Microchips on glass

‘Exotic’ pcb for all-in-one phone

What about a mobile phone that uses a single microchip to receive all the available frequency bands, plus extras such as television, gps, and Internet access? Or, in due time, see-through implants that will monitor your state of health, and equipment that will let you see through fog. Researchers at Delft University of Technology (TU Delft) have discovered a radical new way of integrating communication circuits in a microchip, using an electronic components that was considered utterly unsuitable for the purpose, and an improbable substrate, glass.

“I think the future lies with glass microchips.”

Maarten Keulemans

Exotic, strange, weird; Professor Dr Lis Nanver and Dr Ing. Leo de Vreede have heard it all before. The piece of glass they have placed on the conference table looks ordinary, but is rather special. “So far our results in this field are the best in the world,” says De Vreede. Nanver adds: “With this technology I can almost create the perfect device. I even believe that the world will be forced to switch to this type of technology in a couple of years.” The subject of our conversation is a small, circular sheet of glass looking nothing like a normal wafer with microcircuits on it. The object rather resembles a piece of engraved glass. Or, perhaps, a prop from an episode of Star Trek. It’s not just because of the unusual material used for the substrate, but also because of the wafer-thin silicon circuits it carries. Look closely and you can see that some of the circuits have metal terminals on the back – highly unusual. Three-dimensional microchip technology on glass? And then there are these strange rectangles around which the circuits have been created. They are variable capacitance diodes, or ‘varactors’ as the jargon would have it. Even more peculiar, since varactors belong to the realms of cruder electronics like radios, television sets, amplifiers. They are useless in mobile phones, is the current consensus. Much too sensitive to signal interference. Nonetheless, De Vreede and Nanver, who both work at DIMES, the Delft institute for microelectronics, are convinced that this is the way forward for microelectronics. They think that one day their glass microchips will end up in our mobile phones. It would mean phones with a much more efficient layout, longer periods between recharging, and most of all, added functionality. “We would just have a phone offering standard access to all kinds of ether-based networks and services,” says De Vreede. “Think TV-on-mobile. Think gps, or communication networks using different frequency bands and protocols, like they have in the United States.”

“It is certainly an interesting technology, and it might very well be a breakthrough,” says innovation manager Dr Ir. Bart Smolders of NXP Semiconductors, formerly known as the microchip division of the Philips electronics company. Smolders is currently engaged in research to find out if discrete components using silicon on glass could be a business proposition. “You need a lot of money to bring an exotic process like this up to production standard, so we want to make sure we get our sums right.”

Maze

On the outside, mobile phones may appear to be state-of-the-art devices but on the inside they are a collection of compromises. One of the most notorious problems is the lack of circuit integration. For each transmission protocol, the average mobile phone has a separate, discrete circuit on board, a
Background

Photos: Sam Rentmeester/FMAX
bit like an old-fashioned telephone exchange from the nineteen-fifties, a jumble of plugs and cables. Bluetooth, GPS, wireless LAN, foreign telephone protocols, they all have their own circuitry to rule out interference as much as possible. “You’re simply not alone in this world, and for each signal you’re trying to receive, there are countless competing signals,” says De Vreede. This means you’re stuck with a maze of separate circuits. “The result is hardware proliferation, meaning users are looking at buying a new phone every time they want to use a new feature, like GPS for example.”

What the microelectronics world wants is a general control, a variable component that will make a single radio transceiver circuit suitable for all purposes. But such a component would have to satisfy many different criteria like being small, cheap, reliable, fast-switching, lossless, and capable of picking up exactly the right signal at any given moment.

So far, attempts by other researchers have yielded a mixed bag of results. Some are betting on adjustable, microscopically small machines (microelectrical mechanical systems, MEMS). Although these offer good capabilities in the way of signal loss, they need a vacuum to work in and are slow to switch. Others are focusing on circuits using a barium strontium titanate (BST) alloy, a material with adjustable properties — a variable dielectric constant, to be precise. But BST, too, has its drawbacks.

