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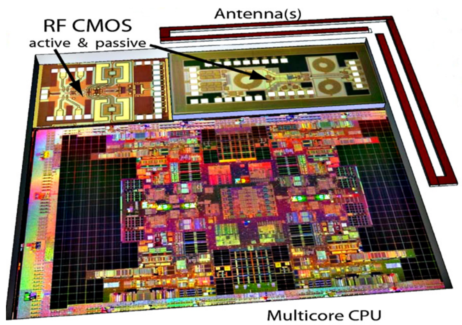
Can You Build a Wireless Network on a Chip?

NQPI member and Engineering Professor, Savas Kaya, together with fellow Engineering Professor, Avinash Kodi, partnered with a team in computer architecture to design a better way for the components of computer chips to communicate. Ten years ago, progress in computer technology involved using ever faster clock speeds, until the discovery of multiple core technology. Multiple cores working together as a team sped up the central processing unit (CPU) by sharing work among them.

But speed comes at a price. The more cores that are combined, the more energy is spent. There is hardware added to communicate with the cores. "Think of this like a room full of 16 kids. Each one wants to speak at the same time. The more you can get them to talk to each other, the more work you can get done," Kaya said.



A multicore CPU with wireless hardware.

Kaya, Kodi, and their team believe they have found a solution for improving the communication flow, by implementing wireless technology. While the expert team in computer architecture runs simulations, Kaya comes up with best practice scenarios. In a new article published in the journal *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems,* they detail their findings.

"With wireless technology, you don't have to drive through the whole neighborhood to get to your location," he explained. Right now, standard technology involves a layer of metal wires that connect the different chips. Wireless technology involves only one hop. "Consider this a city with multiple highways that are interconnected. The highways are transferring people from one point to another without disrupting flow and with minimal interruption," he said. In a similar way, wireless networks can transfer large amounts of data efficiently.

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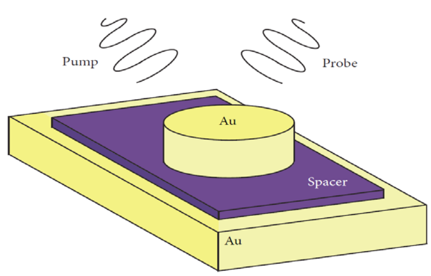
Harvesting Energy from Light

When light interacts with matter, its energy typically dissipates into heat. However, Dr. Alexander Govorov, a physics and astronomy professor at Ohio University and NQPI member, is researching how to extract as much energy as possible from the interaction of light with matter. He recently published two articles in *Nature* about the conversion of solar energy into electrical or chemical energy at the surface of nanostructures. Other members of the team involved in this research include his graduate student, Larousse Khosravi Khorashad, his Postdoctoral collaborator, Lucas V. Besteiro, and several collaborators in the physics departments at Emory, Northwestern and Vanderbilt Universities.

Within nanostructures, high-energy electrons can be created from interactions with light. Dr. Govorov's team described theoretically an ultra-fast contribution to this process in certain hot spots within the nanostructure. Such contributions have been observed experimentally and reported in joint papers published in *Nature*.



Light interacting with gold nanoparticle.

Dr. Govorov says, "It's challenging to convert solar and optical energy into electronic energy. In these nanostructures, we observed how to convert photon energy into electronic energy, the energy of excited electrons."

Dr. Govorov's research is designed to show how energetic electrons are generated in nanostructures. This involves the creation of plasmons in metallic nanoparticles, a process in which electron-electron interactions play a significant role. The generation of energetic electrons is the key for applications since such electrons can be extracted through a barrier from a metal nanostructure.

There are many applications where nanostructures could potentially be used. The generation of energetic electrons could be used for photocatalysis, which is the acceleration of chemical reactions by light. Also, another instance where electron generation is beneficial is within photodetectors, which are devices that detect or respond to light by using the charge generated by the absorption of individual photons.

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Director's Corner

Dear Colleagues,

Greetings! I am happy to welcome you to the 14th edition of the newsletter and to update you on some of the exciting actvities taking place within the institute.

First, please join me in congratulating Dr. Gerardine Botte, who earlier this year was named an Ohio University Distinguished Professor, the highest permanent recognition of outstanding scholarly and creative accomplishments attainable by faculty at Ohio University. Dr. Botte's internationally recognized work in electrochemical engineering is an excellent example of the high quality research here at Ohio University and NQPI.

I would also like to recognize Andrada Mandru, a senior Ph.D. student in Dr. Smith's group, who was the 2015 recipient of the Russell and Sigurd Varian Award at the American Vacuum Society International Symposium in San Jose, CA, where she was also the winner of the Leo M. Falicov Student Award within the Magnetic Interfaces and Nanostructures Division. Andrada and many of our NQPI graduate students have gained national and international recognition at the highest levels and we could not be more proud of their accomplishments.

