OFFICE OF STRATEGIC INTELLIGENCE & ANALYSIS (OSI&A)
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S&T Global Highlights

FEATURED ARTICLES

[Solid-state reaction among multiphase multi-component ceramic enhances ablation performance](#) (Pg. 2)
Researchers from China have reported a new solid-state reaction process between different multicomponent phases during ablation in multicomponent ultra-high temperature ceramic. This process potentially meets the stringent demands for thermal protection materials for aerospace and hypersonic vehicles.

[New super-pure silicon chip opens path to powerful quantum computers](#) (Pg. 2)
Researchers from Australia and the United Kingdom have invented a breakthrough technique for manufacturing highly purified silicon that brings powerful quantum computers a big step closer.

[Eyes of tomorrow: Smart contact lenses lead the way for human-machine interaction](#) (Pg. 3)
Scientists from China have developed eye-tracking smart content lenses based on radio frequency tags that can be used for various applications, including health care and augmented reality. This development has potential applications in human control of computers using the eyes.

ABOUT

S&T Global Highlights

This newsletter features recent publications in science and technology research directly relevant to the DoD's Critical Technology Areas or adjacent to those fields and potentially of interest to the broader OUSD(R&E) Enterprise. S&T Global Highlights is intended to provide insights into global research efforts, and intentionally limits the inclusion of U.S.-based research and excludes DoD research efforts.

Inclusion of a research article or summary is in no way an endorsement by the DoD or OUSD(R&E), and does not constitute validation of the research findings. Articles may have been abbreviated, synopsized, or excerpted.

Questions, feedback, or suggestions?

Please contact OSI&A's Tech Watch & Forecasting Cell.

TABLE OF CONTENTS

FEATURED ARTICLES

Solid-state reaction among multiphase multi-component ceramic enhances ablation performance

From: Central South University (China)
8 May 2024 | Press Release | DOI

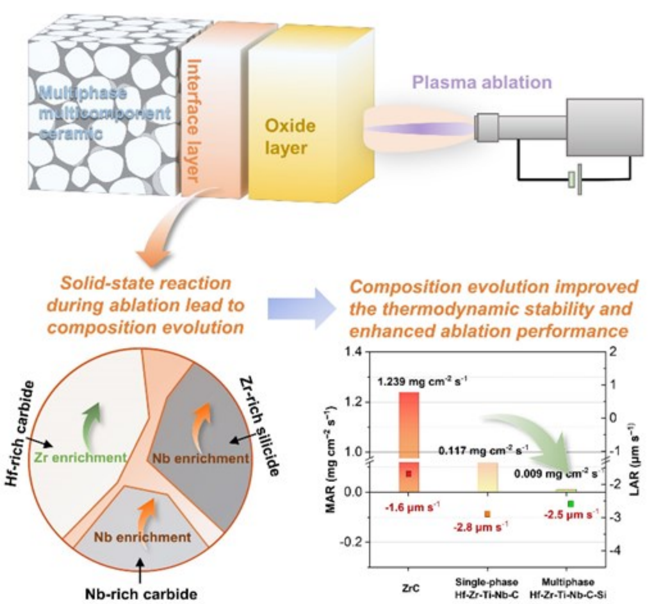
Multicomponent ultra-high temperature ceramic (UHTC) has attracted much attention in research due to its superior high-temperature mechanical properties, lower thermal conductivity, and enhanced oxidation resistance.

Multiphase design is a promising approach to achieve improved ablation resistance of multicomponent UHTC, potentially meeting the stringent demands for thermal protection materials (TPMs) for aerospace. However, understanding the ablation mechanism of multiphase multicomponent ceramic is foundational.

In the past, it was generally believed that the constituent phases among the multiphase multicomponent UHTC would not react with each other during ablation. However, a team of researchers led by Xiang Xiong and Yi Zeng at the Central South University in China reported a new solid-state reaction process between different multicomponent phases during ablation.

The work is published in the journal *Advanced Powder Materials*.

Their investigation focused on a three-phase multicomponent ceramic consisting of Hf-rich carbide, Nb-rich carbide, and Zr-rich silicide phases. More importantly, they found the ablation performance was also affected by this solid-state reaction.



The solid-state reaction process among multiphase multicomponent ceramic during ablation and its role in enhancing ablation performance.
Credit: Central South University

Specifically, this solid-state reaction occurred in the matrix/oxide scale interface region. During this process, metal cations counter-diffused between the multicomponent phases, resulting in their composition evolution.

"The composition evolution allowed the underlying multi-component phases to remain stable even under a higher oxygen partial pressure, which led to the improvement of thermodynamic stability of three-phase multicomponent ceramic," explains Xiong.

"Moreover, this solid-state reaction process appeared synergistic with the preferential oxidation behavior among the oxide scale in enhancing of the ablation performance within a specific temperature range."

"The present findings proved that multiphase design allows the multicomponent ceramic to achieve even better ablation performance. The obtained results may also provide a preliminary basis for the future development of multiphase multicomponent UHTCs," Zeng adds.

