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_ 1 Acoustics Research: Altering sounds and minimising noise _ 2 Mechanical Engineering: Reusing heat _ 3 Theoretical Quantum Physics: Developing high-performance computers using qubits _ 4 Biology: Research into the regeneration of the rainforest

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Electricity from nanochannels

Our world produces heat around the clock – through the operation of smartphones, heating systems, servers and factories. In the field of nanotechnology, a team of researchers at TU Darmstadt is finding a way to better utilize this heat for the generation of electricity and thus making a contribution to sustainability.

By Boris Hänßler

Every time that we play a YouTube video or simply google a word, a little heat is created in the computer centres located around the world. A robot arm that welds together car parts in a factory, a truck and naturally our own bodies all produce heat. This heat only makes a small contribution to global warming but it is also energy. Around 70 percent of the heat that is produced by people disappears unused into the atmosphere. While large industrial plants use heat as a source of energy, it has not yet been worthwhile to convert this type of energy at temperatures less than 100 degrees Celsius. Converting waste heat into electricity using current technologies is an inefficient process. As well as being scarce, the materials needed for this process are expensive and not environmentally friendly.

"Our cooperation could lead to a new, highly efficient technology for the utilization of low-grade waste heat that will have an enormous impact."

This situation could change in the future. The first steps in this direction are being taken in an unusual field of research in the Department of Mechanical Engineering at TU Darmstadt: Professor Steffen Hardt and his team are conducting research into fluids at the nano and micrometre scale – often without focussing on the specific types of application for which their findings could be relevant. The researchers are aiming to break new ground and trying to understand how liquids and gases behave in different states and environments at small scales. And one of the phenomena that the researchers have observed has now attracted the attention of energy researchers. This is because it has the potential to allow electricity to be generated from lower temperature differences more efficiently than ever before in the future – using cheaper and more sustainable materials.

The phenomenon observed by the researchers is similar to a familiar effect: When a thermoelectric material is exposed to a temperature gradient, electrons flow from one end to the other – generally from warm to cold. This creates an electromagnetic field and thus a voltage. The greater the difference in temperature, the higher the voltage that is produced. "However, these types of thermoelectric materials are not especially efficient", says Steffen Hardt. "This means that they can only convert a small fraction of the heat into electrical energy, which to some extent is due to the principal limitations of the physics behind the process." These materials are also difficult to produce and require the elaborate process of atomic layer deposition in some cases. Such technologies are not suitable for broad applications.

Using theoretical models the researchers have now discovered that an ion flow can be created in certain structures with overlapping so-called "electric double layers" when exposed to a temperature gradient. These types of nanochannels have a diameter of around 10 nanometres. They are thus smaller than, for example, viruses – the coronavirus is around 100 nanometres in size. If there is a saline solution in these nanochannels, the ions located near to the wall create a charged layer within the fluid. This layer expands as the temperature increases, which causes the ions to move when one end of the tube is warmer than the other. This motion also generates an electrical field. The voltage produced is, however, many times higher than the one due to the so-called Ludwig-Soret effect. The latter describes the movement of electrolytes due to a temperature gradient. However, the researchers still face considerable challenges before this conversion process in nanochannels can be used in practical applications. The physics is extremely complex due to various superposed phenomena and it is not yet clear how to design systems where the efficiency of the energy conversion process is optimised. In addition, it tends to be difficult to produce tailor-made nanostructures based on theoretical findings.

"Our research in this field was initially based on purely theoretical and knowledge-driven investiga-

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tions that allowed us to discover this phenomenon", says Hardt. "But this was completely uncharted territory for us and we did not have any plans in the beginning for how to put the theory into practice. We lacked the experimental capabilities for this purpose." His team at the institute is not able to produce the nanonchannels required for the research. But then Justin Holmes, Professor of Nanochemistry and Head of the Materials Chemistry & Analysis Group (MCAG) at University College Cork in Ireland, became aware of the work published by the team at TU Darmstadt. His group has just the right facilities to develop these types of materials.

