lightweight. Moreover, if they are to be worn comfortable in clothing, or on the skin, they should be flexible, stretchable, biocompatible, breathable, watertight and washable.

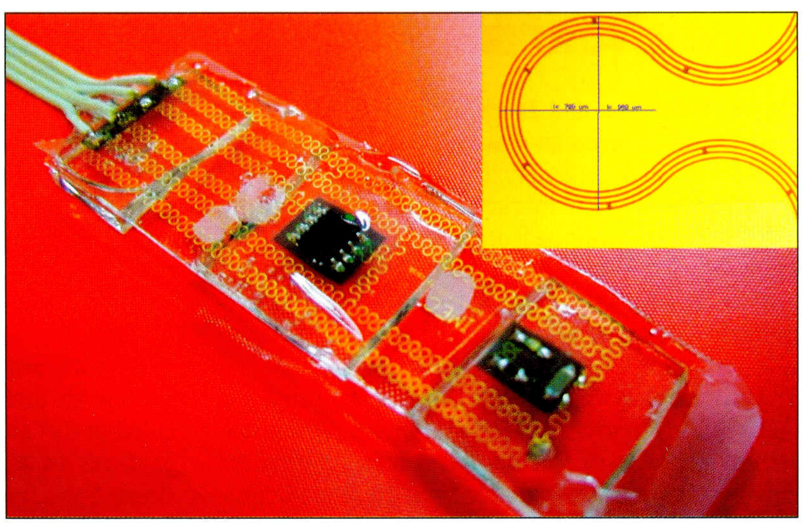
Once such a tissue-like circuitry is available, a wide range of new applications will become viable. Obvious examples are heart rate monitors in sports clothes, fall detection bandages for the elderly or handicapped, stretchable thermometers or position-tracking devices for children playing on the beach. But researchers are also aiming for more complex medical applications such as intelligent patches, implanted brain electrodes that help treat epilepsy and depression or a bladder implant to overcome incontinence.

Researchers on flexible and stretchable electronics at the TFCG Microsystems lab hold that many of these applications exist already today, in some form or other, but they come in rigid packages – think of portable phones or blood pressure monitors. If they are integrated in the environment at all, they are often simply hidden from the user's view – for example, in the clothing fabric. These devices cannot flex or stretch with the textiles or with the skin. Further, users have to disassemble their clothes before washing them, or they have to strap on an uncomfortable monitor. There is still a long way to go before users will feel comfortable with these devices. All solutions to integrate complex electronics into clothing or skin with maximum user comfort are in a research or even visionary phase. Currently, there are no satisfactory solutions available to embed electronic devices in the user's environment.

Following the stretching of the skin

Apart from all the other requirements, such as biocompatibility, a prerequisite for ambient electronics are flexible and stretchable circuits for electronics and sensors. Human skin or tissue can flex and stretch up to 10%, so for maximum comfort, embedded electronics should be able to follow this movement and still function. Therefore, research groups at IMEC and its associated TFCG Microsystems lab at the Ghent University are involved in several research projects that aim to create such flexible and stretchable electronic and sensor circuits. These projects are BioFlex (Biocompatible Flexible Electronic Circuits) with funding from the Institute for the Promotion of Innovation by Science and Technology in Flanders, STELLA (Stretchable Electronics for Large Area Applications) with funding by the European Commission, and SWEET (Stretchable and Washable Electronics for Embed-

Figure 1 – A stretchable thermometer showing embedded components



ding in Textiles) with funding by the Belgian Science Policy.

TFCG Microsystems believe that real-life stretchable appliances will be hybrid. They will contain rigid or flexible components connected with stretchable circuitry. The circuitry will stretch and bend like rubber or skin while preserving its conductivity. At the lab, the aim is to combine stretchable interconnection technology with flexible circuit technologies, as developed in the EC-SHIFT project. An example is the Ultra-Thin Chip Package, or UTCP, which is only 100 micron thick.

