Preface March 2017

The 5 highlights of February

Making car electronics safe again

Photonics-on-chip makes doctors dream

First EUV lithography high-volume manufacturing solution for N5 BEOL

Smart apps for smart cities

New plastic chip in the making that communicates with touchscreens

Innovative communications satellite launched with DARE-enabled chips inside

Ava & Trix: the classroom digital game showing children the fun side of science

General, Smart Health, Semiconductor technology & processing
A fresh look at chips

Twice a year I go off to visit our partners in the US to discuss the research we are doing together in the area of computer and memory chips. We also talked about the latest results we have achieved in Leuven, working in conjunction with their researchers. You will read more about one of these results elsewhere in this issue of the magazine. Basically, they relate to the total solution that we have developed with our partners to produce the finest structures for the back-end of line of future chips, based on EUV lithography. Areas such as resist materials, design techniques, masks and etching processes have all been optimized, meaning that the process is now ready for industry.

Our new website also happened to be included in the conversation during my visits to the chip companies. The site features nice examples of the ‘smart applications’ we are working on: a sensor patch for pregnant women, self-driving cars, etc. This magazine also includes one such example: a ‘smart health’ platform that uses chips with light to detect molecules. We call it ‘biophotonics’ and it will help doctors and hospitals to monitor their patients better. But now that such a lot of attention is being paid to smart applications, the question naturally comes to mind of whether chip technology will become less important for imec.

Absolutely not! That’s because chip technology is at the very foundation of all these innovations and new developments will continue to be required if we are to deliver the enormous raw computing power and memory capacity for servers and supercomputers. And we need these machines to deal with all the data generated by our connected world. We also need to be able to keep developing chip systems ourselves to make the new smart applications possible as they come on stream. This in turn means that a whole range of technologies have to be upgraded and optimized with the system. Because each and every application has its own specific needs – just think of the conditions in which chip systems for driverless cars have to operate, or the ultra-low power specifications for implantable chips.

Last month, I gave a talk on this very topic in Korea. How Moore’s Law and developments in chip technology have brought us to where we are today – and why they are essential in this era of the Internet of Things, the age of smart applications. We will take Moore’s Law further, with us not only scaling technology in the traditional manner, but also developing new ways of incorporating additional complexity in chips.

After a busy month in the US and Asia, I went somewhere quieter: the Swiss Alps, where I go skiing with my family each year. Even though my two children are adults now, we still find it important to do things together as a family. But you don’t need to go on a trip to have some ‘quality time’ with your family. In the article on Cartamundi in this magazine, I read that it is a hype again to play board and card games with your family and friends. And if we can include imec technology in these games, they will become even more engaging for the smartphone generation.
Imec establishes first comprehensive solution for EUVL enablement in high-volume manufacturing

At the SPIE Advanced Lithography conference in San Jose, Calif. (USA), imec and its partners presented a patterning solution for a 42nm-pitch M1 layer and a 32nm-pitch M2 layer in logic design compatible with the foundry N5 requirements. The approach includes two scenarios for EUVL insertion that, when combined with an array of scaling boosters, serve as a basis of the industry requirements for power, performance, area and cost. Including proposals for design rules, masks, photoresists, etching, and metrology and an extensive process variation assessment, imec’s R&D has thus established the first comprehensive solution for EUVL enablement in high-volume manufacturing. Read more.

Five Flemish start-ups join the imec.istart incubation program

The last quarter of 2016 brought five new promising high-tech start-ups on-board the imec.istart entrepreneurship program. The newcomers are active in very diverse sectors – such as construction (BuildEye), transportation (BusOnline.eu), gaming (FanArena), business services (KnowledgeFlow), virtual reality (Yondr). For the next 6 to 18 months, the five companies can count on imec’s financial support, professional coaching and access to several co-working facilities to get their business off the ground. Continue here for more info on the imec.istart entrepreneurship program.

• BuildEye: connecting construction professionals and architects in one app
• BusOnline.eu: an easier way to book your bus ride
• FanArena: create and manage your football dream team
• KnowledgeFlow: easily sharing and accessing knowledge within your company
• Yondr: your virtual travel platform

The 5 highlights of February

Life is busy. So maybe you don’t have the time to read all the interesting in-depth articles we have written for you in this issue. On this page you can find a quick heads-up on what imec has been doing in the past month.
Flemish Government increases financial support of imec

In a new five-year strategic commitment, the Flemish Government has raised imec’s annual grant to 108 million euro – with extra money being invested in imec’s longer-term strategic research. This will help imec consolidate its global position in advanced semiconductor R&D and digital technology; moreover, it will allow imec to expand its innovation capabilities in application domains such as smart health, smart cities, smart mobility, sustainable energy & Industry 4.0. Read more.

Registrations for ITF Belgium have started

ITF Belgium is the flagship edition of the worldwide series of Imec Technology Forums. Each year, it rallies experts and visionaries from around the world at a two-day event to discuss the future of technology and how tech innovation can be brought to market. This year’s theme is: “Nano-Bytes Creating Magic” – uniquely fusing the fascinating worlds of nanoelectronics and digital technologies following the merger of imec and iMinds. Amongst the executive keynote speakers are Kinam Kim (Samsung Electronics), Dieter May (BMW), Matt Grob (Qualcomm Technologies) & Peter Lee (Microsoft Research). For more info about the program, and to register, please visit http://www.itf2017.be.

Imec, Holst Centre & ROHM present breakthrough solution for ultra-low power Internet of Things radios

At the 2017 International Solid-State Circuits Conference in San Francisco, imec, Holst Centre and ROHM presented an all-digital phase-locked loop (ADPLL) for Internet-of-Things (IoT) radio transceivers. Whereas a PLL is traditionally one of the major power consumers in a radio and can take up to 30% of the radio area, this new ADPLL features a small area (0.18mm² in 40nm CMOS), low power consumption (0.67mW) and excellent performance. With all spurs lower than -56dBc and jitter below 2ps, which is beyond state-of-the-art digital PLLs, the new ADPLL shows an excellent robustness. Read more.

Smart Mobility, Smart Cities

Making car electronics safe again

A new security architecture for networked embedded devices.
Modern vehicles are managed by a network of control processors that interpret sensor readings and operate actuators. These processors control much of the car’s behavior and safety functionality, intervening when necessary e.g. for braking, steering, switching on the lights, popping up the airbags, optimizing the powertrain output, and much more. But only fairly recently these networks have also been hooked up to the outside world. This renders them vulnerable to attacks by hackers, a vulnerability for which today there is no effective mitigation available. Jan Tobias Mühlberg, research manager at imec – DistriNet – KU Leuven, explains how researchers at imec have risen to the challenge. The result is a new security architecture for networked embedded devices, carefully designed to fit in today’s environments, a solution ready to be used to secure not only smart vehicles, but also other critical infrastructure, e.g. medical equipment, smart buildings, or power grids.

Islands of smart electronics

“Today’s complex industrial equipment is monitored and steered by networks of electronics, with sensors, actuators and control processors that continuously exchange messages,” says Mühlberg. “In cars, e.g. this interaction is organized around the so-called CAN bus (Controller Area Network), designed as a closed, wired network; an island with no obvious access points for intruders.”

The specification of the CAN bus, and thus of networked sensing and computing in vehicles, is about 30 years old. Before, cars were mostly mechanical. The CAN offers a way for the growing number of heterogeneous sensors and control processors in a vehicle to send and receive reliable and timely messages without any sort of central computer. It connects e.g. the rotation sensors in the wheels with the anti-lock braking system (ABS) and with the drivetrain. For the purposes that it was designed for, as a standalone network, CAN works just great.