Subhajit Biswas, a researcher in Holmes' group says: "When we came across the theory paper on the conversion of heat in a confined electrolyte solution, we realised that combining this theoretical knowledge with University College Cork's expertise in materials, membranes and heat-to-electricity-conversion technology could create a new and highly-efficient low grade waste heat harvesting device with enormous impact."

Holmes proposed to Hardt that they should work together to push forward the research and apply for one of the highly sought-after EU Horizon grants – with great success. The project named "Translate" was recently awarded funding of 3.5 million euros from the EU Horizon 2020 "EIC Pathfinder Open" programme. The University of Lithuania and the Spanish company Cidete Ingenieros S.l., a specialist in thermoelectric technology, are also involved in the project. The initial aim of the "Translate" project is to develop a theoretical model for how ions move through nanochannels. The researchers are using computer simulations for this purpose. A special focus is being put on the processes that occur at the walls of the nanochannels. The researchers plan to gradually optimise the architecture of the channels and also the materials used to produce them. Furthermore, the system should not only be able to convert energy but also store it.

Any future applications will ultimately depend on, among other things, how expensive the materials and the resulting structures are. Possible materials include, for example, aluminum or silicon. At the University of Maryland in the USA, they are carrying out research into a cellulose-based material that is much easier to procure and thus has a better environmental footprint. A realistic application could be, for example, converting the exhaust gas heat from HGVs into electricity to power the onboard computer or the vehicle lights. This would reduce the consumption of fuel.

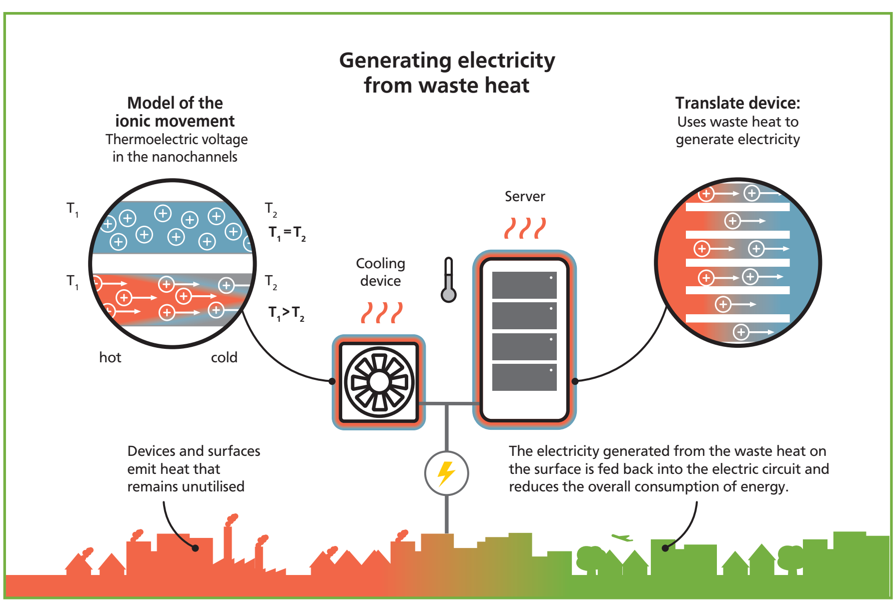
Photo: Katrin Binner

However, also IT companies are aware of the potential offered by this type of research. For example, Facebook operates a large computer centre covering an area of 50,000 square metres in Odense. Air conditioning systems are used to cool the servers and maintain the temperature at below 30 degrees Celsius in these types of computer centres. The hot air is often released directly into the atmosphere. The company recently joined forces with the local supplier of district heating Fjernvarme Fyn to transfer the heat generated by the servers to radiators in the nearby community. If it also becomes possible to generate electricity from these types of computer centres in the future, this will make an important contribution to the sustainable generation of energy.

The author is a technology journalist.

Prof. Steffen Hardt from the Department of Mechanical Engineering is conducting research into more sustainable use of energy.

Prof. Hardt and his team are carrying out research that will enable waste heat released by people and machines to be converted into electricity in the future. The basic principle behind this energy conversion process is the transport of ions in nanochannels within a temperature field.