Golden undulating horseshoe patterns are more flexible

Recently, researchers at the lab reported on a new method to design and make such elastic interconnections for stretchable electronic circuits. They embedded interconnection wires with a 2D undulating pattern in an elastic silicone film. The 2D springs were designed and optimised in co-operation with the IMEC IPSI/REMO group, which is specialised in mechanical modelling and reliability prediction. They differ from other comparable designs in the following optimisations. First, the researchers inferred, based on finite element analysis, that an undulating horseshoe shape is the ideal form for the connection wires. It dissipates the stretching and flexing stresses better than comparable elliptical patterns. Second, they further improved the stress resistance of the interconnections by splitting each interconnection wire into four parallel wires with a smaller width. Lastly, in the initial technology development phase, they chose gold as a material for the wires, because of its high ductility, which again allows for greater stress resistance.

The resulting interconnection wires consist of four parallel tracks, each 15µm wide, and are made of a 4µm-thick gold layer. The tracks are coated with a 2µm-thick nickel layer for soldering to components. At regular intervals, in positions where the deformation stress is calculated to be minimal, neighbouring tracks are cross-connected. This allows for fail-safe operation in case of fabrication errors or mechanical failure.

Assembly practices

The interconnection wires are embedded in a silicone polymer substrate: polydimethylsiloxane (PDMS). In itself, PDMS is an electrical insulator, but it can be made conductive by adding silver particles. While not as good a conductor as copper or gold, this modified polymer can carry a signal over very short distances. Should a wire be overstretched, resulting in a micro-crack, the surrounding polymer will still conduct the signal, bridging the gap created by the crack.

The team at TFCG made interconnections with different angles and radii for the horseshoe shape. They tested the circuits by stretching them in the longitudinal direction to the point of electrical failure, which would be caused by a rupture in the gold tracks. The best interconnection stretched from 3 to 6 centimetres without failure. Moreover, all interconnections recovered their conductivity when returned to their normal length.

To assemble the stretchable interconnections and the more rigid electronic components, joints were soldered using normal electronics assembly methods. Next, the silicone polymer was molded around the assembly, taking care not to cause any bubbles in the silicone. For each design, a dedicated mould was made. This mould takes into account the locations on the assembly where the rigid parts are located. At these locations, the silicone wrapping should be thicker so that the circuitry is locally less stretchable.

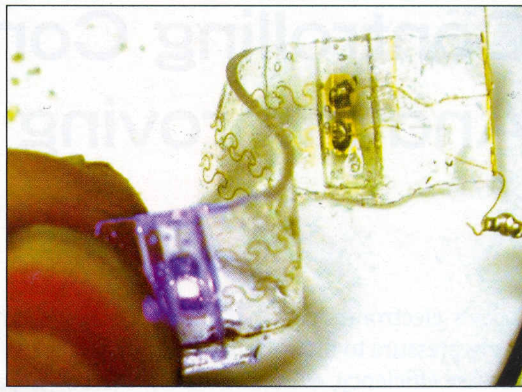
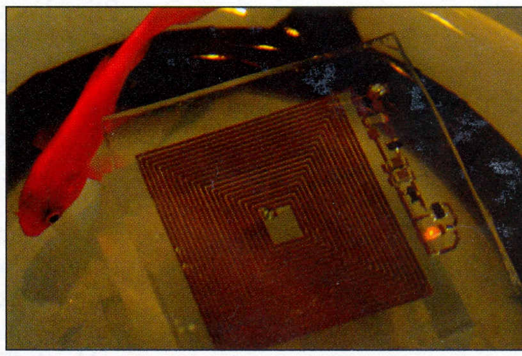


Figure 2 – Blue LED embedded in 500µm thick silicone substrate

Figure 3 – Led powered by inductive coil embedded in PDMS



What the future holds

Researchers are now studying the use of conducting materials other than gold. Copper, the standard material in PCB manufacturing, is the obvious candidate. Wiring with copper is of course much more cost-effective than with gold, but the main reason for choosing it is the drive to develop a technology that is compatible with existing industrial PCB and assembly practices. This will greatly facilitate the transfer of the technology to a production environment.

Within 3 years, and based on its current research results, the TFCG Microsystems lab expects to have technology and a demonstrator that can be commercialised. They believe that the first flexible and stretchable appliances will most probably be used in intelligent clothing, with medical applications following later. The circuits that are being worked on will not only be flexible and stretchable, but also washable – which is a big step forward for intelligent clothing. For first commercial products, expect to see clothing with signalisation, using LEDs and sensors, for example to track movements.