In this newsletter you will read about the varied and exciting research being done by NQPI members on topics such as computer chip design, chalcogenide glasses, graphene, single atom chemical characterization, and obtaining energy from light. For example, graduate student Sneha Pandya, working with Dr. Kordesch, has deveopled a high yield, dry method for synthesizing nanoparticles which has resulted in a patent application.

NQPI was pleased to participate in and sponsor Spintronics 60, a summer conference in Cancun, Mexico, organized by Dr. Saw-Wai Hla. This conference, which brought 40 scientists together from Europe and North America to share their research, provided an open platform to encourage discussions and collaborations on both the national and international levels.

Please enjoy this newest newsletter!
Eric Stinaff, NQPI Director

Distinguished Professor

Gerardine Botte

NQPI member, Gerardine "Gerri" Botte, is the 2015 Ohio University Distinguished Professor. Botte is known internationally for developing the electrochemical engineering "pee-to-power" process in which hydrogen can be created from human and animal wastewater for use in fuel cells with clean water as the only byproduct. This award recognizes outstanding research and scholarly accomplishments and is the highest permanent recognition attainable by Ohio University faculty. A lengthy nomination process is involved in selecting a Distinguished Professor, starting with a call for nominations by the President, followed by a screening committee evaluation, and culminating with an election by all previous Distinguished Professors. Botte is the third woman to have this honor bestowed upon her in its nearly 60 years of existence. "I am thrilled to receive this distinction and especially thankful to my peers who supported my nomination."

Can Electron Flow in Graphene be Controlled?

NQPI members are busy researching new materials, which may lead to the development of even faster electronic devices. Nancy Sandler and Sergio Ulloa, physics and astronomy professors at Ohio University and NQPI members, have been working for more than ten years on a project that studies two-dimensional materials. They were recently awarded a three-year grant for $405,000 from the National Science Foundation to study spin correlations in two-dimensional materials.

Research on these materials kicked off when scientists from The University of Manchester started looking at the structure of graphite in 2004. "Graphite is a material that at the atomic structure looks like a deck of cards," Sandler explained. Manchester researchers observed under the microscope, that by scribbling with a pencil on a folded up piece of scotch tape, then unfolding the tape, the layers of graphite had been deposited on the tape, and that some of the layers were thinner than others. By separating graphite's layers, the researchers had stumbled upon a way to isolate a single atomic layer of carbon atoms, thus producing the material known as graphene.

Since this discovery, many researchers have been studying the properties of graphene and its promising potential for device applications. It is the world's thinnest material, and a good conductor of electricity, as well as being stronger than steel. It is speculated that this material could replace silicon in the manufacture of computer chips.

To implement the use of graphene in the development of improved devices, researchers are now faced with the challenge of finding out how to manipulate the flow of electrons in it, so that it can be switched on and off like in a semiconductor. Separating layers of other materials, which have similar properties, may be the solution.

Sandler and Ulloa's project titled, "Spin correlations and spin-orbit effects in new quantum materials," will explore combining atomically thin materials with the ability to conduct electricity. The materials studied include: graphene, transition metal dichalcogenides, flat-band Kagome crystals and 3D Dirac semimetals. Using data from state-of-the-art transport, scanning tunneling probe, and optical experiments, they will develop models to investigate how these structures react in experiments meant to test the materials' behavior under electromagnetic and strain fields.

Does the frequency of incident light change how fast the electrons move on the planes? What happens when materials are stretched? These questions and more will be tackled through an international collaboration that includes researchers from Argentina and Brazil, as well as an additional research team located at University of Florida.

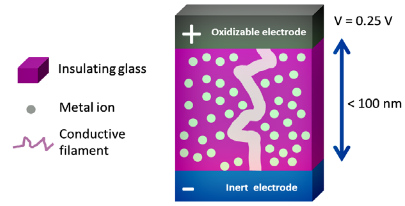
New Memory Device Spawns Research into Chalcogenide Glasses

A new memory technology is emerging in the market, that is faster and more energy efficient as a replacement for standard flash memory. Gang Chen, an Ohio University physics and astronomy professor and NQPI member, said, “Current flash drives run at microsecond speeds but this new device could run in the nanoseconds. So it’s about one thousand times faster.”

Adesto Technologies Corporation released a press announcement in 2010 about a new computer memory called conductive-bridging RAM (CBRAM) that promised lightning speeds. Then, many other technology companies jumped onboard with the new technology. CBRAM is used in various devices such as cell phones and health monitors. But scientists are trying to understand how it works.

