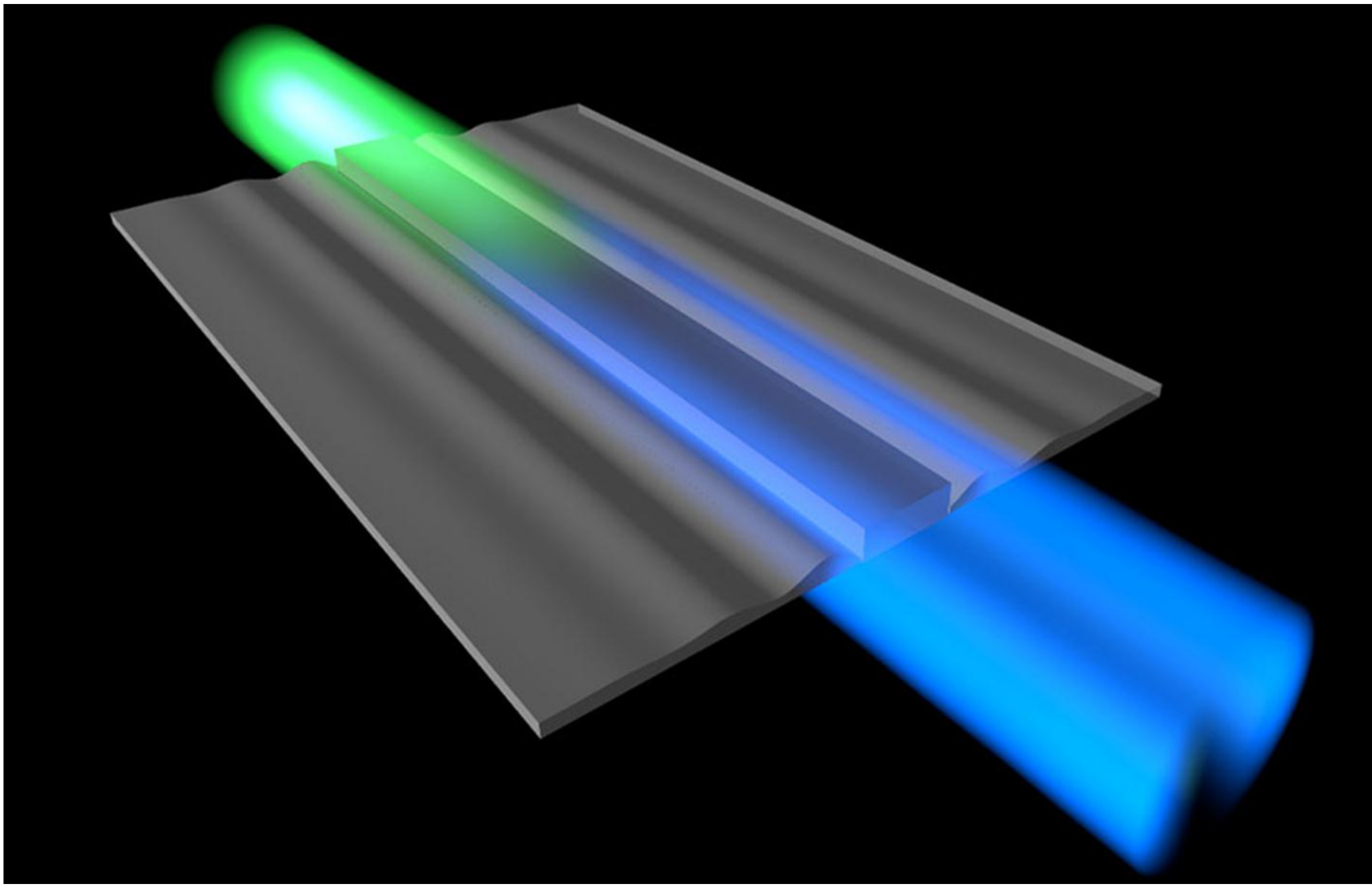
Physicists Use Laser Light to Cool Traveling Sound Waves in Silicon Chips

TOPICS: PhotonicsPhysicsYale University

By JIM SHELTON, YALE UNIVERSITY NOVEMBER 27, 2018



Cooling sound waves with light involves converting sound energy into light energy, which changes the color of the light. (Image credit: Eric Kittlaus and Nils Otterstrom)

Yale scientists have discovered that laser light can be used to cool traveling sound waves in a silicon chip. Their findings appear in the Nov. 27 online edition of the journal Physical Review X.