Jan Tobias Mühlberg: “You’ll find comparable networks in industrial control systems and robotic assembly lines. They were all carefully designed and tested to take into account all kinds of exceptional states and errors, which made them quite safe … until recently.”

Opening up to the world

Modern high-end cars have infotainment and navigation systems that are hooked up both to the CAN network and to the “outside world”. Via these external networks, infotainment components communicate with the driver’s mobile phone or headset, and receive software updates from their vendors. And with information from the CAN network, it is e.g. possible to turn up the volume of the music when you start to drive faster, or when you enter rough terrain. Autonomous vehicles will take this a step further and communicate with each other and with the traffic infrastructure to steer the car.

“So suddenly a car’s CAN network does have potential entry points for intruders. All this communication with the outside is done over Bluetooth or IP networks, some of which may even connect to the Internet. And the Internet, if anything, is a highly untrusted network”, says Mühlberg. “The CAN bus and its hard- and software components were not designed to operate in such an unsafe environment. CAN, for example, has no real form of authentication or authorization. If a syntactically correct CAN message arrives at the car’s brake system, the brakes just assume that the message is legitimate and comes from a trusted source, not from somewhere else.”
Moreover, the processors are designed to be very small, good enough for their task, inexpensive and consuming as little power as possible. They may run tiny operating systems and a communication and control application. But in contrast to, e.g., laptop or smartphone processors, they don’t have memory protection or an isolated sandbox to run processes in. Every application running on a processor, also an application that shouldn’t be there, is able to access and rewrite the complete processor memory.

Where is the risk in all this? Mühlberg: “Recently, researchers have demonstrated that they can remotely control a car by hacking its Wifi or Bluetooth gateway. In a high-stakes case in Ukraine, it was demonstrated that electricity grids may be taken over. And researchers at imec – COSIC – KU Leuven even demonstrated that they could hack pacemakers, eavesdropping on the devices and even injecting potentially fatal commands.”

This is not to say that such attacks are easy: They require a high level of sophistication, ingenuity and patience. But because of the sheer number of, e.g., electronically identical cars, an attacker that manages to find a way into one system, poses a real threat to the security of very many such systems.”

Creating isolated, safe harbors for processing

Today, there is no commercial mitigation available. In contrast to higher-end processors in e.g. laptops and smartphones, controller chips are small and resource-constrained. They lack the security features that have become standard on other processors, such as privilege levels and memory segmentation. And replacing all embedded processors with high-end systems is not an option, mainly because of high cost, complexity and higher power consumption.

“Therefore, we set ourselves the task of designing a secure architecture from the ground up”, continues Jan Tobias Mühlberg. “An architecture that is suitable to secure today’s embedded systems, such as CAN networks in cars, industrial control systems in manufacturing, or very small IoT devices. Such a system has to be low on complexity and cost, which is a definite requirement from the industry.”

The researchers took a lightweight microcontroller as basis, and extended its design, adding secure memory management and a crypto unit that is optimized for low-power consumption. The result is a processor that is not much larger and doesn’t consume much more energy (about 6 percent). But it can isolate the critical software, creating a kind of safe harbor for it to run in. Because of this isolation, the software cannot be compromised. Its trusted computing base is restricted to the hardware on which it runs. Barring vulnerabilities in a protected application itself, no software, be it applications or operating system components, running on the same processor or outside processes, can override security checks and read or overwrite the protected runtime state.
Knowing whom to trust

“But even if the processor that controls the brakes of your car can no longer be hacked, it will still obey a brake command that comes from an illegitimate source”, admits Mühlberg. “Therefore, we limited the trusted sources of messages to those that can authenticate as legitimate. Thus a brake command should only come from a trusted processor, which itself cannot be hacked, and from an authenticated software component. That way, a car’s CAN network is made up of small unbreakable applications that mutually authenticate and trust each other.”

And as an embedded system will still be contacted from the outside, e.g. from a software provider that needs to install updates, or from the traffic infrastructure, imec’s specialists have also implemented secure communication and remote attestation. Thus an outside party can send or receive messages to and from a specific software module on a specific node while being sure that it is the correct module (authenticity), that it has not been changed (integrity), and that its status is correct (freshness).

Demo at ITF Belgium and future work

Sancus, as the solution is called, is a security architecture for resource-constrained, extensible networked embedded systems, that can provide remote attestation and strong integrity and authenticity guarantees with a minimal trusted computing base. It consist of the extended microprocessor, the dedicated software to run in the safe harbors and a C compiler that generates Sancus-secured code.

Sancus is an ongoing project, and the researchers from imec’s DistriNet – KU Leuven and COSIC – KU Leuven groups have a number of outstanding issues that they’d like to tackle.

One is ensuring the availability and real-time functioning of the network. “With our innovation, we can guarantee that any messages that arrive in a module are legitimate,” says Mühlberg. “But we cannot yet guarantee that they will arrive. It would still be possible for an attacker to drop messages, which our solution can detect. In most cases this would probably not lead to dangerous situations, as the receiving node would raise an error and halt the system in a safe way. But it is of course inconvenient.”

A second issue has to do with the safe operation of the secure software modules. Without formal design methodology and inherently safe programming languages, these modules are poised to have vulnerabilities that may lead to unsafe circumstances. But because we have managed to isolate small modules of trusted code, it should now also be possible to design these in a more formal, fault-free way.
Mühlberg’s team is looking for collaboration opportunities with partners to develop suitable hardware/software solutions that are adapted to their needs: “At the Imec Technology Forum in Antwerp (ITF Belgium, May 16-17), we’ll demonstrate Sancus, either in an automotive scenario or as a smart metering solution, another use case where embedded processors need security. It’s also an excellent opportunity for any interested companies to come and talk with us. We can discuss in technical detail how we’ve managed to add tight security to these embedded networks, an issue that will become all the more pressing as smart autonomous cars start to communicate with their surroundings.”

Want to know more?

- To ensure that the Sancus results can be verified and reproduced, the hardware design and software of our prototype have been made publicly available. The hardware designs, all source files, as well as binary packages and documentation can be found here.
- Sancus has been implemented by imec – DistriNet – KU Leuven and imec – COSIC – KU Leuven, two research groups famed for their work on security. The development has been supported in part by the Intel Lab’s University Research Office. It was also partially funded by the Research Fund KU Leuven, by the EU FP7 project NESSoS, and by the Belgian Cybercrime Centre of Excellence (B-CCENTRE).

---

Biography Jan Tobias Mühlberg

Jan Tobias Mühlberg is a research manager at imec – DistriNet – KU Leuven. Before joining this research group, he did research at the University of Bamberg (Germany, until 2011), obtained his Ph.D. from the University of York (UK, 2010) and worked as a researcher at the University of Applied Sciences in Brandenburg (Germany, until 2005), where he obtained his M.Sc. Tobias is active in the fields of software security, and formal verification and validation of software systems, specifically for embedded systems and low-level operating system components. Tobias is particularly interested in security architectures for safety-critical embedded systems and for the Internet of Things.
Photonics-on-chip makes doctors dream

Chip technology and photonics allows to make ultra-small spectrometers, cytometers and microscopes.

If you can produce small structures on a chip that can handle light, then suddenly all sorts of things become possible. For instance, a whole range of devices are used in medicine that examine cells, molecules and fibers with the help of fluorescent light. And now, thanks to photonics-on-chip, mini-versions of those same large devices can also be produced.

**What is biophotonics-on-chip?**

Chances are, you use photonics every day without even realizing it: glass fibers enable you to use a computer or watch television without any problems. With the help of light, these glass fibers send data much more quickly and power efficient than with traditional digital cables.

You can also do the same thing on a chip. Using ultra-small ‘fibers’ and structures, you can direct light on to a chip and carry out a whole range of tasks. Those tasks can involve processing or sending data, but biological tasks are also possible. In fact, light is the most frequently used medium in medical diagnostics – just think of microscopes and spectroscopes. Light enables you to count or visualize cells, measure the properties of materials and tissue, define a DNA sequence, etc.