Chen and fellow Ohio University physics and astronomy professor and NQPI member, David Drabold, have teamed up to help solve this mystery. By a combination of theory and experiment at Ohio University, and utilizing research facilities at the Argonne National Laboratory, they will study the physical properties of the material behind this technology. This project is supported by a $500,000 four-year grant from the National Science Foundation.

The material being studied is called a chalcogenide glass, which replaces conventional silicon in CBRAM devices. Silver-doped chalcogenide glass is a solid electrolyte. Since the material is a glass, it’s insulating in its ordinary state. But if an electric field is applied, the material can grow filamentary structures that make it conductive. One can reverse this change, and the material behaves again like an insulator, Drabold and Chen explained. “It has two states to carry information: zero or one. So you can put it into a state where it’s conducting (call it zero) or a state where it’s insulating (call it one). There’s a big contrast between those states and you can store information in those states and can change them around or rewrite them,” Drabold said.



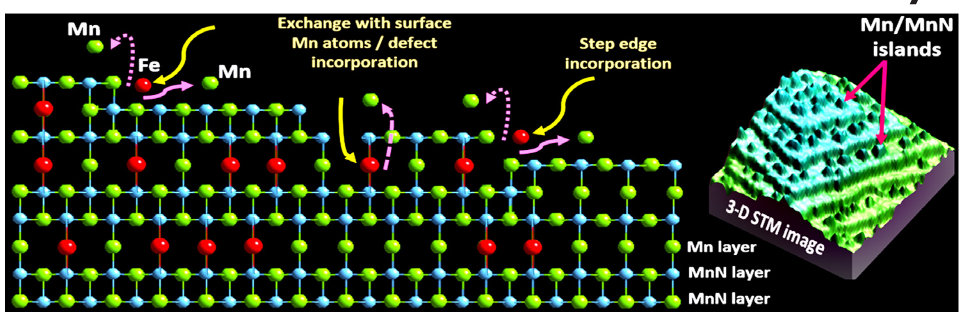
A schematic view of a CBRAM device.

One day, if CBRAM can be made fast enough, it may be able to fill the need for the two kinds of memory storage: permanent storage (like hard drives or flash solid state drives), and fast volatile memory (like cache in the central processing unit). “In general, a computer uses two kinds of memories: one memory for running calculations and the other for storage. So the CBRAM has the potential to combine the two together – a universal memory device,” Chen said.

Studying Magnetic Interfaces Leads to New Discovery

NQPI members are making scientific discoveries that advance the understanding of magnetic materials by coupling a ferromagnet and an antiferromagnet. Such a system has potential applications in magnetic recording, where the antiferromagnet pins the magnetic state of the ferromagnet across the interface. NQPI member and physicist Arthur Smith, his graduate student Andrada Mandru and research professor, Jeongihm Pak, joined with a team in Mexico, Professor Noboru Takeuchi and Jonathan Guerrero-Sanchez.

“Exploring the manner in which a ferromagnet adapts to different antiferromagnetic surface environments could lead to new insights into this complex behavior and open new pathways to achieving more successful devices as well as fundamental understandings,” they wrote in an article published last spring in *Physical Review B*.



Possible scenarios for iron incorporation and subsequent migration of manganese atoms to the surface, where they form islands.

Their study involved depositing small amounts of ferromagnetic iron onto antiferromagnetic manganese nitride, and exploring the properties of the system. The material system was grown in Smith’s lab using molecular beam epitaxy, a method which allows scientists to deposit one atomic layer at a time. To study the interface, Mandru combined spin-polarized scanning tunneling microscopy (to measure the electronic and magnetic properties down to the atomic level) and Auger electron spectroscopy (to determine surface composition ratios).

Under the microscope, tiny islands were found everywhere on the surface of manganese nitride, a scenario which seemed consistent with their expectations. But while studying the sample using spectroscopy, Mandru found that the amounts of iron were a lot smaller than expected. Something didn’t quite add up.

Guerrero-Sanchez’s theoretical calculations showed that iron atoms are not stable at the surface. Instead, iron atoms prefer to sink into specific subsurface layers. In order for the subsurface layers to accommodate the iron atoms, they give up some of their manganese atoms, which migrate to the surface and forms islands (as visible in the figure).

“Ideally, the interface between a ferromagnet/antiferromagnet system would be sharp and no intermixing would occur. However, that is not always the case, as we also found in our study. Results show that such complex interfaces could play a role in the resulting properties for other systems as well,” Mandru said.

NanoUpdate

Ph.D. Student Andrada Mandru was named the 2015 recipient of the Russell and Sigurd Varian Award at the American Vacuum Society International Symposium in San Jose, CA. In the same meeting, she was also the winner of the Leo M. Falicov Student Award within the Magnetic Interfaces and Nanostructures Division.