Enter the glass varactor microchip created by Dimes. “Our results are whole orders of magnitude better than anything anybody else has managed to achieve, and there is still ample room for improvement,” says De Vreede.

Troublemaker

The whole thing started as a bit of a game, Lis Nanver recalls. Running up to the millennium Nanver had inherited a technique developed by researcher Ronald Dekker at Philips which had then been put on the back burner. That technique was a simple way of making microchips using glass. The process is extremely straightforward. You take a silicon wafer containing circuits, attach a glass sheet to it using special glue, turn it over, and etch away the silicon on the other side to leave just the circuitry and the glass (see infographic).

Meanwhile, one floor up and a corridor further along in the same building, Leo de Vreede was engrossed in what at first sight looked like an utterly boring problem, signal distortion in varactors. Varactors (variable capacitance diodes) are known to cause signal attenuation and distortion when used for high-frequency communication applications. If you put in a radio wave it will come out less strong and slightly different in shape, just like waves hitting the shore. De Vreede was about to discover a way that would instantly change varactors from being born troublemakers into immaculately operating, lossless supercontrollers. “It’s a rather complicated story,” De Vreede warns. “What we found out is that, in a certain circuit configuration, and in combination with the right profile and the right impedances at the right frequencies, you can make these varactors work exactly how you want them to.” Loosely translated, De Vreede discovered how to connect varactors in such a way that they no longer distort the signal. And ‘no distortion’ in this case really means ‘no distortion’. “Zero distortion! In theory our configurations are perfectly linear.”

Finger layouts

By now the time was ripe to test the concept in practice. “I first tried to hand the project to a doctorate student, but he couldn’t believe it was be true,” De Vreede grins. In the end, he found a student, Koen Buisman, who was prepared to test...
the varactor circuits. This was in the summer of 2004. Buisman immediately ran into problems. To make the super circuit work, so the theory goes, he needed a ‘leakproof’ microchip. He also needed to connect the varactor circuits with a very low resistance, without any lossy detours like the ubiquitous finger layouts or any unwieldy auxiliary circuits buried deep inside the chip itself. “You want just the device, without any of the rubbish that usually surrounds it.” That was where the glass microchips came in handy. Glass is a perfect insulator, and in the meantime Nanver had been able to devise a method for connecting circuits using a short-cut route on the back of the microchip. She does this by injecting silicon from behind with arsenic ions, and hitting the microchip very locally with a laser beam, which activates the injected silicon. “Only twenty nanometres or so of silicon are melted this way, and this happens very quickly, within a microsecond. So you can create extremely good contact points without damaging any other parts of the wafer.”

In 2005 Buisman had got the varactor circuit working - switchable, suitable for high frequencies, and extremely distortion-free (see text box for details). Gradually, Nanver, De Vreede and their students and supervisors started to redesign the mobile phone. Bit by bit, circuit by circuit, component by component. The growing list of completed microcircuits already includes a number of tunable filters, phase shifters, and several

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**Careful, fragile!**

Of course, glass microchips can break. And especially so if you stick a thick layer of copper on top, according to Rik Jos of NXP. “The coefficients of expansion of copper and glass are very different. I wonder if the whole lot isn’t going to break under the strain of temperature changes.” No problem, according to Dimes. It’s simply a matter of building a bridge. “We call it a via,” De Vreede (photo) explains. “First you create little stilts down to the circuitry, and then you put the copper on top of those. You then have an elastic structure that prevents thermal expansion problems.”

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**The underside is infused with arsenic ions**

![Diagram: Infusing arsenic ions into the glass microchip](image)

**In certain areas, the wafer is hit with a laser to forge a connection**

![Diagram: Laser beam hitting the wafer](image)

**To provide protection, a layer of metal is attached to the underside**

![Diagram: Metal layer protecting the microchip](image)
amplifiers. All of them perform beautifully, and none of them measures more than a handful of square millimetres.