In the last several decades, the ability to cool clouds of atoms using laser light has revolutionized atomic physics, leading to the discovery of new states of matter and better atomic clocks. Laser cooling relies on the fact that photons, or light particles, carry momentum and can exert a force on other objects.

These techniques have recently been adapted to slow down, or cool, mechanical oscillators comprised of billions of atoms. This type of cooling has become an enabling technique for exploring the quantum properties of mechanical objects and reducing forms of noise that would otherwise corrupt precision measurement.

Yale researchers have extended these phenomena by showing how light can be used to cool sound waves traveling within solid materials. To do this, the researchers developed a special type of nano-scale silicon structure that allows propagating light and sound waves to interact.

“By tailoring the optical and acoustic properties of these waveguides, we’ve been able to enhance and shape the interaction between light and sound,” said Peter Rakich, an associate professor of applied physics at Yale who led the research. “This is the key that allows us to reduce the energy carried by thermally excited sound waves.”

When a photon interacts with sound waves propagating in a solid, it scatters to different colors of light. When the photon becomes red-shifted, it loses a portion of its energy, imparting it to the sound wave. Simultaneously, the light absorbs the acoustic energy and carries it away as a blue-shifted photon. This second process slows the motion of the sound wave, bringing it to a lower effective temperature.

Normally these two opposing processes would counteract and balance out. However, Yale researchers designed a waveguide in which a certain group of sound waves only experience the cooling process. “We call this symmetry breaking, and it’s the essential ingredient for the cooling process to dominate,” said Eric Kittlaus, a Yale Ph.D. student and co-author of the study.

