IMPACT

TOWARDS MORE EFFICIENT USE OF GREEN ENERGY

InRel NPower

InRel-NPower project

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Towards more efficient use of green energy

*Gains from green energy production are lost if power distribution and use is wasteful, so the **Innovative Reliable Nitride based Power Devices and Applications (InRel-NPower)** project is developing the technology to make these systems cheaper and more efficient*

The reliance of the world on electrical energy is already huge and will only get bigger. Currently, up to 40 per cent of the world's energy use comes in the form of electrical power and is expected to reach 60 per cent in the coming decades. While a large segment of scientific research is focused on producing cleaner and renewable electrical energy, a second segment of equally important energy research is simultaneously working to address the problems of electrical waste and efficiency.

Reducing the overall amounts of electrical energy needed to serve our current and future demands would be a key pillar of any energy strategy moving forward. Increasing efficiency of our electrical infrastructure frees up more energy to be used by consumers and relieves pressure on the power stations needed to produce it in the first place. Right now, one of the biggest ways we can reduce demands on electrical energy, is first of all, don't waste it.

There is a significant amount of energy lost to waste whenever electricity is converted, which occurs daily. Electrical conversions are required for a variety of appliances, often going from 220V mains to 12V DC, or within machines like electric cars where the DC current produced by the battery must be converted to AC for the motor drive, for example. The devices at the heart of these conversions are transistors. Unfortunately, the current silicon-based devices that have been used for around 50 years are reaching their limits in terms of power conversion and this is resulting in wasted energy in the form of heat and higher consumption. To combat this problem, devices based on materials other than silicon, for example gallium nitride (GaN), aluminium nitride (AlN) and silicon carbide (SiC), are being developed and these new transistors have the potential to be significantly smaller and more efficient.

COST AND RELIABILITY HURDLES

Gaudenzio Meneghesso, Professor in the Department of Information Engineering at the University of Padova, Italy, and the coordinator of the InRel-NPower project, has been working in the field semiconductors and power electronics for a long time. 'In 1998, I started to work on the study of GaN based High Electron Mobility Transistor devices,' he says. 'Together with my research group, we saw a great opportunity to become a worldwide reference group on the characterisation and reliability investigation of these devices.' Specifically, Meneghesso is working on what are known as devices made with wide bandgap (WBS) semiconductors, or more simply, electronic devices based on materials like GaN and not silicon.

'The GaN based devices developed within our project will be able to operate at high temperatures, frequencies and voltages, all of which helps to eliminate up to 90 per cent of the power losses in electricity conversion compared to the current technology,' explains Meneghesso. 'Furthermore, power electronics that use WBG semiconductors have the potential to be smaller, perform better, to be more efficient and to cost less.' Meeting such energy saving targets is an important challenge for most industrialised nations and work on this technology has been going on for a while, however, a few hurdles remain. Mainly, this technology is confronted with issues of cost and reliability and it is the goal

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of InRel-NPower to overcome these issues and bring WBG semiconductor devices into widescale usage. The project aims to develop reliable GaN based devices and systems that can be used in high and medium power electrical systems. Their first targets are for industrial applications, but results will also be beneficial for automotive, avionic and renewable energy systems. Moreover, the overall goal is bringing these devices one step closer to being fully incorporated into the energy saving environment.

A BOTTOM UP APPROACH

The project is designed to meet its goals using a bottom up cascade methodology. 'Every work package (WP) provides material for the subsequent packages, and in return, receives valuable feedback on the developed structures,' says Meneghesso. The first team covers the techniques of overlaying the GaN materials onto a substrate, which is used as the basis for a device. The development of the device continues in the next work package. Work package two aims to develop processes and characterise the GaN power devices. The work packages are designed with a fast feedback loop, such that the results from the subsequent steps and new findings can be picked up immediately. Thanks to such a structure, the project gains a dynamic character. Next, specific limitations and reliability issues are identified in WP3, so the final WP can develop two innovative packaging systems and two demonstrators in order to fully exploit the potential of the GaN devices.

This tight structure is key to the project's success and hinges on collaboration with several labs and industry partners from Europe and Japan. The unique structure works in part because Meneghesso strongly believes collaboration is essential to any project, large or small. Recent successes have seen teams in Belgium making progress on the optimisation of the starting material required for device development using several high grade sapphire templates provided by the groups in Japan. Progress has also been made on increasing breakdown voltages of some device components, a big step in making them more reliable. Understanding materials in their very interior and identifying new sophisticated ways of analysing the influence of defects on reliability, requires very intensive collaboration. According to Meneghesso, these reliability studies will be crucial to gaining widescale acceptance of the technology: 'our reliability studies and qualification will provide a great contribution towards the market penetration of these devices in industrial applications'.