New super-pure silicon chip opens path to powerful quantum computers

From: University of Melbourne (Australia), University of Manchester (United Kingdom)
7 May 2024 | Press Release | DOI

Researchers at the Universities of Melbourne and Manchester have invented a breakthrough technique for manufacturing highly purified silicon that brings powerful quantum computers a big step closer.

The new technique to engineer ultra-pure silicon makes it the perfect material to make quantum computers at scale and with high accuracy, the researchers say.

Project co-supervisor Professor David Jamieson, from the University of Melbourne, said the innovation – published in *Communication Materials* – uses qubits of phosphorous atoms implanted into crystals of pure stable silicon and could overcome a critical barrier to quantum computing by extending the duration of notoriously fragile quantum coherence.

“Fragile quantum coherence means computing errors build up rapidly. With robust coherence provided by our new technique, quantum computers could solve in hours or minutes some problems that would take conventional or ‘classical’ computers – even supercomputers – centuries,” Professor Jamieson said.

Quantum bits or qubits are susceptible to tiny changes in their environment, including temperature fluctuations. Even when operated in tranquil refrigerators near absolute zero (minus 273 degrees Celsius), current quantum computers can maintain error-free coherence for only a tiny fraction of a second.

University of Manchester co-supervisor Professor Richard Curry said ultra-pure silicon allowed construction of high-performance qubit devices – a critical component required to pave the way towards scalable quantum computers.

“What we’ve been able to do is effectively create a critical ‘brick’ needed to construct a silicon-based quantum computer. It’s a crucial step to making a technology that has the potential to be transformative for humankind,” Professor Curry said.

Lead author Ravi Acharya, a joint University of Manchester/ University of Melbourne Cookson Scholar, said the great advantage of silicon chip quantum computing was it used the same essential techniques that make the chips used in today’s computers.

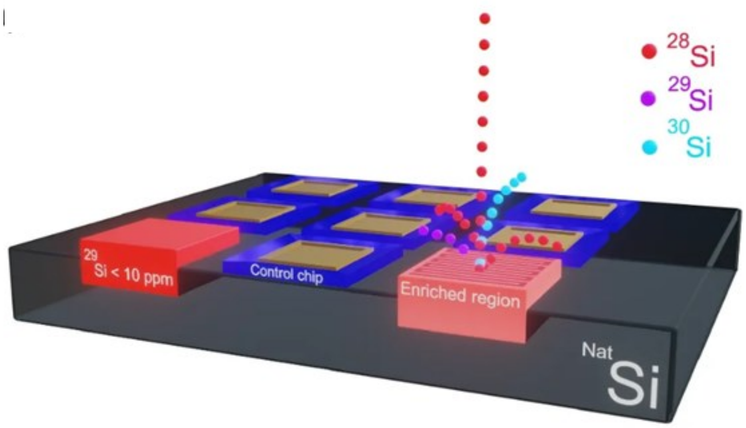
“Electronic chips currently within an everyday computer consist of billions of transistors — these can also be used to create qubits for silicon-based quantum devices. The ability to create high quality silicon qubits has in part been limited to date by the purity of the silicon starting material used. The breakthrough purity we show here solves this problem."

Professor Jamieson said the new highly purified silicon computer chips house and protect the qubits so they can sustain quantum coherence much longer, enabling complex calculations with greatly reduced need for error correction.

“Our technique opens the path to reliable quantum computers that promise step changes across society, including in artificial intelligence, secure data and communications, vaccine and drug design, and energy use, logistics and manufacturing,” he said.

“Others are experimenting with alternatives, but we believe silicon is the leading candidate for quantum computer chips that will enable the enduring coherence required for reliable quantum calculations,” Professor Jamieson said.

“The problem is that while naturally occurring silicon is mostly the desirable isotope silicon-28, there’s also about 4.5 percent silicon-29. Silicon-29 has an extra neutron in each atom’s nucleus that acts like a tiny rogue magnet, destroying quantum coherence and creating computing errors,” he said.



Schematic depicting the isotopic enrichment of localised volumes using a focused ion beam composed of 28Si where compatible qubit control and interconnect electronics are shown to be integrated. Credit: University of Melbourne

The researchers directed a focused, high-speed beam of pure silicon-28 at a silicon chip so the silicon-28 gradually replaced the silicon-29 atoms in the chip, reducing silicon-29 from 4.5 per cent to two parts per million (0.0002 per cent).

“The great news is to purify silicon to this level, we can now use a standard machine – an ion implanter – that you would find in any semiconductor fabrication lab, tuned to a specific configuration that we designed,” Professor Jamieson said.

In previously published research, the University of Melbourne set – and still holds – the world record for single-qubit coherence of 30 seconds using silicon that was less purified. 30 seconds is plenty of time to complete error-free, complex quantum calculations.

Professor Jamieson said the largest existing quantum computers had more than 1000 qubits, but errors occurred within milliseconds due to lost coherence.