Biophotonics-on-chip is a fairly recent area of research that is becoming very important in the medical sector for diagnosis, treatment and follow-up. Doctors will soon be able to use the technology to analyze a blood sample without bulky (fluorescence) microscopes, as well as examine a tissue sample without large spectroscopes.

It is quite a challenge to make photonic structures very small and then combine them into a photonic circuit capable of carrying out a specific task with great efficiency and reliability. If you produce structures using silicon, such as computer chips, or based on silicon-compatible materials (SiN), you can incorporate electronic and photonic functions, creating a smart and compact system. And if you can do that, you can easily make hundreds and thousands of systems function alongside each other at the same time, which means you’ll also get the result much faster than with a single system on its own. Thanks to biophotonics-on-chip we will soon have small, cheap test chips that will assist doctors in their decisions.
Small ‘fibers’ of silicon nitride (SiN) are produced on top of a silicon chip. These waveguides direct the light along a well-defined path over the chip and along detection sites.

Some of the photonic components made by imec: spectrometer, fiber waveguide, waveguide and multi-mode interferometer.

**Counting and viewing cells**

Fluorescent labels are often used to analyze a blood sample in the traditional way. These labels are in fact molecules that bind specifically with, for example, (parts of) a bacterium, gene, cancer cell, etc. Using a cytometer, the blood sample and hence also the labels are illuminated, making them radiate fluorescent light that can be detected. This enables the number of bacteria and cancer cells to be counted or the presence of a specific gene or DNA sample to be determined.

Usually, cytometers are very large and expensive devices that are used in medical laboratories. Imec is developing more compact solutions: cytometers on a chip. In these chips, the cells flow in a microfluidic channel and there are structures above and/or below this channel for identifying and counting specific cells – for example cells with a fluorescent label.
A recent development in this area is a photonic structure called a ‘focusing grating coupler’. A grating coupler is usually used to couple the light coming from a laser (which shines on the chip) in the waveguide paths on the chip and to shine the light coming out of the waveguides back from the chip (e.g. to a detector that is not integrated on a chip). In the new development, the focusing grating coupler allows light, moving in a waveguide, to shine outward from the surface, to create an upward beam of light on top of the chip. The microfluidic channel that the cells flow along runs through this light beam. In this way, the cells with fluorescent labels are illuminated, after which they emit fluorescent light. This fluorescent light is captured by the ‘diffraction gratings’, which sort the light by wavelength. As a result, various fluorescent labels can be detected at the same time. This is a very good example of how compact photonic chips can be used to count cells, even different types of cells (with different fluorescent labels) at the same time. The big advantage of this approach is not so much that the cell can be optically detected, but that hundreds of these structures can work in parallel, having a huge impact on the throughput of these measurements.

Focusing grating couplers can send the light in waveguides outward from the surface, enabling them to efficiently illuminate the cells in the microfluidic channel located above.

Not only is it of value for counting cells, but it is also good for looking at the morphology of the cells. Here again imec has developed an integrated solution: the lens-free microscope. Read more about this in a previous article of imec magazine.

**Spectroscopy in miniature**

Spectroscopy is used in medicine to detect certain substances in tissue, skin or areas of the brain, such as cholesterol, lactic acid and ethanol. Melamine in milk, phthalate in toys, contamination in meat or the authenticity of medical drugs can also be detected with spectroscopy. The substances are detected by their specific interaction with wavelengths of light.

There are many forms of spectroscopy, including absorption, reflection, fluorescence and Raman spectroscopy. Imec is aiming to develop a mini-version of the Raman spectrometer on a chip. This would enable a compact little device to be produced for measuring specific substances in a blood sample regularly and non-invasively. This is not possible with existing desktop Raman spectrometers.

The major challenge in developing a Raman spectrometer is balancing the very small usable signal against the large background signal. That’s why the detector has to be very sensitive. One of the best-known spectrometer designs is the Michelson interferometer. A beam of light is divided into two beams that take different paths before coming together and interfering. This enables tiny differences in the wavelength to be measured. The disadvantage of this design – particularly if you want to miniaturize it – is that two mirrors are used, one of which moves. Unless the moving mirror is in absolutely the correct position, the measurement is incorrect.
Imec has developed a (patented) solution with no moving parts in which hundreds of structures – interferometers – are used next to each other. Light is shone on the tissue and the scattered light is collected by a collimator. This divides the light – with the help of a beam-shaper – across the various interferometers. Each interferometer is a little smaller than the previous one so that tiny differences in wavelengths can also be measured, as is the case with the Michelson interferometer.

![Design of the Raman spectrometer on chip.](image)

**A hypersensitive sensor based on light & sound**

Photoacoustics is a fast, relative cheap and harmless way of producing images of the human body. It can be used, for example, in research into skin and breast cancer.

The photoacoustic effect was discovered in 1880 by Alexander Graham Bell, the inventor of the telephone. He illuminated a block of selenium, which created a weak sound (hence photo = light and acoustics = sound). In fact, light and sound are both forms of vibration. It’s just that we can’t ‘hear’ light, although it can be converted into sound.

With photoacoustics, very brief laser pulses are directed at the patient’s body. A different color of light is chosen, depending on the tissue. When one of these pulses touches the tissue, it is converted into heat. The tissue expands and then contracts again, creating a change in pressure, which moves again as ultrasound. This signal can be picked up by a sort of microphone. The ultrasound can be used to gather spectroscopic information about a material, or else it can be converted into an image. The big advantage of photoacoustics is that there is no background signal, which makes it a highly sensitive technique.

Photoacoustics are already used extensively in medical research, although not yet for diagnosing patients, because the technology is still too expensive. This is where imec aims to introduce a change by making a photoacoustic sensor on chip. One important component for this is the ‘microphone’, which must be able to pick up ultrasound. The ‘mic’ consists of a silicon oxide membrane with an integrated photonic waveguide. When the membrane moves under the pressure of a sound wave, the waveguide is stretched and this movement can be recorded.
For its photoacoustic sensor-on-chip, imec uses a membrane with integrated waveguide. When the membrane is moved by a sound wave, the waveguide is stretched and this movement can be recorded.

Once it becomes possible to miniaturize spectrometers and photoacoustic sensors, the chip may be integrated in a pen like the one in the drawing. The doctor can then use the pen to scan the patient’s skin looking for disorders, such as skin cancer.
**Want to try?**

The PIX4life project began at the beginning of 2016. This is a European project, coordinated by imec, in which a ‘library’ of photonic components is being assembled. This library can then be used by companies – including SMEs – seeking to produce a medical application. By using multi-project wafers, the photonic chips can be produced more cheaply. The aim of the project partners is to lower the entry level for companies in order to take products featuring biophotonics more quickly to market. This will enable our doctors to have portable spectrometers, cytometers and microscopes sooner, meaning that the diagnosis of diseases and the follow-up of a revolutionary treatment can be improved.

**Want to know more?**

In this imec magazine read the article about a lab-on-chip that uses light to detect tuberculosis.

The PIX4life project is funded by the European Community as part of the Horizon 2020 research and innovation program (grant agreement nº 688519). More information at [http://pix4life.eu](http://pix4life.eu).

---

**First EUV lithography high-volume manufacturing solution for N5 BEOL**

At the 2017 SPIE Advanced Lithography conference, imec – in close collaboration with its suppliers – presented an industry relevant platform for patterning the most advanced back-end-of-line metal layers, conform with the foundry N5 technology node.