Graphic : Helga Jordan

New dimensions in quantum physics

Theoretical physicist Vladimir M. Stojanović took a circuitous route to his research on quantum computers. He is now presenting findings that could provide decisive impetus to this field of research.

By Christian J. Meier

The development of a completely new kind of computer will require input from outstanding scientists. Vladimir M. Stojanović is one of them. The physicist has recently published several theoretical papers that could accelerate the development of quantum computers and their applications. Stojanović believes that in just a few years such computers could solve some complex tasks faster than even the most powerful supercomputers in the world.

Stojanović demonstrated his talents at an early age. As a pupil in his native country of Serbia, he not only excelled in sports but also won competitions in mathematics and physics. He then received his physics degree with the best grades. Stojanović has taken a circuitous path in his research but has been able to develop fresh ideas precisely for this reason. His current field of research is theoretical physics, which bounces ideas back and forth with experimental physics to develop new technologies.

"I believe that this is important for the future of quantum computers."

In 2003 Stojanović was doing research on the transport of electrical charges in organic semiconductors at TU Eindhoven in the Netherlands. The aim was to develop "plastic electronics" for e.g. particularly inexpensive solar cells. "But then I became interested in another field", says Stojanović. He moved to Carnegie Mellon University in the US, which is particularly strong in computer science research. As a result, Stojanović was now doing research in a field of physics that is decisively important for the data processing of the future: quantum physics. His research focussed on so-called "superfluids". These fluids exist at extremely low temperatures and display bizarre properties thanks to quantum physics. For example, superfluids in a rotating vessel do not rotate with the vessel. But this still did not have much to do with quantum computers.

After completing his doctorate at Carnegie Mellon, Stojanović moved to the University of Basel where he carried out research into important building blocks of quantum computers –- "qubits". For this new type of computer, they are what bits are for standard computers. While a bit can only store one of the two numbers 0 or 1 at any one time, a qubit can store both values simultaneously. A qubit can be made using a neutral atom that has two energy levels. This is a concept that Stojanović learned at his next stop – the renowned Harvard University in Boston, USA. An atom can exist in a superposition of two energy levels, meaning that it can exist in two states simultaneously.

Several qubits can be in many different states simultaneously and are thus able to store a vast amount of information. Instead of only being able to gradually process information sequentially, which means that complex tasks can take a very long time to be completed, a quantum computer would be able to process huge amounts of data in parallel without any delays.

In the Theoretical Quantum Physics Group at TU Darmstadt, Stojanović is focussing on one of the biggest hurdles on the path to developing a quantum computer. Before qubits can work together in a computer, they have to be linked with one another in a special way. Physicists call this "entanglement". You can think of several entangled atoms as a sort of collective like a superatom. The problem is that the time needed to entangle qubits increases sharply as the number of qubits grows. This is a paradox because the aim is to use as many qubits as possible to actually save computing time.

Stojanović had an idea for how a special type of multi-qubit entanglement – the so-called W-type entanglement – could be used to link qubits together much more quickly. The approach is very simple. Systems made of many particles have several states with different energy levels. The state with the lowest energy is called the "ground state". The system will naturally move towards this state itself. Stojanović asked himself whether it would be possible to design

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a system so that its ground state is the desired entangled W state. Even if the system contained a lot of particles, it would reach its ground state very quickly. The problem would thus be resolved. This type of entanglement would also be stable like a swing that remains at its lowest point unless it is pushed.

"The next ingredient came from my work in Eindhoven", says Stojanović. Although his work in Eindhoven did not focus on qubits, it involved systems in which an itinerant particle interacts with multiple point-like oscillators. The ground state of the system had similar properties to the entangled qubit state that the physicist had imagined. For example, a relatively large amount of energy is needed to bring it into another state. "Once you have reached this ground state, it is very stable because no other states with similar energies are available", says Stojanović to describe one of the advantages.

The physicist then transferred this principle to two different physical systems that are already routinely used in quantum-computing research. In one of them, the qubits are made of special electronic materials – so-called superconductors – that conduct electricity without any losses at very low temperatures, while in the other one, the qubits are formed from neutral atoms. "I was very fortunate because this idea came from my experience in other fields of research", says Stojanović. "The fact that I had always been willing to try new things was thus beneficial." His perseverance was ultimately rewarded. The journal Physical Review Letters, which is highly renowned among physicists, published his work. It was a huge distinction because this journal rarely publishes papers by single authors.