“Now that we can produce extremely pure silicon-28, our next step will be to demonstrate that we can sustain quantum coherence for many qubits simultaneously. A reliable quantum computer with just 30 qubits would exceed the power of today's supercomputers for some applications,” he said.

Eyes of tomorrow: Smart contact lenses lead the way for human-machine interaction

From: Nanjing University (China)
27 April 2024 | Press Release | DOI

Scientists from Nanjing, China, have developed eye-tracking smart content lenses based on radio frequency tags that can be used for various applications, including health care and augmented reality (AR). The lenses are biocompatible and imperceptible, requiring no battery or conventional silicon chips.

Smart contact lenses that can keep track of various health factors and can be used for human-machine interaction (HMI) are a relatively new technology. These rely on tracking eye movements using methods like pupil center corneal reflection and electrooculography (EOG).

While these methods have shown some success, they lack accuracy and are susceptible to interference. Additionally, EOG, which uses skin electrodes for collecting data, has been shown to pose a risk to the skin.

The new study published in *Nature Communications* aims to overcome the challenges posed by traditional eye-tracking methods.

Speaking of what inspired him to develop smart contact lenses, Prof. Fei Xu from the College of Engineering and Applied Sciences at Nanjing University spoke about how science fiction can drive scientists' imaginations and creativity.

"Mission: Impossible 4 proposed a smart contact lens with a facial recognition function. If small contact lenses can achieve a seamless combination of the virtual and real worlds, it will be the ultimate form of AR technology. The human-computer interaction technology based on eye tracking is one of the more important components," he said.

Human-machine interaction

The interaction of humans and machines is the next step or challenge in the technological world, and HMI is at the heart of this.

It has the potential to impact several domains, including gaming, health care, AR, and robotics. Eye-tracking using smart contact lenses is one of the ways in which we can facilitate HMI.

It can help to monitor various health parameters, make it easier to communicate with robots, and give a more immersive AR experience. However, as mentioned before, present eye-tracking methods have challenges, which has required scientists to take a new approach.

The researchers propose a frequency-encoding approach to overcome these challenges.

Frequency-encoding

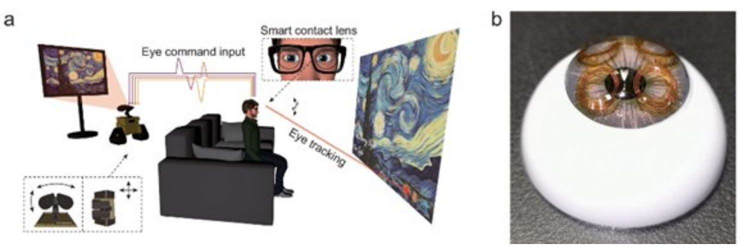
The frequency encoding method used by the researchers for the smart contact lens involves encoding information about eye movements into radio frequency or RF signals.

The RF signals are generated by RF tags which have been embedded within the contact lens. Each tag emits a unique frequency signal corresponding to different eye movements or positions. As the eye moves, the relative positions of the RF tags change, which alters the frequency of the emitted signal.

By detecting and analyzing these frequency changes, the system (or machine) can determine the direction and extent of eye movements in real time.

This frequency encoding strategy allows for precise and accurate tracking of eye movements without the need for conventional silicon chips or batteries, making smart contact lenses more compact, lightweight, and biocompatible.

Additionally, it is very secure. Prof. Xu explained, "The implementation of this technology eliminates the possibility of the leakage of iris and other biometric information. Human eye information contains the attention mechanism of the human brain, and human intention can be analyzed by tracking eye movement. User authorization is required to use the eye-tracking information."



Human-machine interaction by eye-tracking using smart contact lens. b) shows a photograph of the lens. Credit: Nanjing University

Making and testing the smart contact lens

The researchers used four RF tags and embedded them in a silicone elastomer. Silicone is what regular contact lenses are made from, making these smart contact lenses biocompatible. This setup was tested to minimize toxicity to the cornea, which could lead to corneal inflammation.

A portable sweeping frequency reader was kept nearby to record and analyze the signals from the RF tags (it serves as the machine part of HMI).

The researchers demonstrated that their smart contact lenses can detect gazing directions and real-time gazing points, which could be used for robot control and software interaction.

Further, they showed that the lenses are very stable and can be worn for up to 12 hours in different environmental conditions. They have also shown that the lenses can detect eye closure.

One of the key aspects of these smart contact lenses is their high angular accuracy, which enables eye command recognition for broader HMI applications. "Our eye-tracking contact lenses are highly accurate, with an eye movement angle accuracy of less than 0.5 degrees, even smaller than the viewing angle provided by the fovea. The fovea is the densest area of cones in the retina, providing high-definition imaging and where attention is focused," said Prof. Xu.

They also showed how eye commands can control games like Gluttonous Snake and can be used for web browsing. Moreover, they conducted in-vivo experiments in rabbits to verify the lenses' function and safety.

The smart contact lens is very similar to the commercially available contact lenses and was proven to be hydrated, safe, and biocompatible with the eye.