Imec’s solution includes two scenarios for EUV lithography insertion, as well as proposals for design rules, masks, photoresists, etching, metrology and variation assessment. In this article, one of these scenarios is described in more detail. It combines immersion-based self-aligned quadruple patterning with EUV lithography block patterning, to achieve metal layers with pitches as small as 32nm. To assess the platform’s suitability for high-volume manufacturing, the uniformity of the layers and their local variability is discussed.
The patterning of advanced logic back-end-of-line layers

As we move towards more advanced technology nodes, the patterning of critical back-end-of-line (BEOL) metal layers with ever more aggressive pitches (e.g. 32nm) has become very challenging. In these BEOL layers, typically, trenches are created which are then filled with metal in a final metallization step. In order to create a disconnection in the continuous trenches, block layers perpendicular to the trenches are added, resulting in small metal tip-to-tips. In the industry, various options are considered to pattern the most aggressive BEOL layers and blocks. One option is to use immersion lithography in combination with so-called self-aligned quadruple patterning (SAQP) for the metal lines, and triple patterning for the block layers. This option however requires a triple block mask and a triple litho-etch process flow, which adds to the cost and complexity of the proposed solution. Another option is to pattern the BEOL metal layers directly with EUV lithography (EUVL) in one single exposure. Although this direct EUVL integration flow is very simple and cost-effective, pattern fidelity (e.g. the shape of the pattern) and pattern variability, as well as mask making are expected to be extremely challenging, especially for very small tip-to-tips.

One of the alternatives imec is evaluating is a ‘hybrid’ option, in which immersion-based SAQP of metal lines is combined with a direct EUV print of the block layer – using ASML’s NXE:3300 scanner.

The imec N7 (iN7) EUV platform

To evaluate the viability of this ‘SAQP + EUV block patterning’ option, imec makes use of its iN7 platform. This platform has been developed to evaluate EUV patterning of advanced logic BEOL layers. The platform considers two layers: metal1, with 42nm pitch, and metal2, with 32nm pitch and 7.5 track design. Via1 connects the two metal layers using a dual damascene process flow. With these aggressive pitches, iN7 corresponds to IDM N7 and foundry N5 requirements for the BEOL. The patterning of both metall and via1 can be achieved through EUV single exposure. The iN7 platform is used to evaluate the hybrid immersion/EUVL solution for patterning metal2.
Optimizing design rules, mask and etch process

Prior to printing and evaluating the pattern, considerable efforts and innovations were performed in various litho-related areas. First, imec developed compliant design and design rules to support the possible patterning schemes. Also, an appropriate resist material was chosen for the EUV block process, and its impact on the optical proximity correction was studied – leading to a 2D OPC full-chip model. This model and other computational lithography techniques were used to design and fabricate the right EUV block masks. And finally, new chemistries and novel integration schemes for the etch process have been developed.

Creating SAQP lines and EUV blocks

SAQP (or self-aligned quadruple patterning) is a double spacer technique that is already well established in industry. Basically, this process uses one lithography step and additional deposition and etch steps to define spacer-like features.

Imec’s process flow starts from metal2 core lines, i.e. a (pre)pattern of lines created by immersion lithography (using the ASML NXT:1970i immersion scanner). On top of this pattern, a layer of spacer material is deposited. Then, the spacer is etched and the core material is removed. This second ‘core’ pattern is then used to apply the second spacer, by re-iterating the sequence of spacer deposition, spacer etch and core removal. After these steps, each edge of a core line results in a doublet of spacer lines. As a final result, groups of 6 spacer lines are created with a 4x denser pitch (16nm half pitch) than the initial (pre)pattern. This grating is then transferred into SiN, leaving a pattern of SiN lines on top of a TiN layer.

Illustration of the iN7 SAQP process.

In a next step, block features are added on top of the SAQP pattern. First, spin-on carbon (SoC) is coated on top of the spacer pattern. After resist coating, EUV exposure on the ASML NXE:3300 scanner then creates the block features in the resist material on top of the SoC. After SoC etch, pillar-like SoC block features of 65nm height stand on the spacer lines. This joint SAQP + block pattern is then patterned into the underlying TiN layer, which serves as a hard mask. By etching the trenches within this pattern into the low-k dielectric layer below, and metallizing them, the final metal2 pattern is obtained. The width of the block features determines the metal2 tip-to-tip critical dimension.
Assessing pattern fidelity and local variability

An important part of this work is to qualify the pattern fidelity and variability, as this will contribute to the viability of the proposed solutions for industrial manufacturing. At this small pitch of 32nm, even minor process variations in EUV lithography may have significant impact on the device performance. Such variations are due to overlay and CD uniformity, but also to stochastic effects in the resist.

In particular, the uniformity of the width and length of the block features are important parameters. The width of a block at the location of a trench determines the resulting metal tip-to-tip on that trench. The final target for the iN7 design is to achieve a critical dimension of 21nm metal tip-to-tip after low-k etch. The experiments show that the critical dimension is sufficiently uniform over the wafer. With further fine-tuning, it is expected to remain below 1nm 3sigma. Also the local variation of the block width and placement are important and determine the overlap of the metal line-end with the via that connects to a layer above or below. The major contributor to the local variation turns out to be the stochastic noise, coming from statistical variations in how the available photons interact with the resist. Added to the overlay (which involves the ability of the scanner to align the various layers accurately on top of each other), an edge placement error of the metal tip position of -5nm 3sigma is obtained. Whether this provides sufficient overlap with the via layer, will depend on the design rule. For example, if no direct neighboring vias are allowed, there will be sufficient margin through the design extension of the metal tip over the via.

Another critical dimension is related to the length of the block, as this will be critical in determining the metal trench ‘blocking’ efficiency. A too short block feature could lead to an incomplete cut of the metal trench, and a too long feature can pinch neighboring metal trenches. Ideally, the block end is positioned halfway the spacer line. The maximum budget for the variation of the block end vs. the spacer edges is +/- 8nm. The dominant consumers of this budget are again the overlay and stochastics, adding to a local variation of -6nm 3sigma. Thus, with a 3sigma requirement and if other contributors (such as intra-wafer CDU) can be kept small, the spacer width (16nm) is expected to provide sufficient budget to enable the SAQP + block technology for the iN7 node. Exact specifications may vary depending on the company and product.
(Left) the length of the blocks determines the metal trench 'blocking' efficiency, while (right) the width determines the metal tip-to-tip.

**Towards EUV implementation for high-volume manufacturing**

Imec researchers have investigated the use of SAQP in combination with a single EUV blocking step for printing the critical 32nm pitch metal2 layer in the back-end-of-line. An important finding is that the current imaging performance of the ASML NXE:3300 is sufficient to print the metal2 block layer. The results clearly show the successful integration capability of the EUVL defined block. However, overlay and stochastics came forward as key attention points and will need further improvement, especially if further downscaling is pursued.

The proposed solution is a viable alternative to SAQP + immersion triple block patterning of the 32nm metal layer. From a cost perspective, a 20% cost reduction can be expected from the ‘hybrid’ solution with direct EUV block print, and EUV print of the vias. An additional cost reduction of 3% is expected from a scenario that uses only EUV in one single exposure for patterning the BEOL metal layers. First results point towards pattern fidelity and mask making as the main challenges for this option. Optimizations for this option are ongoing.

As pitch-only scaling doesn’t meet the full requirements for the foundry N5 node, the solutions have been complemented by co-optimizing the technology and the standard cell libraries, resulting in significantly lower standard cell heights. This will allow a full node definition whereby the wafer cost increase of scaling boosters (approx. 3%) is offset by an area reduction gain of approx. 21%.

Including the proposals for design rules, masks, photoresists, etching and metrology, for which imec worked in close collaboration with equipment and material suppliers, all these studies form the first comprehensive solution towards EUVL enablement for high-volume manufacturing.
Smart apps for smart cities

PhD thesis of VUB & imec describes ground rules for a successful deployment of apps in cities.