Although the findings of Stojanović are still theoretical, he has also considered how to implement them in an experimental setting. "All of the steps can be carried out with established experimental methods", says the physicist, whose work was supported by the Collaborative Research Center CROSSING at TU Darmstadt. In systems proposed by Stojanović, the time needed to entangle the qubits is thus no longer dependent on the number of qubits, which represents a decisive step towards the development of large, powerful quantum computers. "Another advantage is that the achieved W state is extremely robust", says Stojanović. It is even retained if individual qubits are lost, which can sometimes occur in practice.

"I believe this to be important for the future of quantum computing", says Stojanović confidently. He is currently looking for experimental physicists who want to test his concept in the laboratory and is confident that this will be possible. Stojanović believes that the most useful application for his design will be for so-called "optimisation problems" in which the aim is to find the best possible solution from countless different solutions. "It will help to resolve difficult traffic problems", says Stojanović. This includes things such as a railway timetable with thousands of connections within a complex network that needs to operate as quickly and energy efficiently as possible, while also providing good connections for millions of passengers. Quantum computers could thus enable passengers to enjoy a much more relaxed journey in the future.

The author is a science writer and holds a doctorate in Physics.

Dr. Vladimir M. Stojanović is carrying out research into the development of quantum computers. He is supported by the Collaborative Research Center CROSSING.

Photo: Katrin Binner

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Not without the poison dart frog

A research group headed by Professor Nico Blüthgen at TU Darmstadt is investigating how nature returns to recovering rainforest. The comeback of key species and interactions indicates successful regeneration.

By Hildegard Kaulen

Stop! The poison dart frog's bright colouring clearly indicates to its enemies that it will not be enjoyable prey. It produces its poison from the ants and mites that it eats. "When we encounter the poison dart frog in the tropical rainforest in Ecuador, we know that we have found a complex ecosystem", says Nico Blüthgen, Professor of Ecological Networks at TU Darmstadt. "The threatening mix of its garish colouring and accumulated poison indicates a highly specialised predator-prey relationship that can only function in a complex and closely meshed ecosystem. The more complex this type of ecosystem is, the more resilient it will be. And this is precisely what we want to see in the natural regeneration of barren land."

"We need a deeper understanding how nature regenerates itself and what is going on in the process."

Blüthgen heads a consortium consisting of twelve universities and foundations that want to find out how natural forests returns to fallow land in the rainforest. Which species are the first ones to come back? How long does the natural regeneration take? Will the old biodiversity be restored? Will all of the complex inter-relationships be re-established? How close will the new ecosystem come to the functionality of the old one? Blüthgen and the members of his team do not want to simply take an inventory but rather to measure the level of complexity found deep within the resurgent ecosystem. This is actually a natural process because areas of the forest are constantly being destroyed by natural catastrophes and then recover again. But nobody knows precisely how close to their original condition they come after this regeneration.

A lot of things are different today Ecosystems are disappearing at a rapid pace in large deforestation events. An area the size of ten football pitches is lost every minute in the tropical rainforest. And the rate at which living creatures are becoming extinct has tripled over the last hundred years. "We still don't understand enough about how an ecosystem works in order to be able to easily rebuild it", says Blüthgen. "We don't have a playbook for how to quickly repair the damage and we also need to better understand how nature regenerates itself and what happens during this process. It is only then that we can make targeted interventions", according to Blüthgen. "If you were to ask me whether we are prepared for the challenges we will face in renaturalising our planet then my answer is currently no. We simply know too little." Reforestation alone is not sufficient for Blüthgen. He is interested in restoring the complexity and thus the resilience of an ecosystem – so that it can also cope with climate change. The United Nations are also increasingly following this approach and have designated the next ten years as the "Decade on Ecosystem Restoration".