"In situ, eye tracking can be achieved through contact lenses, which are small and lightweight, not easy to detect, compatible with fashion, and do not affect interpersonal social interaction," added Prof. Xu.

Potential applications

Since the launch of the Apple Vision Pro, it has prompted researchers and the public to explore the potential applications of computer and human interaction using the eyes.

"Contact lenses are the ultimate form of AR. The seamless integration of the virtual world and the real world through contact lenses has been depicted in many science fiction works."

"With the development of optoelectronic technology and the improvement of the flexible integration of optoelectronic devices, contact lenses will realize more and more functions in human-computer interaction and medical health," concluded Prof. Xu.

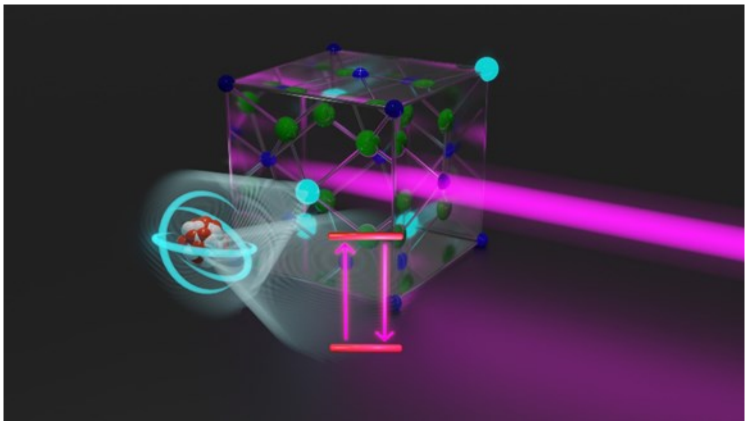
This will not only promote technological innovation but have a positive impact on people's quality of life.

ARTICLE SUMMARIES

Decades in the Making: Laser Excites Atomic Nucleus in Groundbreaking Discovery

From: Vienna University of Technology (Austria), National Metrology Institute Braunschweig (Germany)
29 April 2024 | Press Release | DOI

Physicists from Vienna University of Technology have made a significant breakthrough in more accurate time measurement by manipulating atomic nuclei, specifically thorium-229, using lasers. Previously, researchers believed it was impossible to apply laser techniques to atomic nuclei due to the high energy required. However, thorium-229 has two closely adjacent energy states that make it a good candidate for potential manipulation. The challenge was knowing the precise energy needed to induce the transition with a laser beam. To overcome this, researchers at Vienna University of Technology and the National Metrology Institute Braunschweig developed special thorium-containing crystals that allowed them to study large numbers of thorium nuclei simultaneously. On November 21, 2023, the team successfully hit the correct energy needed for the thorium transition, switching the state of the thorium nuclei with a laser beam. The ability to manipulate atomic nuclei with lasers has the potential to revolutionize precision measurements and advance our understanding of the fundamental laws of nature. This technology could be used to analyze the Earth's gravitational field for indications of mineral resources or earthquakes. It could also help answer fundamental questions in physics, such as whether the constants of nature are truly constant or if they change over time. One long-term goal is to build an atomic clock that uses the oscillation of the light exciting the thorium transition as a timer, surpassing the accuracy of current atomic clocks. This atomic clock could be used for improved position, navigation and timing.



A laser beam hits thorium nuclei, embedded in a crystal.
Credit: Vienna University of Technology

Animal brain inspired AI game changer for autonomous robots

From: Delft University of Technology (Netherlands)
15 May 2024 | Press Release | DOI

A team of researchers at Delft University of Technology has developed a drone that flies autonomously using neuromorphic image processing and control based on the workings of animal brains. The drone's deep neural network processes data up to 64 times faster and consumes three times less energy than when running on a graphics processing unit. This breakthrough could enable drones to become as small, agile, and perceptive as flying insects or birds. The researchers used neuromorphic processors, which mimic the way animal brains process information asynchronously and communicate via electrical pulses called spikes. This sparse processing approach is more energy-efficient and faster than traditional deep neural networks. The team also used neuromorphic cameras, which perceive motion more quickly and are more energy-efficient than traditional cameras. The signals from these cameras feed directly into the neural networks running on the neuromorphic processors. The researchers trained the drone's neural network to visually perceive motion and map it to control commands. The drone can fly at different speeds under varying light conditions and even with flickering lights. The researchers believe that neuromorphic AI will enable all autonomous robots to be more intelligent, particularly tiny drones that can navigate in narrow environments and be deployed in swarms for faster coverage of an area. This neuromorphic AI approach improves energy efficiency and speed, making it suitable for deployment on smaller autonomous robots.