Smart cities communicate with their citizens via smart apps: mobile applications that make living and working in cities much more comfortable. The number of apps that citizens can use, has skyrocketed. Some are offered by commercial players, while others are made available free of charge by local authorities. So, what type of apps should smart cities focus on? Nils Walravens (imec - VUB) provides policy makers with strategic advice on this topic. In his PhD thesis, Nils took an in-depth look at the role of cities in offering smart city apps. In this article, he presents a few ground rules.

**Smart city apps: what works, and what doesn't?**

Every one of us has access to hundreds of smart city apps via our smartphone. For example, there are apps that highlight correlations between time of day, traffic and air pollution – information we can use to decide when to take our daily walk. In New York, there is even a ‘Don't Flush Me’ app that, at times of heavy rainfall and overburdening of the sewer system, lets residents know when it is best (not) to flush their toilets. At the same time, these apps also generate new data – about mobility patterns or broken street lighting, for example – which allows policy makers to tune the city even better to local needs.

So, this is a clear win-win situation, one would think. However, in practice, many policy makers are still in the dark when it comes to understanding how they can best serve their citizens with smart city apps. For example, they are struggling with the question which applications they must invest in themselves and which can be left to the market to develop.

As part of his PhD thesis, Nils Walravens (imec - VUB) studied what works in the smart city app landscape, and what doesn't – and how a city can ideally position itself in this value chain. He started by doing a broad inventory of European and American smart city apps and investigated how successful they were, based on a number of parameters (larger versus smaller cities, adoption level of the apps, etc.). Then he made a more specific review of three hundred apps related to the Belgian city of Brussels – and also tried to assess their impact (based on their ratings, download statistics, etc.). Transforming these insights into concrete tips, he now lends cities a helping hand in defining their smart city strategy.
The key concept: ‘public value’

“Public value is a particularly important barometer for determining where public authorities can really make a difference,” states Nils Walravens. “First of all, we have to make a distinction between direct and indirect public value. Smart city apps with a direct public value are especially useful for individual users, and focus on the shorter term. Think of apps that show shops’ opening hours or useful places in your neighbourhood. I found countless examples of such applications, so it is really a market that is spontaneously – and largely – covered by commercial partners.”

“On the other hand, local authorities should focus on offering smart city apps with an indirect public value, which serve collective and longer-term interests – such as apps that allow citizens to report fly tipping, or damage to bike paths. I encountered these types of apps much less often, and when they were available, they were barely used – as they were often still in an experimental stage.”

In other words: many cities are not yet ready to offer such services. While the app can be made pretty quickly, successfully rolling out smart city apps takes a whole lot more!

Think long term, appoint a clear owner, focus on open data – and work together!

A first important success factor in the rollout of smart city services is the definition of a long-term vision and the appointment of a clear owner. By doing this, local authorities can better predict the longer-term consequences of the choices that they make today – from partnerships and financing to clear agreements about how smart city data can be used.

“It has become a bit of a cliché to say that data is the new gold. But if you want to develop and offer smart city apps with an indirect public value, having good – and open – data is indeed an absolute necessity. And this is not just about real-time sensor info, but also about opening up and interlinking static information – such as geographic data or street lists,” observes Nils Walravens. “In other words: first the data, and then the apps!”

This is also the philosophy behind the ‘Smart Flanders’ initiative that the Government of Flanders launched in January 2017; an initiative in which the Flemish Government and imec will support the 13 largest cities in Flanders and the Flemish Community Commission in Brussels to open up their smart city data. This will be done in accordance with the newest European standards and formats, so that everyone can make optimal use of these data to develop smart city applications.

“For the next three years, we will provide these cities with intensive support during their ‘open data’ journey. It’s not only about helping them develop a vision; we are also ready to help them determine standards and define the underlying open data architecture,” says Nils Walravens. “Moreover, we will help them define how their partners can leverage the open data. And besides the activities organized by imec Brussels, they can also access our City of Things living lab to set up and evaluate pilot tests.”
Obviously, cities should not have to reinvent the wheel, as has been demonstrated by similar initiatives abroad — such as the ‘Six City’ program in Finland, in which (between 2014 and 2020) six cities (and their partners) are investing around 100 million euros in smart city apps in the domains of smart mobility, clean technology, open data, etc. Each of them looks at the program based on their specific needs, but share a focus on the use of open standards.

Another – pan-European – example is the ‘SELECT for Cities’ initiative, in which Antwerp, Helsinki and Copenhagen, together with six partners (including imec), are looking for businesses that can help them develop a large-scale Internet of Things (IoT) platform. “This is a nice example of what we call pre-commercial procurement,” says Nils Walravens. “Businesses and developers who are interested in getting involved can still take part in the tender process, which remains open until April 14.”

“And finally: don’t embark on this journey alone: it is not obvious to put all of this into practice,” concludes Nils Walravens. “Smart city projects are incredibly diverse and require continuous interaction between local authorities, commercial partners and citizens. Research institutes such as imec have the domain expertise — from technical standardization and administrative considerations to co-creation and living lab research — to play a supporting role in this and to complete the so-called ‘quadruple helix’. In the longer term, collaboration will be absolutely crucial to generate a rich assortment of commercial and public apps with which we can lift quality of life in our cities to a new level. Think of a multi-modal traffic app that uses a wide variety of data, yet provides us with highly-personalized recommendations. We can only reach that objective when we have the right players on board, when they are all on the same page, and when we manage to open up — and link — sufficient data from various sectors.”

And what about the citizens?

If you want to find out more about how citizens fit into this picture, and how we can avoid creating a society from which some people are digitally excluded — then please read this following opinion piece from imec - VUB colleague Ilse Mariën

Want to know more?

Businesses and developers who are interested in getting involved in the SELECT for cities tender process, (open until April 14) can find more info at this website.
Biography Nils Walravens

Nils Walravens graduated cum laude as Master in Communication Sciences at the Free University of Brussels in July 2007 with a thesis on the introduction of High Definition Television in Flanders, from a political economy perspective.

Nils started working for imec - SMIT - VUB in August of 2007 as a researcher in the Media, Market & Innovation cluster. His main expertise is in the field of business modelling research in both the mobile and media industries. He has been involved in short-running consultancy assignments, national imec projects and European FP6, FP7 and H2020 projects.

In 2011, Nils started working on a 4-year Prospective Research for Brussels project, funded by Innoviris and the Brussels Capital Region. The aim of the project was to define policy recommendations related to business models and platformization of mobile city services, in the context of the ever-evolving mobile sector. This research led to a PhD on Smart Cities and the public value that could be created from mobile apps, which Nils successfully defended in October 2016. He is now working as a senior researcher in the Smart Cities team at imec - SMIT - VUB and coordinates the Smart Flanders project.
New plastic chip in the making that communicates with touchscreens

Imec and Cartamundi, the manufacturer of board games and playing cards, are developing a revolutionary new technology, plastic C-tokens, for short-distance communication.

Imec was recently in the news with a plastic NFC* chip that enables all sorts of objects (that have an NFC chip built in) to communicate with tablets and smartphones. Like RFID and QR, NFC is a technology that links objects with one another over a short distance. Imec and Cartamundi, the manufacturer of board games and playing cards, are developing a revolutionary new technology for short-distance communication. It involves plastic C-tokens capable of interacting with any touchscreen. Better still, they’re flexible, thin – and inexpensive. Sarah Schols (imec) and Steven Nietvelt (Cartamundi) talk about their plans.

* NFC: Near Field Communication; RFID: Radio Frequency Identification; QR: Quick Response; C-tokens: Capacitive tokens.

Why put chips in playing cards?