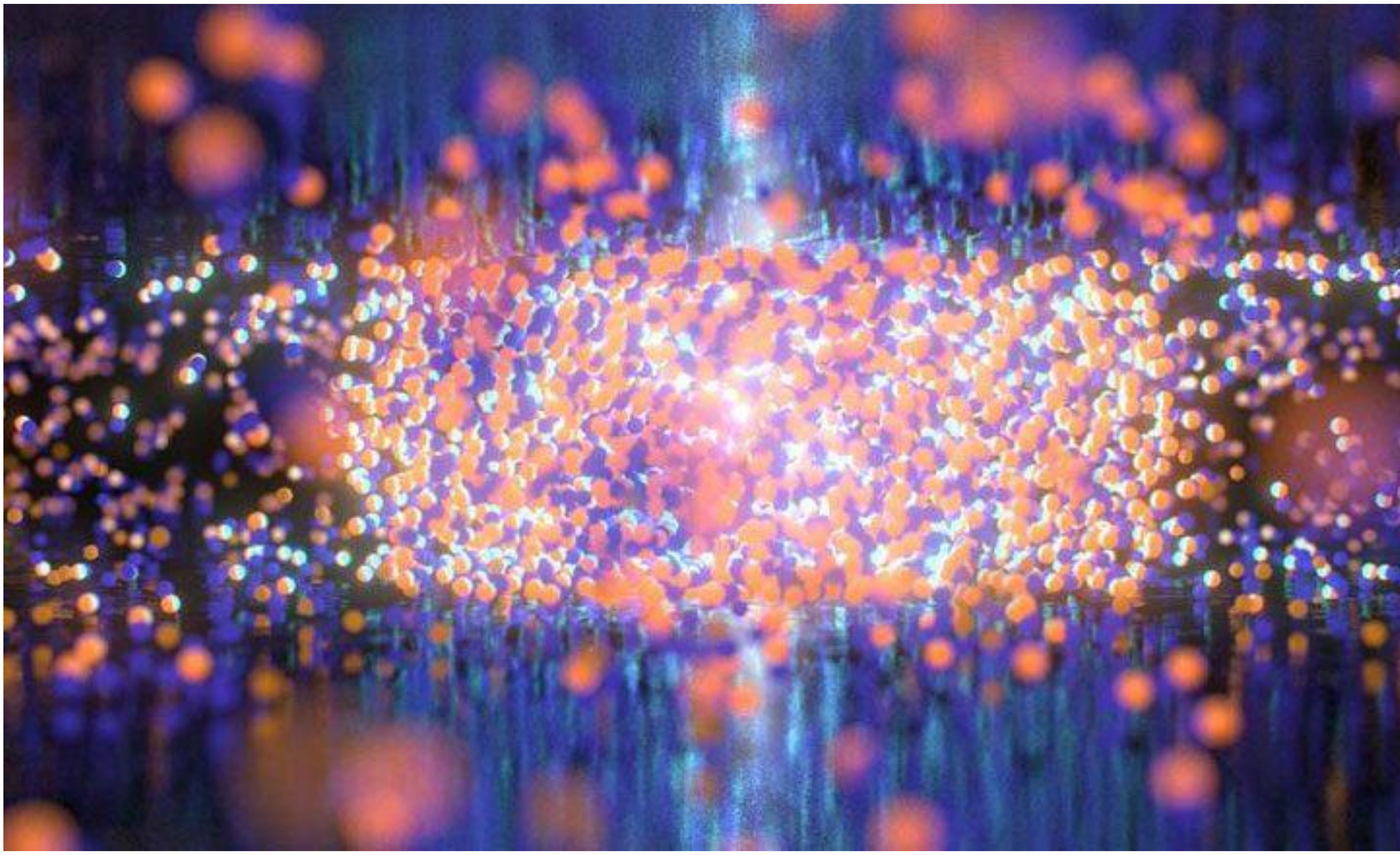
First author Nils Otterstrom, a Yale Ph.D. student, noted that the researchers were surprised by the strength of the cooling effect. He said it led the team to develop a rigorous theoretical framework for understanding the phenomena, as well as coming up with systematic experimental studies.

“We now have a knob that allows us to control processes that are at the heart of emerging chip-scale technology, including new types of lasers, gyroscopes, and signal processing systems,” Otterstrom said.

Physicists Create First “Electron Liquid” at Room Temperature

TOPICS: PhotonicsPhysicsUniversity Of California Riverside

By DENNIS MEREDITH, UNIVERSITY OF CALIFORNIA RIVERSIDE FEBRUARY 4, 2019



Electrons (blue) and holes (red) condense into liquid droplets akin to liquid water in devices composed of ultrathin materials.

By bombarding an ultrathin semiconductor sandwich with powerful laser pulses, physicists at the University of California, Riverside, have created the first “electron liquid” at room temperature.

The achievement opens a pathway for development of the first practical and efficient devices to generate and detect light at terahertz wavelengths — between infrared light and microwaves. Such devices could be used in applications as diverse as communications in outer space, cancer detection, and scanning for concealed weapons.

The research could also enable exploration of the basic physics of matter at infinitesimally small scales and help usher in an era of quantum metamaterials, whose structures are engineered at atomic dimensions.

The UCR physicists published their findings online Feb. 4 in the journal Nature Photonics. They were led by Associate Professor of Physics Nathaniel Gabor, who directs the UCR Quantum Materials Optoelectronics Lab. Other co-authors were lab members Trevor Arp and Dennis Pleskot, and Associate Professor of Physics and Astronomy Vivek Aji.

In their experiments, the scientists constructed an ultrathin sandwich of the semiconductor molybdenum ditelluride between layers of carbon graphene. The layered structure was just slightly thicker than the width of a single DNA molecule. They then bombarded the material with superfast laser pulses, measured in quadrillionths of a second.