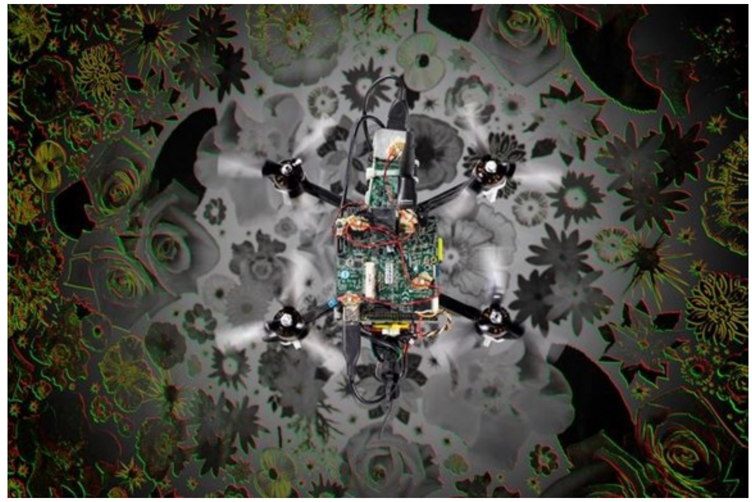
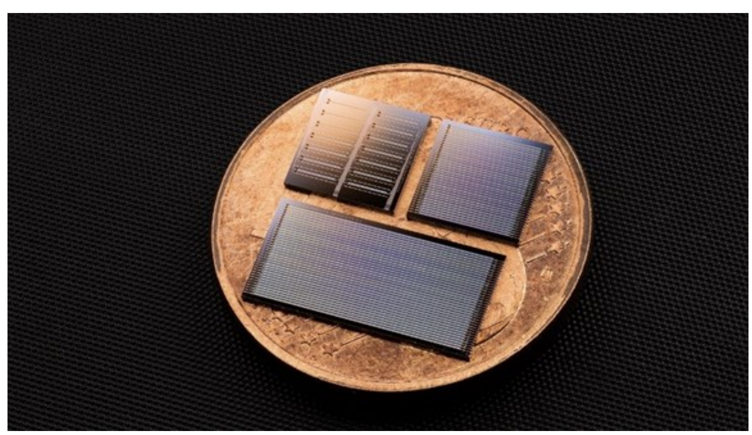


Photo of the "neuromorphic drone" flying over a flower pattern. It illustrates the visual inputs the drone receives from the neuromorphic camera in the corners. Red indicates pixels getting darker, green indicates pixels getting brighter.
Credit Delft University of Technology

A new, low-cost, high-efficiency photonic integrated circuit

From: Ecole Polytechnique Federale de Lausanne (Switzerland), Shanghai Institute of Microsystem and Information Technology (China)
8 May 2024 | Press Release | DOI

Researchers at Ecole Polytechnique Federale de Lausanne and the Shanghai Institute of Microsystem and Information Technology have developed a new photonic integrated circuit (PIC) platform based on lithium tantalate, a material with excellent electro-optic qualities. The team used a wafer-bonding method compatible with silicon-on-insulator production lines, and etched optical waveguides, modulators, and microresonators using deep ultraviolet photolithography and dry-etching techniques. The resulting lithium tantalate PICs exhibited high efficiency, with an optical loss rate of just 5.6 dB/m at telecom wavelength. The electro-optic Mach-Zehnder modulator on the platform had a half-wave voltage-length product of 1.9 V cm and an electro-optical



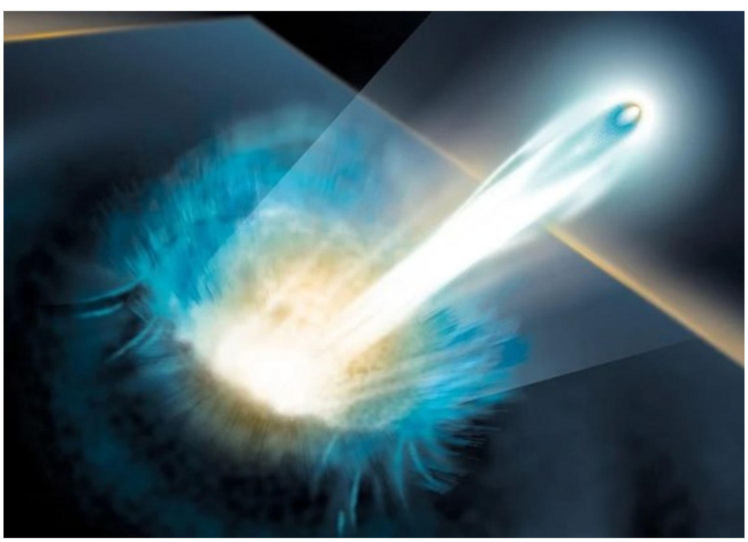
Lithium tantalate photonic integrated circuits.
Credit: Ecole Polytechnique Federale de Lausanne

bandwidth of up to 40 GHz. This allows for dense circuit configurations and broad operational capabilities across all telecommunication bands. This breakthrough supports to scalable and cost-effective manufacturing of advanced electro-optical PICs, offering a promising alternative to silicon-based PICs. This research expands the possible uses in optical communications, and systems suitable for applications such as parallel coherent light detection and ranging, and photonic computing.