**Tricks**
As they progressed, the Dimes researchers developed additional tricks, including a diode with an insulating layer of boron only ten atoms thick. “The result is a very nicely performing diode, with a large capacitance and very low losses,” says Nanver. “And there is much more. Practically every piece of the technology is new.” So far it has brought the Delft researchers two patents, a growing pile of scientific publications, and of course, enquiries by NXP. There are also some drawbacks. Glass microchips are relatively expensive to make because production always starts with an expensive type of wafer, a silicon-on-insulator wafer. Another problem is heat. Glass does not conduct heat very well, and so the circuits cannot get rid of their excess heat very easily and can become overheated. In the current generation of circuits the scientists have solved the problem by using very thick metal connections to act as heat sinks. Another solution developed by Nanver and her colleagues is to spray the glass microchip assemblies with an electrically insulating material that will carry away the heat, all without affecting the performance of the superchip.

Dr Ir. Rik Jos, a research fellow at NXP who has been involved in the Delft research for many years now, foresees a different obstacle. The Delft scientists could well be on the wrong track altogether. When asked what he meant, he suggested that varactors made from the semiconductor gallium arsenide might work much better. This is a material which allows electrons to move about much faster, resulting in a higher Q-factor, or quality factor. “I have a problem with silicon on glass. It is very exotic, so the production costs are huge. Varactors made from gallium arsenide involve a much more conventional process. There are lots of companies that can do this.”
Gallium arsenide is in fact one of the materials being investigated by Nanver and De Vreede in collaboration with American company, Skyworks. Even so, De Vreede has not yet been convinced. “The fact remains that nobody so far has achieved the values Lis managed to get using silicon on glass. Saying that the same can be done with gallium arsenide is easy, but we don’t have any proof to date. Our calculations say that the conventional production methods for gallium arsenide offer no easy solution either. The best option would be a combination of gallium arsenide with glass. This might be more expensive, but it would offer superior performance, and could well be an interesting alternative for other, more demanding applications than mobile phones.”

Health care
So what if the glass microchip really takes off? According to Nanver, we can then expect to find them inside everything that’s wireless and communicates in next to no time. “The glass microchip opens the way to integration of functions, to microchips that interact with their environment. You could have a microchip inside your body that monitors your state of health, or they could be used for climate control, or in chipped products that can scan themselves when they pass the till.”

Or think in terms of miniaturised terahertz scanners, deep infrared devices that can see through clothing and inside suitcases. Nanver laughs: “You might soon find just such a scanner on your mobile phone. Who knows what it could be used for?” De Vreede can see the technology return in all-weather systems that will let you see through fog. “There will be all kinds of new applications that will affect our life in many different ways.”

For the time being, don’t expect to find any glass PCBs inside your phone. If the technology is ever going to be applied, glass PCBs will probably first find their way into discrete components, which will in turn be snap-linked to other microelectronics. But Nanver is fairly sure that in the longer term the glass version will triumph. “I can really see it happening. Silicon will increasingly be mounted on glass. You simply cannot avoid doing so for very small dimensions. That’s easy to predict. Given what we stand to gain from glass-based circuitry, I think this will be the technology of the future.”

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By the numbers
The varactor diodes made at Dimes can be coaxed into delivering their wonderful performance by switching them in an anti-series configuration at the right connection impedances. Given the right conditions, the varactor element will achieve a Q-factor in excess of 100 at 2 GHz for very high capacitance values (approx. 25 pF). Until recently the assumption was that semiconductor varactors could not exceed a Q of 60 at the required capacitance. MEMS can achieve a Q of up to 200 for small capacitances, but at higher values (10 pF) they offer a significantly lower Q factor (approx. 50). The use of BST generally results in a Q of less than 30. The Delft varactor diodes have a high capacitance per surface area, which results in very small circuits. They also have no moving parts and do not require expensive packages, so they can be easily integrated into complicated microcircuits. They require a relatively low control voltage (Vcont < 10 V) and feature a very high linearity, which is very important for use in mobile telephones. “During the last tests we even had quite a bit of trouble measuring linearity. And that was using a purpose-built test rig.”