What exactly are Blüthgen and the international team planning to do? The researchers will be studying 62 areas of the Chocó lowland rainforest in the northwest of Ecuador over the next four to eight years. These areas of land had been used for some time for grazing animals or for cocoa farming but have now been abandoned. Some of these areas have already been regenerating for twenty or thirty years without any external influences, while others have only just started the regeneration process. The researchers will focus on some important processes: the relationships between predator and prey, trees and pollinators, mammals, seeds and dung beetles, and ants, termites and deadwood – to name just a few.

The "REASSEMBLY" research group is being funded by the German Research Foundation. It is also being supported in Ecuador by a consortium consisting of the Jocotoco Foundation and two universities in the country. The foundation has been buying up land in the region for 20 years, which is then left to develop on its own. Some of the funding will also be used to train Ecuadorian students and set up local structures.

The research group chose Ecuador for a number of reasons: "The conditions there are excellent", says Blüthgen. "The areas of land are located directly next to a rainforest, which acts as a good reservoir for the natural regeneration of the land. The rainforest in the Chocó lowland region is also especially productive. Everything grows extremely quickly and there are numerous animals to redistribute seeds from the trees. There is thus a good chance that we will actually be able to answer many of our questions within a few years. By observing the different stages of regeneration in which the areas of land find themselves, we should also be able to draw some conclusions about the speed of the process."

Die Anwesenheit des Pfeilgiftfroschs the presence of the poison dart frog is an important indicator for the complexity of the restored rainforest. Dung beetles are another indicator. They bury dung and the seeds within it and these seeds then germinate. However, dung beetles only bury mammal dung. If there are a lot of dung beetles in an ecosystem, it must also have a sufficiently large number of mammals that excrete

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Photo: Katrin Binner

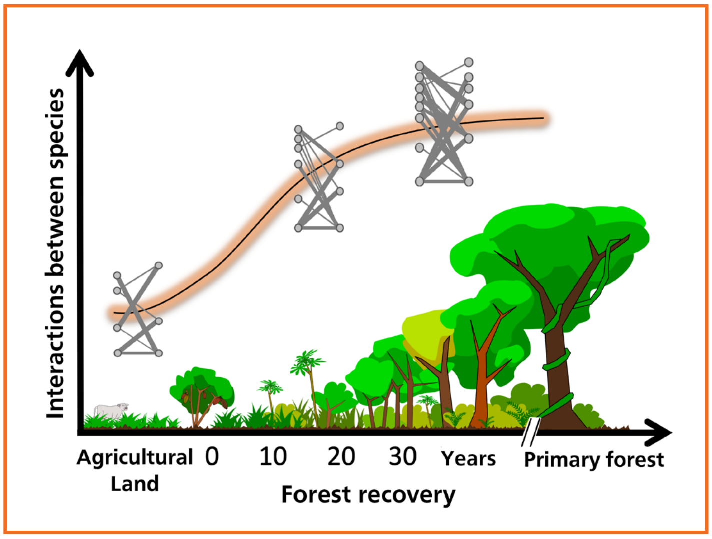
The rainforest is regenerating in selected areas of land in Ecuador and this process is being observed by, among others, Prof. Nico Blüthgen and his working group.

seeds in their dung. The researchers can find out precisely which mammals are present in the forest by analysing DNA from the stomachs of the dung beetles. It could come from, for example, fruit-eating howler monkeys or marmosets but also from a puma or jaguar. The latter play an important role as predators, especially at night. The stomachs of poison dart frogs will also be analysed in the same way. The resulting DNA can be used to identify a whole network of predator-prey relationships because the presence of one species is always dependent on the existence of another.

Pollination is another important process. To learn more about pollination processes, Blüthgen and his research group will trap animals using a light trap and analyse the pollen stuck to them. A DNA test will once again provide information on the identity of the individual pollens and the researchers can use this information to find out which animals have pollinated the respective plants. It is thus not necessary to climb to the top of the trees in the rainforest to find out. The answers can simply be found on the ground.