Compact laser plasma accelerator breaks proton energy record

From: Helmholtz-Zentrum Dresden-Rossendorf (Germany)
13 May 2024 | Press Release | DOI

Scientists at the Helmholtz-Zentrum Dresden-Rossendorf have achieved a new energy record for proton acceleration using laser plasma acceleration. This innovative method allows for more compact and energy-efficient accelerators compared to conventional ones. By firing high-intensity laser pulses at wafer-thin foils, electrons are emitted, creating a strong electric field that can accelerate protons to high energies over short distances. Previous experiments relied on high energy lasers (100 MeV) but this team developed a new approach. The team used the phenomenon of light rushing ahead of the laser pulse, which is typically seen as a flaw. When this light hits a specially manufactured plastic foil, it causes the foil to expand, melt, and become transparent. This allows the primary pulse to penetrate deeper into the material, triggering a cascade of acceleration mechanisms that significantly increase proton energies. The team achieved proton energies of 150 MeV, almost double the previous record of 80 MeV. This breakthrough has promising applications in medicine and materials science, and can be used for efficient neutron generation, benefiting science, technology, and materials analysis.

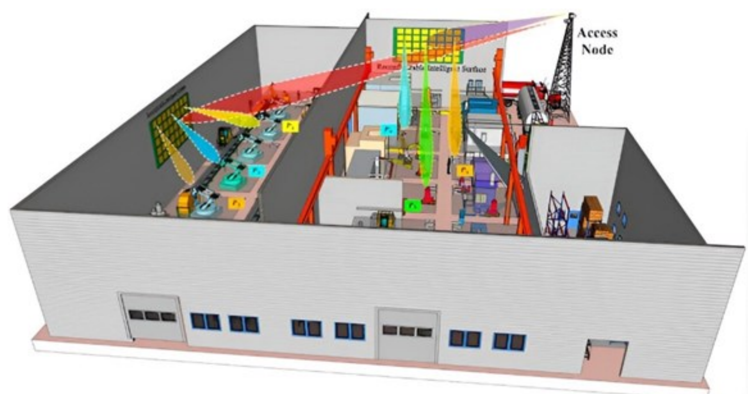


A research team at the HZDR has succeeded in significantly increasing the acceleration of protons via laser pulse by using an innovative method. Credit: Helmholtz-Zentrum Dresden-Rossendorf

New advance in wireless communications could help precisely pinpoint the locations of people and objects

From: University of Glasgow (United Kingdom)
10 April 2024 | Press Release | DOI

Engineers from the University of Glasgow have made a breakthrough in wireless communications that could enable precise indoor positioning by improving the performance of Reconfigurable Intelligent Surfaces (RIS). RIS is a wireless communication technology that uses programmable surfaces to manipulate electromagnetic waves. By placing RIS sheets on indoor walls and ceilings, the technology can intercept and intelligently reflect, redirect, and focus wireless signals to enhance performance. The integration of RIS into existing and future communication networks, including 5G and 6G, could address the limitations of established positioning technologies like GPS, which often struggle in indoor environments due to signal interference and weakened reception. The researchers conducted experiments using a large RIS setup and machine learning algorithms to accurately determine the location of a receiver. The findings demonstrate the potential of RIS technology for indoor localization tasks in future communication networks. This advancement could have various applications, such as aiding emergency services in locating individuals in smoke-filled buildings, assisting the navigation of blind or partially sighted people in public spaces, and it could eliminate the need to move around indoors to find the best signal reception for mobile phone calls.

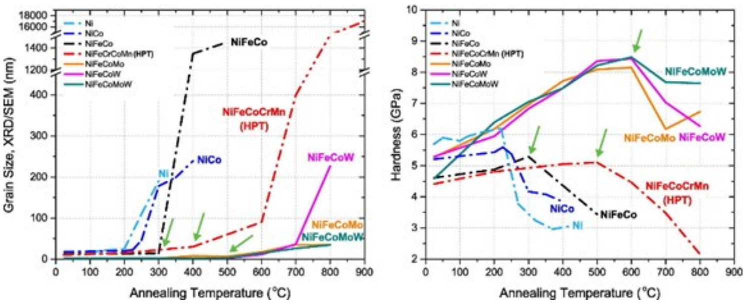


A real-life visualization of a reconfigurable intelligent surface (RIS)-enabled system efficiently localizing the indoor target nodes. Credit: University of Glasgow

Researchers establish commercially viable process for manufacturing with promising new class of metals

From: University of Saskatchewan (Canada)
30 April 2024 | Press Release | DOI

Researchers at the University of Saskatchewan, working with the Canadian Light Source, have discovered a cost-effective and scalable method to produce new alloys using electrodeposition. Nanostructured high entropy alloys (HEAs) are metals composed of a chaotic mix of multiple elements, offering strength and stability at high temperatures. However, their production is expensive and energy-intensive. This process involves dissolving metal ions in water and using an electric current to extract them and form solid materials. The team found that HEAs made of nickel, iron, cobalt, tungsten, and molybdenum could withstand temperatures up to 500°C, compared to 270°C for pure nickel, while also being stronger and harder than less complex alloys. The researchers observed that increasing the number of elements in the alloy improved its properties up to a certain point, with four elements providing the highest temperature resistance. This finding is advantageous as working with fewer elements is easier and more cost-effective. HEAs have potential applications in industries such as automotive and aerospace, where extreme temperatures and mechanical stresses are common. These alloys could be used to manufacture tools and parts that operate under demanding conditions.