Steven Nietvelt is Chief Technology and Innovation Officer at Cartamundi and loves playing cards: “My favorite game is ‘Rikken’, a variant of Whist. Every Wednesday – and we’ve been doing this for over 30 years – I get together with some of my childhood friends for an evening of Rikken. We always have a really great time!”

And in doing so, Nietvelt is underlining the trend: card and board games bring people closer together. And particularly these days, in times of smartphones and the Internet, people seem to have an additional need to do so. Nietvelt: “Board games are experiencing a genuine revival. They have really come back – especially at parties or on vacation – because it is so much nicer to play a game together than for everyone to sit on their own, staring at a smartphone screen.”

So, where does the need to give board games and playing cards a digital component come from? Nietvelt: “We at Cartamundi believe that we can give games an extra dimension by involving a smartphone or some other form of display screen. This is definitely the case if we want to get the ‘smartphone addicts’ – or those youngsters who seem to have been born with a tablet in their hand – round the table together. You can either pine for the days when kids still played soccer outside (instead of playing FIFA on their PlayStation) or cowboys and Indians (instead of Grand Theft Auto)... or you can do something about it!”
“A good example is Pokemon Go, which is an app that encourages youngsters to get outside. There’s also the game Speak Out – the hit of the year – which is a great blend of the traditional game and new media. The games consists of trying to read out sentences or sayings through a mouthpiece that distorts your voice, while the person you are playing with tries to guess what you are saying. Millions of videos featuring people with mouthpieces have already been shared, usually accompanied by hilarious pictures. Which goes to show that the young (and the old) are prepared to play games with a little extra digital something, provided it stays social and fun.”

In addition to his head office in Turnhout, Cartamundi has also opened a branch in Ghent: Cartamundi Digital. This is where a.o. the Shuffle series was developed – a new generation of card games with that something extra. Nietvelt: “Often it’s a card game that can be played in conjunction with an app. If you bring the card close to your smartphone or tablet, additional information may appear, such as a video in which it looks as though your card comes to life, complete with sound, etc.”

Depending on the specific application, Cartamundi chooses from a range of technologies, including image recognition using the smartphone camera, barcodes, RFID chips embedded in the card, etc. Nietvelt: “In casinos we use cards with RFID chips so that the playing table ‘knows’ which cards are on it. This is important in major tournaments where a constant picture of the table (and the cards in the hands of the players) is displayed during live TV broadcasts.”

And Cartamundi is always looking for new ways of getting cards to communicate with smartphones or with display screens in general. Or to have playing pieces and dice communicate with the game board. Which is how they ran into imec in 2009. Initially for a feasibility study and then for two Flanders Innovation and Entrepreneurship (VLAIO) projects and also two EU projects: ORCA (Oxide RFID enabled gaming cards), WOOPI, PING and CAPID (Capacitive Identification Tokens).

Cartamundi produces card games with a little digital extra. That’s why they are always looking for technologies able to provide a link between the paper and the digital world.
Silicon or plastic?

The RFID tags (currently) used by Cartamundi in casino cards are made from silicon. But there are other ways. Sarah Schols, R&D Manager Thin Film Electronics at imec, explains: “Silicon technology is behind the success of the chip industry. But you can also make chips by printing thin layers of metal oxide on plastic. Of course these plastic chips will not replace the silicon chips in our smartphones and computers, but they are the best choice for other applications. Namely where you need very cheap, thin, flexible chips. Pallets in logistics are being tracked currently using a silicon RFID chip, but if you want to track every object on that pallet individually, you need cheaper (metal oxide) RFID labels. Or, if you want to produce an affordable deck of cards with RFID chips in each card, metal oxide technology is definitely a step forward. And with oxide tags you can also make the cards just as thin and flexible as traditional ones.

Imec has been working on the development of plastic chips for over 10 years. In 2012, the R&D center hit the world news with the first ever fully functional plastic microprocessor. Key for the researchers is to develop a technology that is compatible with industrial manufacturing. To do so, they collaborate with partners that today manufacture plastic displays (for smartphones, televisions...) and that are ready to take the next leap and start producing plastic chips for logistics and other applications. Schols: “A first challenge is to make our plastic chips more energy-efficient. Today, they typically use 10 milliwatt, but our ultimate goal is to lower that down to 10 microwatt and even lower. So we want our chips to be a 1000x more energy-efficient, a goal we’d like to reach within five years. As a second challenge, we want to make the thin-film transistors, the building blocks of our plastic chips, faster. We’ve already managed to reach the speeds needed for RFID communication, and recently even for NFC communication, which is really formidable. And as a last challenge for our plastic technology, I’d like to mention the design of circuits. To our luck, we have an enormous body of expertise in designing silicon circuits that we can leverage. Where we have 1,000 transistors per circuit today, we want to reach 100,000 in five year’s time. With that number of transistors, we’ll be ready to make plastic tags for the Internet of Things, such as sensors with integrated circuits for computations. Of course, silicon chips to that already today, but plastic chips are flexible and – most important – much cheaper!”

Thin film microprocessor on plastic film.
RFID, NFC, QR & Capacitive tokens

At the moment there are various different technologies for short distance communication. Schols clarifies: “Most of us know QR codes as the two-dimensional barcodes you see on business cards and flyers. The disadvantage is that you have to be able to scan the code accurately using the camera on your smartphone and you can’t add any extra intelligence to it. They link to a specific website and that’s it. And from an aesthetic point of view QR codes are not always possible. They can’t be integrated ‘invisibly’.”

“RFID chips exist in both silicon and oxide technology. The RFID tag can be scanned by a dedicated RFID reader that has to be brought close to the tag. NFC (near-field communication) tags – also in silicon or oxide technology –can be scanned by any recent smartphone or tablet. Once again you need to place the tag and reader close together.”

NFC and RFID are used in packaging to keep the logistics chain running smoothly. They also work for brand protection (scan an expensive piece of clothing with your smartphone and you’ll find out whether it’s a fake or not); marketing (scan a bottle of wine to see a video about the winemaker); and Cartamundi card games. Schols: “It really becomes interesting if you are going to combine the NFC or RFID circuits with sensors. One good example are disposable diapers with a moisture sensor and tag: the person looking after a group of small children can place her smartphone close to the diaper and the tag will indicate whether the diaper is wet or not.” This enables you to ‘scan’ a whole crowd of kids quickly so that you have more time to have fun playing with them.

In the future, crèches are likely to use diapers fitted with a moisture sensor and (NFC) tag: all the carer has to do is place her smartphone close to the diaper and the tag will tell the smartphone whether the diaper is wet or not.
Sarah Schols: “We are currently working – together with a.o. Cartamundi – on a new technology as part of the European CAPID project. In this case, the labels are oxide-based C-tokens or capacitive tokens. These are very small because they do not need an antenna. In fact they don’t use radio waves, but work with capacitance variation. Because they don’t have an antenna, they are potentially cheaper than RFID and NFC labels. These tokens can communicate with any touchscreen, although they have to be placed on the touchscreen – i.e. not at a short distance, as is the case with RFID and NFC. You could use the tokens in admission tickets (because then they are harder to fake and thus more secure), or for payments (apply your bank card to the computer screen to make a payment), or in playing pieces and dice combined with a playing board made of a display screen. Capacity technology is also of great interest for the Internet of Things, because you can then have every object (that has a capacitive token) communicate with the display screens in the vicinity. It’s important to notice that this new technology will exist next to NFC and RFID labels. For many applications it is more convenient to scan from a short distance instead of having the direct contact necessary for C-tokens. Depending on the distance needed to communicate, the most suitable technology will be chosen. Having all these different technologies at your disposal will allow to efficiently link the objects making the Internet of Things.