A BRIGHT ENERGY FUTURE

'Energy not only needs to be produced in environmentally-friendly manners, but it should also be distributed and used efficiently,' says Meneghesso, and for him the future is bright: 'I see even more research activities in the near future on the development of technologies that will create more efficient systems to address the great challenge of energy saving.' Meneghesso's optimism is reflected in the activities of the InRel-NPower project itself. Last year, the project was enthusiastically presented at the European Centre for Power Electronics forum on the potential of WBG semiconductors in power electronic applications. Roughly 240 people were present, many of whom walked away carrying brochures for the project. They have also produced a short video for YouTube about the project and the energy challenges facing Europe. Plus, they are active on social media, sharing research and engaging with users from inside and outside the field of power electronics.

Always with an eye on the future, the project will also host its second summer school. The workshop, taking place in Ghent, Belgium, will feature content based on results obtained in the InRel-NPower project. The aim of the summer school is to inform and engage both young and experienced researchers alike. Spreading the message of the importance of this work and recruiting young minds to the field goes hand in hand with Meneghesso's beliefs on collaboration; different groups will see problems and solutions differently, which ultimately leads to the best ideas coming forward and bright ideas are indeed welcome and needed. ▶

Project Insights

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PROJECT COORDINATOR BIO

Gaudenzio Meneghesso graduated in Electronics Engineering from the University of Padova, Italy, in 1992, working on the failure mechanism induced by hot-electrons in MESFETs and HEMTs. Since 2011, he has been a Full Professor at the University of Padova. His research interests involve mainly the electrical characterisation, modelling and reliability of microelectronics devices. Within these activities he has published more than 800 technical papers (with more than 100 Invited Papers and 12 best paper awards). He has been nominated to IEEE Fellow class 2013, with the following citation: "for contributions to the reliability physics of compound semiconductors devices". More information can be found at: www.meneghesso.it.

InRel NPower

Impact Objectives

- Develop robust and efficient alternatives to silicon based semiconductors for high and medium power electronics systems
- Overcome the key issues of cost and reliability so as to move gallium nitride (GaN) semiconductors one step closer to being fully incorporated into the energy saving environment
- Work towards proving the reliability of the GaN semiconductors, so as to move towards market penetration of these devices in industrial applications

A new class of green energy

Semiconductor devices built without the use of silicon, instead using other materials such as gallium nitride (GaN), have the potential to outperform their silicon predecessors while being a fraction of the size. ***Gaudenzio Meneghesso*** *discusses his work to overcome the challenges involved in developing this new technology*

Could you begin with a brief explanation of the overarching objectives of the InRel-NPower project?

The global strategic target of this project is to help to address important and globally relevant social issues, such as electrical energy savings, sustainability in energy consumption and measures against climate change. The InRel-NPower project in particular is about developing robust and reliable gallium nitride (GaN) and aluminium nitride (AlN) based power devices for high and medium power electronics systems, targeting energy conversion efficiency applications and bringing the wide bandgap semiconductors (WBS) power devices another step towards broad applicability in the energy saving environment and exploiting the full potential of this semiconductor material.

Why GaN-based power devices? Could you explain more about their energy saving capabilities?

Wide bandgap semiconductors such as silicon carbide (SiC), GaN, AlN and diamond show superior material properties compared to silicon; specifically, higher maximum current densities, breakdown voltages and temperatures of operation. Due to these unique characteristics, WBS allow the realisation of transistors that have performances 10 to 100 times better than the silicon-based power transistors. In other words, you may have devices that, for the same current and voltage levels, can be 10 to 100 times smaller than the Si-based devices, allowing for the reduction of many parasitic elements and consequently reducing power losses. This paves the way for systems with efficiency higher than 99 per cent and, at the same time, much smaller sizes than those currently possible with silicon devices.

Can you expand on current problems relating to GaN-based power devices and systems – what issues with existing systems and gaps in understanding are you trying to address?

Today, the great issue associated with the GaN is related to its relatively new and not well-assessed technology. There are four major challenges to be faced to bring this technology to a maturity necessary for industrial level applications. First, is the production of GaN substrates with high material quality. Second, to process devices with innovative architectures. Third, to be able to demonstrate the superior performance and robustness with respect to the current silicon-technology and fourth, to produce the new devices based on GaN technology at a cost comparable to those based on silicon technology. Our project will address all these major challenges.

How important is collaboration to the success of your work?

I am convinced that collaboration and the exchange of both experience and data is one of the most important ingredients to achieving success in any research activity, at any level; from a single research lab to the largest European project with many partners. The sharing of expertise from different groups, that very likely analyse the problems from a different perspective, helps considerably in reaching the objectives, with a higher probability of success.

What new device concepts has the project formulated so far and how are things progressing in terms of evaluating and testing their reliability and robustness?

Special focus has been given to reducing current leakage, through optimisation of the epi buffer stack and the layout of the device. It is believed that local removal of the silicon substrate under these drain contacts will substantially reduce the off-state leakage current, and thus will have a positive impact on reliability. Likewise, replacing the silicon substrate with AlN, a WBG material, should improve current leakage and thermal dissipation.