Listening to quantum radio

Date:

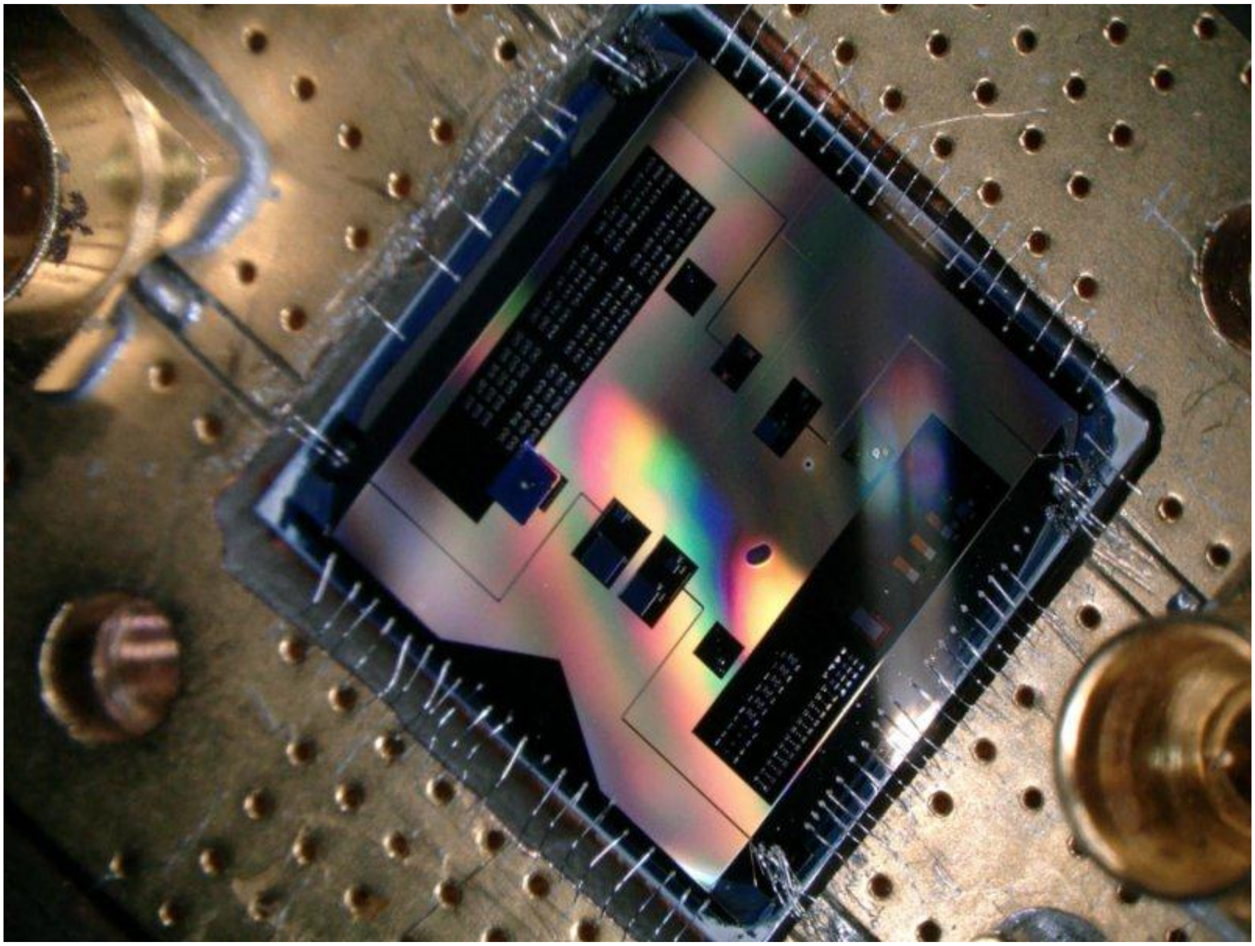
March 8, 2019

Source:

Delft University of Technology

Summary:

Researchers have created a quantum circuit that enables them to listen to the weakest radio signal allowed by quantum mechanics. This new quantum circuit opens the door to possible future applications in areas such as radio astronomy and medicine (MRI). It also enables researchers to do experiments that can shed light on the interplay between quantum mechanics and gravity.