The future of playing cards and board games

So there are still plenty of new opportunities that Cartamundi and its customers (Hasbro, Mattel, Disney, Konami, Ravensburger, McDonald’s, Wizards Of The Coast, etc.) can use for their games. We also asked Nietvelt to look into his crystal ball: how will card and board games evolve? Nietvelt: “Traditional card games will continue to exist. They are still the most-played games in the world (especially in countries such as Spain, Italy and in South America and Asia, where people sit outside a lot or get together in a café). We are also doing very well with our Shuffle series of games where you can play a card-based version of Monopoly, Guess Who, etc., combined with an app. People like to be able to play a quick, compact game with simple rules. Most of us don’t have a lot of spare time and don’t want to spend hours sitting around playing a difficult board game. The combination of card games and digital techniques will be sure to play a role in the future. For example, it would be very interesting to be able to play Trivial Pursuit with questions updated online or with extra video and audio clips. Or imagine Monopoly keeping pace with the latest news, with house prices changing, for instance, because of the changing airplane routes above the city. Or maybe we’ll even be able to play Monopoly remotely, with Dad taking a Monopoly card game away with him on a business trip so that he can play a game with his kids in the evening by interacting with the computer screen or TV in his hotel room. No one really knows what the future will bring, but I believe that traditional card and board games will continue to exist, boosted by a nice little digital extra. There are countless possibilities and with new technologies such as oxide tags, a whole new world will open up for game inventors.”
Want to know more?

- Read the press release about the NFC chip that imec, Holst Centre and Cartamundi presented at the ISSCC conference
- Get an overview of Cartamundi’s technologies on this website
- The PING project is funded by the European Community as part of the Horizon 2020 research and innovation program (grant agreement n° 644331).
- The CAPID project is funded by the European Community as part of the Horizon 2020 research and innovation program (grant agreement n° 732389).
- The ORCA and WOOPI project was funded by VLAIO (Flanders Innovation and Entrepreneurship). (ORCA project number: 130993).

---

**Biography Sarah Schols**

Sarah Schols was awarded her PhD in electrical engineering in 2009 from the Katholieke Universiteit Leuven, Belgium. Her Doctoral Research, which was funded by the Belgian Fund for Scientific Research (FWO), focused on the design of new device architectures and material concepts for organic light-emitting devices. Currently, she leads the Thin Film Electronics group in the Large Area Electronics Department at imec, focusing on organic and oxide electronics on film.

---

**Biography Steven Nietvelt**

Steven Nietvelt studied Industrial Engineering at Groep T, followed the MBA course at Flanders Business School and a Masterclass in Innovation at Vlerick Business School. For more than 20 years he has worked for Cartamundi and contributed to the growth from 30 million to almost 400 million Euros of turnover. Steven took many management roles within the company at the HQ in Turnhout but also in Cartamundi USA. Today he is Chief Technology and Innovation Officer, overseeing the global technology and innovation activities of the group.
On January 28, a Soyuz rocket successfully launched the HISPASAT36W-1 satellite from the European Space Agency’s launching site in Kourou, French Guyana. The HISPASAT36W-1 is an innovative communications satellite to be positioned in a geostationary orbit, 35,786 kilometers above the Earth’s surface at a position of 36 degrees West. Once in place, it will provide relay coverage and multimedia services across Europe, the Canary Islands and South America at the service of Hispasat, a world leader in Spanish and Portuguese broadcasting. The satellite’s electronics contain an impressive 645 chips to which imec has contributed. “And it is the first flight mission of chips designed with imec’s DARE (Design Against Radiation Effects) platform,” explains Steven Redant, ASIC Design Services Manager at imec.IC-link, imec’s industrial service for innovative chip design and fabrication.

The Hispasat36W-1 satellite is the first to use SmallGEO, the Small European Geostationary Platform developed under the ARTES program of the European Space Agency (ESA). With SmallGEO, the satellite’s German manufacturer OHB hopes to produce its next satellites faster, at lower cost, and with a great flexibility. SmallGEO is highly modular, and satellites based on it can be fitted to the customer’s requirements without major modifications to the design and with various types of payloads, e.g. for telecom but also for earth observation. Also, future SmallGEO satellites will be able to use full electric propulsion to get into orbit. This will substantially reduce their weight, as they no longer need to carry additional compressed gas.

The payload of Hispasat36W-1 is the RedSAT telecommunication system commissioned by Hispasat and developed in collaboration with ESA by a Spanish consortium.

“Compared to conventional telecom systems in satellites, RedSAT makes a much more agile and efficient use of the on-board power and bandwidth,” says Steven Redant. “This improves the service to end-users because they can do with smaller terminals and can have communication among users in a single satellite hop. Moreover, RedSAT slashes the conventional satellite signal delay - or latency - by half, which greatly boosts real-time applications such as videoconferencing. All this thanks to RedSAT’s on-board signal regeneration and its active antenna.”
Improving transmissions in space

In traditional telecom satellites, the incoming signals are basically echoed: they are transmitted unchanged and always at the same power, irrespective of, e.g., the available channel or the weather conditions. But this consumes too much energy under all but the worst-case conditions. Moreover, errors in the uplink signal are resent and compounded with additional downlink errors.

Not so in the Hispasat36W-1 satellite, which uses a so-called ‘regenerative technology’ that adapts the signal power to the circumstances and corrects uplink errors before retransmitting the signal. This allows the satellite to operate at a lower power budget and transmit a signal that needs fewer error-correction coding, which improves the satellite’s throughput. In addition, the available on-board computation simplifies the ground station processing. The result is a much simpler network, optimizing the size and power of the user terminals and simplifying links that would normally require a double hop, thereby reducing signal latency and providing better real-time services.

To pull this off, the satellite contains 23 transponders, 20 in the Ku band and 3 in the Ka band, two microwave bands used for satellite communication. These receive signals from satellite ground stations, regenerate them, and transmit them on the downlink frequencies to receivers on Earth.

Steven Redant: “At their heart, these transponders contain the Knut chip. Knut is a radiation-hardened mixed-signal ASIC that carries out pulse width modulation for the transponder’s traveling wave tube amplifiers, specialized vacuum tubes used to amplify microwave signals. Knut was commissioned by TESAT Spacecom (market leader in telecom payloads for satellites), financed with the help of DLR (the German Aerospace Center), and, for all but the digital functional description, designed, fabricated and qualified through imec.IC-link.”

“We provided the digital cell libraries to radiation-harden the digital part of the chip: our DARE libraries for the UMC .18um technology. But apart from that, we also designed the analogue blocks, synthesized the chip and made its layout. And we managed and oversaw the chip manufacturing at UMC and the full flight model lot qualification. With this launch, we are at TRL 9 (Technology Readiness Level) for our DARE UMC .18 platform. It means we have shown to companies and institutions in need of radiation hardened chips that imec.IC-link has the knowledge, flexibility and solutions to assist them in all stages of their chip realization.”
**Steering the active antenna**

The second major difference with comparable communication systems is RedSAT’s antenna, nicknamed ELSA (ELectronically Steerable Antenna). It’s the first such active antenna for a commercial communications satellite.

An active antenna is an array of smaller physical antennas that together create a directed beam of radio waves, a beam that can be electronically steered to point in different directions without physical movement. It does so by feeding the radio signals to each individual antenna adding a computed phase shift. The result is that the emitted waves from the separate antennas add together to increase the radiation in a desired direction, while they cancel each other to suppress radiation in undesired directions.

ELSA is managed by a number of hybrid electronic modules, each containing four analog and twenty digital ASICs. In total, the antenna has 622 chips, 102 analog and 520 digital.

Steven Redant: “The use of such a large quantity of ASICs in a single mission is a remarkable technological milestone. A milestone to which imec contributed by assisting in the realization of both antenna chips, which were commissioned by Arquimea, the Spanish electronics integrator for its end-customer Airbus.”