Reinventing a Nanoparticle Growth Technique

Sneha Pandya redesigned a technique for synthesizing nanoparticles (NPs), called Inert Gas Condensation (IGC), as a part of her doctoral project. The practice involves processes like sputtering and condensation for synthesis of NPs, followed by their extraction via a small nozzle. IGC has been around for a few years, but it isn't popular because of the small amount of nanoparticles yielded.

The process starts with a solid source that is fed into the machine. Individual atoms, ions and molecules are extracted from this solid source using a sputtering technique. These atoms, ions and molecules then condense by collision with the inert gas and form nanoparticles. The nanoparticles are extracted out of the synthesis chamber via a small nozzle (2 mm diameter) using the pressure difference between the condensation and deposition chamber. Then, the nanoparticles are deposited on the substrate.

One major flaw of the technique was that few nanoparticles were produced. Pandya, a graduate student working with Physics and Astronomy Professor and NQPI member Martin Kordesch, believed she could increase the yield by simple modifications. The goal was to cover a larger surface area of the substrate with nanoparticles.

She replaced the single 2 mm nozzle, used for extraction of NPs, with multiple holes drilled into a copper gasket. This gasket connects the synthesis chamber and the deposition chamber. The total area of the holes was kept equal to the area of the 2 mm nozzle. She was able to maintain the pressure difference as in the case of a single nozzle, and no upgrade in the vacuum system was required. This resulted into NPs being deposited in multiple hole patterns spread over a larger surface area. This can be used for patterned deposition of NPs, useful for various device applications. However, this did not help deposit NPs over the entire larger surface area.

Then, she tried a 2 cm long slit. Even in this case, the width of the slit was kept so that the area of the slit was equal to the area of the single 2 mm nozzle. She also attached the substrate to a rod with a motor so it would continuously rotate while the particles were deposited.

At first, Pandya found that not all NPs were being deposited. She realized this by studying the large amount of material, found on the copper gasket, in which the slit was drilled. She discovered that some of the edges on the slit were not even. Even the slightest obstruction can completely alter the flow of NPs diverting them off the slit as a result of which they will ultimately not get extracted through the opening. This can severely affect the yield, Pandya reported. After smoothing out the edges of the slit, she found what she was looking for. The instrument deposited a thin film of nanoparticles.

Sneha Pandya is operating her instrument.

"The NPs deposited went from almost 1 square millimeter to 350 square millimeters without any upgrade in the vacuum system," she said. Moreover, patterned deposition of NPs was also made possible using this modified technique. These are significant improvements in the IGC technique and can be very useful for device applications.

This invention may seem like a simple fix, but it could completely reinvent the way in which nanoparticles are made in the industry. "Current methods involve using liquid deposition, which is often complicated and messy," Pandya explained. The liquids have to be dried and carefully deposited onto the substrate. The wet process itself involves numerous steps. By using vapors, there is a physical deposition of nanoparticles, which makes the process cleaner and easier.

Wireless Network...

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There is one element that is crucial for making all of this work: the antenna.

But how do you make an antenna small enough to fit on a chip? Antennae are usually large, because of the long wavelengths involved. "At hundreds of gigahertz, the wavelength is still millimeters or so, which is too large for a chip." Plus, wireless communication tends to be power hungry. "You have billions of little workers all the time passing zeros and ones around all within the space of a few microns. Millions of bits of data flowing around. If you could operate the chip all the time at the maximum intensity, you could cook eggs on it," he said.

Kaya is using nanotechnology to find solutions. All the circuits have tens of nanometers of gatelengths, he explained. All the electronic circuits, digital and communication, will have the absolute smallest number of gatelengths possible to conserve space on the chip. Because the circuits are all in close proximity, the design uses nanomaterials to isolate the signals and to ensure that heat dissipates evenly. "We want to look at this beyond a circuit design problem and see how nanotechnology can help data and power management and the quality of the signals on the chip," he said.

Kaya and Kodi's research was recently awarded another grant by the National Science Foundation to incorporate optical signals and create a new partitioning domain. Light may pass around on specialized layers of devices. "Of course this has its own challenges, but if we can do it, light is the fastest communication and is interference free," he said. Light beams can pass through each other without disturbance and therefore they can occupy the same space. But light cannot be produced on silicon, a chip's main ingredient. However, if this approach succeeds, it would allow much more efficient communication. Kaya explained, "This would be a three-way division, part in light, part in wires and part in wireless communication."

Writing and design by Samantha Peko and Jenna Guyot. Editing by Dr. Horacio Castillo, Kay Kemerer, Samantha Peko and Jenna Guyot. Please email nqpi@ohio.edu with comments.