Researchers at Delft University of Technology have created a quantum circuit that enables them to listen to the weakest radio signal allowed by quantum mechanics. This new quantum circuit opens the door to possible future applications in areas such as radio astronomy and medicine (MRI). It also enables researchers to do experiments that can shed light on the interplay between quantum mechanics and gravity.

We have all been annoyed by weak radio signals at some point in our lives: our favourite song in the car turning to noise, being too far away from our wifi router to check our email. Our usual solution is to make the signal bigger, for instance by picking a different radio station or by moving to the other side of the living room. What if, however, we could just listen more carefully?

Weak radio signals are not just a challenge for people trying to find their favourite radio station, but also for magnetic resonance imaging (MRI) scanners at hospitals, as well as for the telescopes scientists use to peer into space.

In a quantum 'leap' in radio frequency detection, researchers in the group of Prof. Gary Steele in Delft demonstrated the detection of photons or quanta of energy, the weakest signals allowed by the theory of quantum mechanics.

Quantum chunks

One of the strange predictions of quantum mechanics is that energy comes in tiny little chunks called 'quanta'. What does this mean? "Say I am pushing a kid on a swing," lead researcher Mario Gely said. "In the classical theory of physics, if I want the kid to go a little bit faster I can give them a small push, giving them more speed and more energy. Quantum mechanics says something different: I can only increase the kid's energy one 'quantum step' at a time. Pushing by half of that amount is not possible."

For a kid on a swing these 'quantum steps' are so tiny that they are too small to notice. Until recently, the same was true for radio waves. However, the research team in Delft developed a circuit that can actually detect these chunks of energy in radio frequency signals, opening up the potential for sensing radio waves at the quantum level.

From quantum radio to quantum gravity?

Beyond applications in quantum sensing, the group in Delft is interested in taking quantum mechanics to the next level: mass. While the theory of quantum electromagnetism was developed nearly 100 years ago, physicists are still puzzled today on how to fit gravity into quantum mechanics.

"Using our quantum radio, we want to try to listen to and control the quantum vibrations of heavy objects, and explore experimentally what happens when you mix quantum mechanics and gravity," Gely said. "Such experiments are hard, but if successful we would be able to test if we can make a quantum superposition of space-time itself, a new concept that would test our understanding of both quantum mechanics and general relativity."

ESO’s Very Large Telescope Captures a Fleeting Moment in Time

TOPICS: AstronomyEuropean Southern ObservatoryImagesPopular

By CALUM TURNER, EUROPEAN SOUTHERN OBSERVATORY JANUARY 23, 2019

The faint, ephemeral glow emanating from the planetary nebula ESO 577-24 persists for only a short time — around 10,000 years, a blink of an eye in astronomical terms. ESO’s Very Large Telescope captured this shell of glowing ionised gas — the last breath of the dying star whose simmering remains are visible at the heart of this image. As the gaseous shell of this planetary nebula expands and grows dimmer, it will slowly disappear from sight.

An evanescent shell of glowing gas spreading into space — the planetary nebula ESO 577-24 — dominates this image. This planetary nebula is the remains of a dead giant star that has thrown off its outer layers, leaving behind a small, intensely hot dwarf star. This diminished remnant will gradually cool and fade, living out its days as the mere ghost of a once-vast red giant star.

Converting Wi-Fi signals to electricity with new 2D materials

Device made from flexible, inexpensive materials could power large-area electronics, wearables, medical devices, and more

Date:

January 28, 2019

Source:

Massachusetts Institute of Technology

Summary:

Imagine a world where smartphones, laptops, wearables, and other electronics are powered without batteries. Researchers have taken a step in that direction, with the first fully flexible device that can convert energy from Wi-Fi signals into electricity that could power electronics

Devices that convert AC electromagnetic waves into DC electricity are known as "rectennas." The researchers demonstrate a new kind of rectenna, described in a study appearing in *Nature*, that uses a flexible radio-frequency (RF) antenna that captures electromagnetic waves -- including those carrying Wi-Fi -- as AC waveforms.