“The analog ASIC was implemented in a 0.35um technology of On Semiconductor (Belgium). It is a high-voltage chip, for which we provided technology and hardening advice, did a design review and managed the manufacturing. Arquimea designed and qualified the chips, which then were mounted into hybrid modules by Airbus. The second, digital ASIC, also designed by ARQUIMEA, was fabricated in the 0.18um UMC technology, again using imec’s DARE radiation-resistant digital cell libraries. Here, we’ve also done the layout and adapted the IOs to the requirements of the hybrid module. Such flexibility is an important asset in our offer.”

**What’s with imec and radiation-hardened electronics?**

Chips used in spacecraft, airplanes and also e.g. in high-energy physics experiments are prone to failure or intermittent errors caused by effects of radiation in the environment where they operate. To be hardened against these failures and errors, they have to be designed in a specific, nonstandard way.

“But here’s the catch,” says Steven Redant. “Chips for space applications are not produced in the volumes that are commercially interesting for foundries. Therefore, many foundries that used to have technologies specifically for radiation-hard ASICs have left the market. To provide a high quality alternative, we developed the Design Against Radiation Effects platform, with the support of ESA. DARE is a combination of digital cell libraries, methodology support for analog design and the re-use of previously designed analog IP blocks. With DARE, we have the basis to design competitive, high-performance, low-power solutions for non-military applications that will operate in environments with harsh radiation.”
“In addition to using the available building blocks, our experts can develop custom-defined and application-specific blocks, all with the proven DARE hardening techniques. And we can also port the hardening concepts to other technologies and nodes. Examples that we’re currently focusing on are XFAB .18 XH technology for space projects and building blocks in TSMC technologies for use in high-energy physics experiments. We have also built an analog DARE environment for On Semiconductor’s I3T80 process, and we have started DARE activities in 65nm TSMC technology.”

Designing chips is one thing, being able to help customers wherever they lack expertise is another one altogether. Imec.IC-link has made it into its hallmark to provide customers with specialized expertise on the path from idea to electronic application. This includes among others selecting the appropriate technology, designing and reviewing designs, prototyping, but also providing access to the world’s most advanced foundries for volume production.

Steven Redant: “And as we’ve demonstrated with the Knut chips, we have extensive experience in the field of space evaluation (ESCC2269000) and qualification (ESCC9000). This includes developing and customizing the hardware required for screening the flight modules, such as test load boards, packages and sockets as well as managing the whole supply chain.”

**Want to know more?**

Soyuz Flight VS16 with Hispasat 36W-1

---

**Biography Steven Redant**

Steven Redant joined imec in 1989 as an application specific integrated circuit (ASIC) design engineer. He designed ASICS for, amongst others, space and medical applications, taught the use of VHDL as a design and verification language and was involved in the radiation-hardening-by-design proof-of-concept until in 2000 he became group leader of the design team. He has led the path of concept to the current DARE platform offer. His design team also provides chip design services for imec scientific demonstrators as well as for industrial applications.

imec.istart
Ava & Trix: the classroom digital game showing children the fun side of science

‘Ava & Trix’ is supported by the imec.istart entrepreneurship program.

Getting young children to like science and technology can be a challenging task for teachers. Not only it isn’t a subject most kids are usually keen on learning, but current educational methods are also generally not enticing enough to spark their curiosity. With their videogame ‘Ava & Trix’ – supported by the imec.istart entrepreneurship program – Jill Vanparys, Michèle Vanparys and Dieter Honoré want to help schools stimulate children’s interest in this field. The app is already being used by over 300 schools in Flanders.

The story behind Ava & Trix

Even though her highest grades in high school were in science and math, the lack of motivation to pursue a career in this area led Jill Vanparys to choose a design major at university. However, she always felt that if these subjects had been presented to her in a more compelling way, her choice might have been different. Committed to address situations like hers, Jill joined her sister Michèle and Dieter Honoré to create Curious Cats, the company behind Ava & Trix: a story-driven app for boys and girls between 8 and 11 that encourages them to experiment with science and technology in the classroom in a fun way.

After securing funding from VAF/Game Fund – the Flemish fund for the development of videogames – the founders started developing the app, in September 2015. One year later, the first three episodes of Ava & Trix were launched.

A clumsy cat teaching children to think like scientists

Ava & Trix is a series of three episodes, each lasting two to three hours. It tells the story of two sisters (Ava and Trix) who need to solve the problems created by their clumsy cat, Donder, using the elements – such as matches or oil – they have collected during the game.

“In most tools used to teach science and technology at schools, children are basically repeating the experiments the teacher has showed them beforehand,” explains Dieter Honoré. “With our app, students are the ones that need to come up with - and test - the possible solutions to the proposed problems. More than scientific knowledge, our goal is to foster scientific thinking: formulating hypothesis and experimenting to confirm the result.”

But that’s not the only reason why Ava & Trix stands out from other apps. “We wanted to connect the digital and the physical world,” continues Dieter. “The objects that the characters need to solve the problems can easily be found in a classroom. We encourage children to first try the different approaches in class and only then insert the solution in the app.”
Proving that girls can also be scientists

It is no coincidence that the main characters of Ava & Trix are girls: “We wanted to foster scientific vocation in girls, by creating hip, female lead characters that are curious and adventurous. However, so that the boys wouldn’t feel overlooked, we tried not to make the sisters too ‘girly’ and also included strong, supporting male characters, which accompany the girls in their adventures.”

The believers

After VAF/Game Fund, the entrepreneurs were accepted in the imec.istart entrepreneurship program. Next to the financial support – which was crucial in the early stages of development – Dieter Honoré welcomes the unique imec network, which has helped them raise awareness for their project and connected them with potential partners and clients.

The start-up also secured funding from a group of Belgian entrepreneurs who strongly believe in the project’s potential.

First achievements and next steps

The development of the game was done in close collaboration with several schools in Flanders – both teachers and students – which tested and provided feedback on every new feature. This was key to ensure the scientific accuracy, educational potential and overall success of the app, which is already being used by more than 300 schools in Flanders. The start-up also partnered with several Belgian companies who have agreed to donate the app to schools as part of their Corporate Social Responsibility programs.

The founders are now looking to get 300 more schools in Flanders on board, in order to be able to start developing the next episodes of Ava & Trix. “We want to make sure we are successful in Flanders before we take the project abroad,” states Dieter.

Other projects

The early success of Ava & Trix has also landed the Curious Cats’ team with several other projects. These include a partnership with imec and RVO Society for a game that explains electrical circuits to children. Moreover, together with UZ Ghent, the start-up is developing a game to help teenagers cope with depression, which should work as a complement to traditional therapy.

Currently looking for new customers, Dieter Honoré states the team only has a few requirements: “We want our games to be beautiful and fun at the same time. We want to make children discover themselves and the world around them.”

Meet the founders

Jill Vanparys is the graphic designer at Curious Cats. Before launching the company, in 2002 she was one of the founders of Echtgoed, a graphic design agency. Thanks to Ava & Trix, in 2016 she was recognized as one of MIT Technology Review’s Innovators Under 35 in Belgium.
**Michèle Vanparys** is the illustrator at Curious Cats. Having graduated from KASK in 2006, she has worked as a freelancer for commercials, music videos, online games and generics of television programs, as well as illustrations for books, packaging and branding.

**Dieter Honoré** is the legal and business mind behind Curious Cats. With nearly 20 years of professional experience in Law, finance and sales, he also has a strong entrepreneurial background, having worked as a career and a start-up coach before joining the Ava & Trix project.

**Want to know more?**

Visit the website of Ava&Trix to learn more about their project: [https://ava-trix.com](https://ava-trix.com)