Thermal stability of electrodeposited nanostructured high-entropy alloys. Credit: University of Saskatchewan

Next-generation sustainable electronics are doped with air

From: Linköping University (Sweden)
15 May 2024 | Press Release | DOI

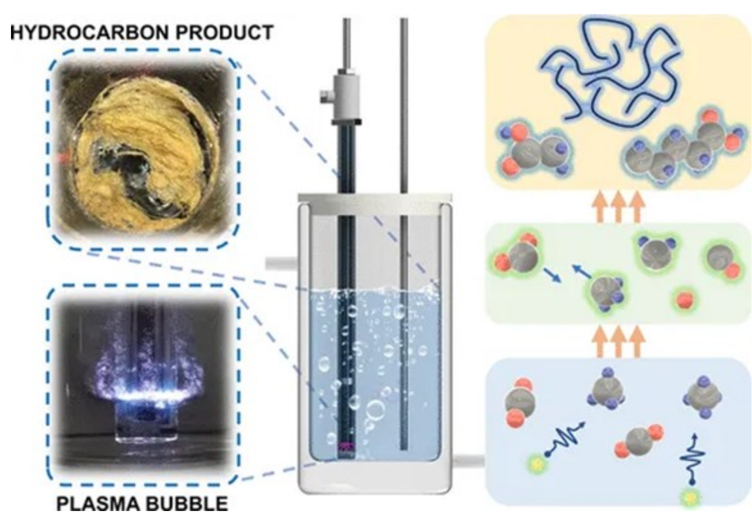
Researchers at Linköping University have developed a novel method to enhance the conductivity of organic semiconductors using air as a dopant. The method involves doping conductive plastics at room temperature, using oxygen as the primary dopant and light to activate the process. This approach mimics photosynthesis, where light activates a photocatalyst that facilitates electron transfer from inefficient dopants to the semiconductor material. The new technique involves immersing conductive plastic in a salt solution containing a photocatalyst and then exposing it to light. The duration of light exposure controls the doping level, with the only consumed substance being oxygen. This process results in a p-doped conductive plastic and allows for the simultaneous combination of p-doping and n-doping, simplifying the production of electronic devices like thermoelectric generators. This innovative method is scalable and environmentally friendly, as the materials used are inexpensive and readily accessible. This breakthrough could lead to affordable and sustainable organic semiconductors for digital displays, solar cells, LEDs, sensors, implants, and for energy storage.

The new method involves dipping the conductive plastic into a special salt solution – a photocatalyst – and then illuminating it with light for a short time resulting in a p-doped conductive plastic in which the only consumed substance is oxygen in the air. Credit: Linköping University

Methane emissions from landfill could be turned into sustainable jet fuel in plasma chemistry leap

From: University of Sydney (Australia)
30 April 2024 | Press Release | DOI

Researchers at the University of Sydney have developed a groundbreaking chemical process that converts methane gas emitted from landfills into sustainable jet fuel using plasma. Global landfill emissions account for an estimated 10-20 million tons of greenhouse gases annually. By creating a closed-loop fuel based on existing emissions, the need for traditional jet fuels can be eliminated. Landfills are major emitters of greenhouse gases, primarily a mixture of carbon dioxide and methane. The new process captures these gases and converts them into fuels, targeting sectors that are difficult to electrify, such as aviation. The process involves extracting methane from a landfill site using a methane well. Non-thermal plasma, an electricity-driven technology, is then used to convert the gas into value-added products. This plasma-based approach operates at low temperatures and atmospheric pressure, requiring less energy and making it compatible with renewable energy sources. This innovative research has the potential to revolutionize the aviation industry by providing a sustainable alternative to traditional jet fuels and reducing greenhouse gas emissions.



Schematic of the NTP reactor configuration employed. The plasma bubbles enable the conversion of CO2 and CH4 into solid long-chain hydrocarbons, liquid products, and gaseous products. Credit: University of Sydney

June 2024

EMERGING TECHNOLOGY SNAPSHOT
SKYRMIONS

Skyrmions are two-dimensional topologically protected magnetic structures that resemble vortex-like strings and exist in certain materials, such as magnetic thin films and heavy metals. They are characterized by swirling spin textures, where the magnetic moments of atoms or electrons arrange themselves in a specific pattern. Skyrmions can exhibit unique properties and behaviors that are of interest for various applications. For example, they can be manipulated and moved with relatively low energy input, making them potential candidates for information storage and processing in next-generation devices. Skyrmions have potential applications in areas such as spintronics, magnonics, and quantum computing. While research is showing promising progress, these applications have only been theorized.