The antenna is then connected to a novel device made out of a two-dimensional semiconductor just a few atoms thick. The AC signal travels into the semiconductor, which converts it into a DC voltage that could be used to power electronic circuits or recharge batteries.

In this way, the battery-free device passively captures and transforms ubiquitous Wi-Fi signals into useful DC power. Moreover, the device is flexible and can be fabricated in a roll-to-roll process to cover very large areas.

"What if we could develop electronic systems that we wrap around a bridge or cover an entire highway, or the walls of our office and bring electronic intelligence to everything around us? How do you provide energy for those electronics?" says paper co-author Tomás Palacios, a professor in the Department of Electrical Engineering and Computer Science and director of the MIT/MTL Center for Graphene Devices and 2D Systems in the Microsystems Technology Laboratories. "We have come up with a new way to power the electronics systems of the future -- by harvesting Wi-Fi energy in a way that's easily integrated in large areas -- to bring intelligence to every object around us."

Promising early applications for the proposed rectenna include powering flexible and wearable electronics, medical devices, and sensors for the "internet of things." Flexible smartphones, for instance, are a hot new market for major tech firms. In experiments, the researchers' device can produce about 40 microwatts of power when exposed to the typical power levels of Wi-Fi signals (around 150 microwatts). That's more than enough power to light up a simple mobile display or silicon chips.

Another possible application is powering the data communications of implantable medical devices, says co-author Jesús Grajal, a researcher at the Technical University of Madrid. For example, researchers are beginning to develop pills that can be swallowed by patients and stream health data back to a computer for diagnostics.

"Ideally you don't want to use batteries to power these systems, because if they leak lithium, the patient could die," Grajal says. "It is much better to harvest energy from the environment to power up these small labs inside the body and communicate data to external computers."

All rectennas rely on a component known as a "rectifier," which converts the AC input signal into DC power. Traditional rectennas use either silicon or gallium arsenide for the rectifier. These materials can cover the Wi-Fi band, but they are rigid. And, although using these materials to fabricate small devices is relatively inexpensive, using them to cover vast areas, such as the surfaces of buildings and walls, would be cost-prohibitive. Researchers have been trying to fix these problems for a long time. But the few flexible rectennas reported so far operate at low frequencies and can't capture and convert signals in gigahertz frequencies, where most of the relevant cell phone and Wi-Fi signals are.

To build their rectifier, the researchers used a novel 2-D material called molybdenum disulfide (MoS_2), which at three atoms thick is one of the thinnest semiconductors in the world. In doing so, the team leveraged a singular behavior of MoS_2: When exposed to certain chemicals, the material's atoms rearrange in a way that acts like a switch, forcing a phase transition from a semiconductor to a metallic material. This structure is known as a Schottky diode, which is the junction of a semiconductor with a metal.

"By engineering MoS_2 into a 2-D semiconducting-metallic phase junction, we built an atomically thin, ultrafast Schottky diode that simultaneously minimizes the series resistance and parasitic capacitance," says first author and EECS postdoc Xu Zhang, who will soon join Carnegie Mellon University as an assistant professor.

Parasitic capacitance is an unavoidable situation in electronics where certain materials store a little electrical charge, which slows down the circuit. Lower capacitance, therefore, means increased rectifier speeds and higher operating frequencies. The parasitic capacitance of the researchers' Schottky diode is an order of magnitude smaller than today's state-of-the-art flexible rectifiers, so it is much faster at signal conversion and allows it to capture and convert up to 10 gigahertz of wireless signals.

"Such a design has allowed a fully flexible device that is fast enough to cover most of the radio-frequency bands used by our daily electronics, including Wi-Fi, Bluetooth, cellular LTE, and many others," Zhang says.