Disturbance experiments will also be carried out on areas of land at different stages of regeneration to test the stability of the newly developed networks. For this purpose, the researchers will clear an eight by eight meter area at ground level and only leave the trees standing. They will then monitor how nature regenerates in these areas. "We suspect that this process will be quicker in those areas where the natural regeneration process in the surrounding land is at a very advanced stage and not just in its early stages", says Blüthgen. „We won't only be looking at the complexity of the revived ecosystem itself during these experiments, but also at the interplay between regeneration that has taken place over decades with its increasingly complex networks and the short-term recovery of small areas of disturbance." Blüthgen and the team are acutely aware of the significance of their experiments. "Our own survival ultimately depends on the survival of the global ecosystem. We have no more time to lose if we want to support natural regeneration processes in a targeted way."

The author is a science writer and holds a doctorate in Biology.



Graphic: Arbeitsgruppe Blüthgen

How long does land that was previously used for agriculture take to regenerate in the rainforest? The working group headed by Prof. Blüthgen is also investigating how the entire ecosystem interacts.

Striking the right note

Photo: Katrin Binner

Dr. Christian Adams and Sabina Benatti Camargo in the new acoustic laboratory at TU Darmstadt.

How can acoustic challenges be mastered so that unwanted sound is minimised while a desired sound environment in each particular situation is also generated at the same time? Researchers at TU Darmstadt are working on new methods and processes to help shape the acoustic properties of machines during their development.

By Jutta Witte

"Acoustic research in the Rhine-Main region will be able to take a real leap forward thanks to our new laboratories", says Tobias Melz, Professor of System Reliability, Adaptive Structures, and Machine Acoustics (SAM) at TU Darmstadt and Head of the Fraunhofer Institute for Structural Durability and System Reliability (LBF). It will now be possible for experimental analyses of individual components and complete machines, including vehicles, to be carried out in future at the Lichtwiese Campus. In cooperation with partners from industry and research, the researchers want to develop new processes and methods to understand better the mechanisms of sound generation and propagation so that they can specifically influence machine acoustics.

In the automotive industry, for example, despite advances in car acoustic design, it is still challenging to control precisely the acoustic properties of such complex mechanical engineering systems during early product development process. If irritating sounds are identified on a product prototype, it will require expensive and time-consuming improvements to the design. At the same time, a brand-specific acoustic experience that drivers are already familiar with is highly desirable and also a crucial factor in their purchasing decision. In order to satisfy these contrasting requirements: "our work focuses on a design for acoustics at the earliest possible stage, beginning in the best case scenario directly with the source of the noise", says Christian Adams, a researcher in the SAM Group.

Three physical variables are important for influencing noise: mass, stiffness, and damping. "To design vehicle components based on these variables, we need a versatile set of methods", says Adams. This is because it is not only important that the components in the vehicle are correctly designed but also that we pay attention to all of the interactions between the different materials and production processes. This is relevant, for example, in future electric mobility systems. An electric motor is quieter than a combustion engine so that the motor will no longer mask undesired noise. Electric vehicles also have to be as light as possible to increase their range. However, lightweight designs and low-vibration solutions with an optimal acoustic design are often not compatible with one another. "This needs to be understood and anticipated at an early stage", says Melz.

Inovative methods and processes are thus required to enable early stage design for acoustics. In the new acoustic laboratories: "We work in a completely noise-decoupled environment, which allows us to focus on those sounds that are relevant for a particular experiment and block out all others", explains Adams. The researchers initially focus on structure-borne sound. When a car starts up, the engine generates vibrations that propagate throughout the structure of the vehicle as structure-borne sound. At the surface of the structure, the structure-borne sound of the engine radiates into the interior of the vehicle, for example, as airborne sound, which can be perceived by passengers. The trick is to ensure that as little noise as possible radiates into the interior of the vehicle, while also traffic noise does not pollute the environment outside.

The team at TU Darmstadt has identified two effective levers for correctly balancing the structure-borne and airborne sound. One of these levers is the structural intensity – a measure that shows how the structure-borne sound energy propagates throughout the structure. The researchers want to understand exactly the paths taken by structure-borne sound energy so that they can control it in a targeted manner. The second lever is so-called "low-tone gearing" of transmission mechanisms. The teeth of gears are irregularly arranged along the circumference. This is an innovation in engineering that should ensure that structure-borne sound is evenly distributed over many frequencies so that unpleasant, individual tones become less prominent.

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