Image source: Beyond skyrmions: Review and perspectives of alternative magnetic quasiparticles - Feb 2021 - Creative Commons Attribution 4.0 International

FOUNDATIONAL CONCEPTS

Skyrmions, and their anti-vortex counterpart antiskyrmions, can exist in materials at room temperature. Creating skyrmions is accomplished using an electrical current pulse. Transition between skyrmions and antiskyrmions is accomplished using the heat from electrical currents. A recent study has shown that the transition can be performed using a thermal gradient and a magnetic field. It is proposed that excess heat normally vented can be used to create the thermal gradient. Being able to reliably transition between skyrmions and antiskyrmions will advance the development of quantum memory.

ENABLING AND EMERGING SCIENCE AND TECHNOLOGY

Spintronics

The field of spintronics focuses on utilizing the spin of electrons for information processing and storage and contributes to the study of skyrmions. Advances in magnetic materials with tailored properties, such as thin films, multilayers, and heterostructures, have enabled the creation and manipulation of skyrmions in various systems.

Creating Skyrmions

Reliable generation of magnetic skyrmions requires controlled positions. They can conveniently be created with an electrical current pulse or with a laser pulse at random positions in the material. Control of skyrmion generation has the potential for further miniaturization of quantum memory.

Nanofabrication Techniques

Nanofabrication techniques, such as electron beam lithography and focused ion beam milling, allow researchers to create tailored structures and devices for studying skyrmions. These techniques enable the precise control of material dimensions and geometries, facilitating the manipulation and observation of skyrmions in controlled environments.

Integration with Existing Technologies

Skyrmion integration into existing technologies requires incorporation into existing electronic and magnetic systems, such as data storage devices, logic circuits, superconductors, and sensors, to enhance their performance and functionality.

Hapfions

Hapfions are three-dimensional topological structure within a magnetic sample volume resembling closed, twisted skyrmion strings in a donut-shaped ring in the simplest case. Hopfions may be of greatest interest when upgrading to the third dimension of technology being developed with magnetic skyrmions, such as racetrack memory, neuromorphic computing, and qubits.

Ultrafast Laser Spectroscopy

Ultrafast laser spectroscopy techniques have provided insights into the dynamics of skyrmions. By using short laser pulses, researchers can probe the ultrafast processes involved in the creation, motion, and annihilation of skyrmions. This enables the study of their behavior on extremely short timescales.

TECHNOLOGY LANDSCAPE

Collaboration

Researchers from different countries are actively collaborating to advance our understanding of skyrmions. Prominent countries leading collaboration include China and the United States. Germany, Japan, South Korea, and the United Kingdom also engage in collaboration efforts. These collaborations foster the exchange of knowledge, expertise, experimental data, and resources to advance our understanding of these magnetic structures.

Funding

The National Science Foundation in the United States provides funding. Similarly, the European Research Council contributes to research in Europe. Private foundations, like the Gordon and Betty Moore Foundation and the Kavli Foundation, also contribute to research into skyrmions.

Global Leaders - Skyrmions

Universities in Europe, Asia, and the United States are leading contributors to research into skyrmions. Notable institutions include Tsinghua University (China), Tohoku University (Japan), Johannes Gutenberg University Mainz (Germany), University of Cambridge (UK), and the University of California, Berkeley (USA).

Global Leaders - Hapfions

Universities in Europe, Asia, and the United States are leading contributors to research into hapfions. Notable institutions include National Institute for Material Sciences (Japan), Johannes Max Planck Institute for Chemical Physics of Solids (Germany), Uppsala University (Sweden), University of Oxford (UK), Massachusetts Institute of Technology, and the University of California, Berkeley (USA).

IMPLICATIONS AND OPPORTUNITIES

Defense

Skyrmions' sensitivity to external magnetic fields makes them suitable for magnetic field sensors used in navigation systems, magnetic anomaly detection, and other defense-related applications. Skyrmion-based sensors could offer improved sensitivity, miniaturization, and energy efficiency compared to traditional sensor technologies.

Economic

Investments in skyrmion research could lead to improvements in computational capability increasing employment opportunities, potential establishment of research centers, and growth of the scientific community. However, development costs and competition for resources require thoughtful management to maximize benefits and minimize risks.

Political

The benefits of skyrmions might not be evenly distributed. There could be political debates on ensuring equitable access to the technology, avoiding a scenario where only the elite or certain nations benefit. This presents challenges requiring thoughtful governance on ethical considerations and a re-evaluation of global dynamics and equity.

Environmental

Information processing systems and storage using skyrmions can decrease power consumption positively impacting greenhouse gas emissions. However, obtaining and processing materials for skyrmion research may have an impact on the environment and requires careful assessment to ensure advances align with sustainability goals.

Information Security

Skyrmions have the potential to improve advanced computing and data storage systems. The increased processing power and storage capacity enabled by these technologies may raise concerns about privacy and unauthorized access to data. Vulnerabilities may require new encryption security protocols to protect sensitive information from potential attacks.

DISCLOSURE & DISTRIBUTION

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