The reported work provides blueprints for other flexible Wi-Fi-to-electricity devices with substantial output and efficiency. The maximum output efficiency for the current device stands at 40 percent, depending on the input power of the Wi-Fi input. At the typical Wi-Fi power level, the power efficiency of the MoS_2 rectifier is about 30 percent. For reference, today's best silicon and gallium arsenide rectennas made from rigid, more expensive silicon or gallium arsenide achieve around 50 to 60 percent.

There are 15 other paper co-authors from MIT, Technical University of Madrid, the Army Research Laboratory, Charles III University of Madrid, Boston University, and the University of Southern California.

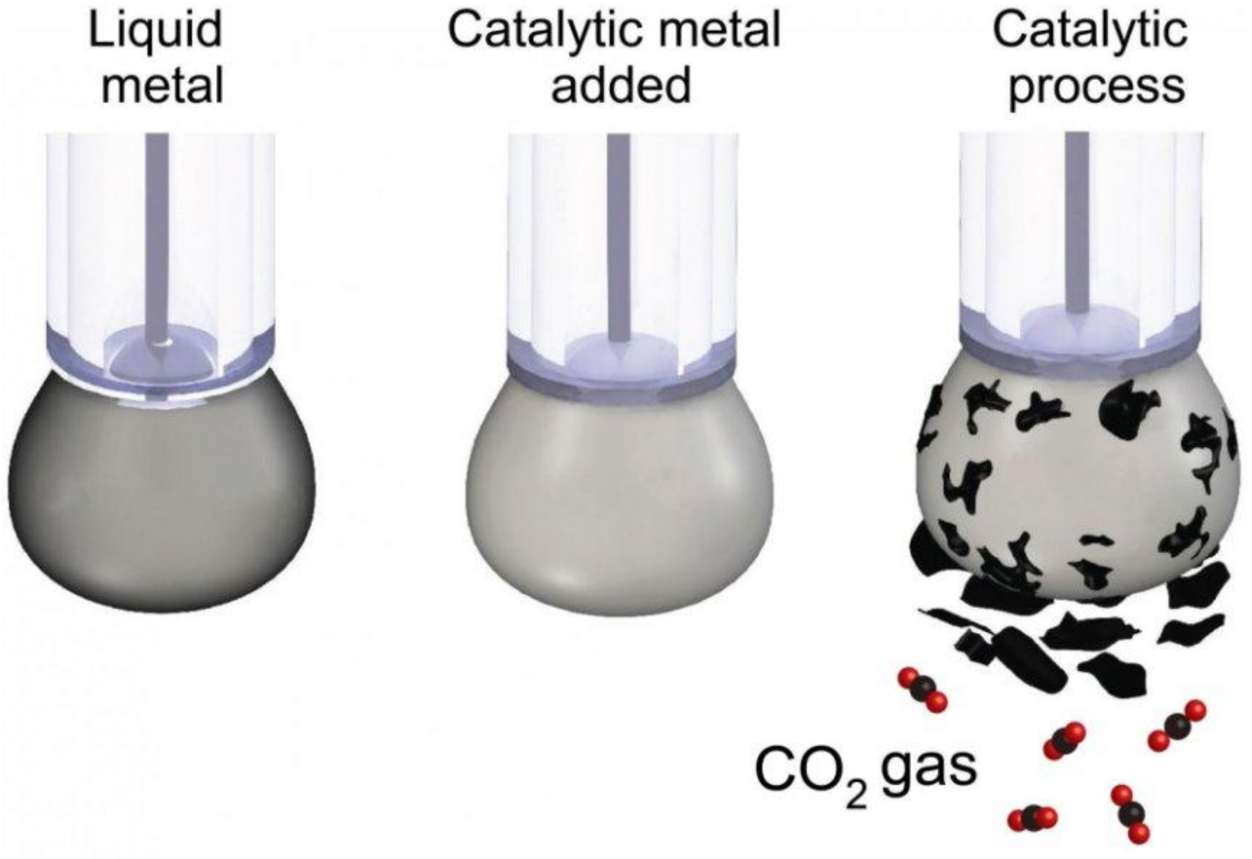
The team is now planning to build more complex systems and improve efficiency. The work was made possible, in part, by a collaboration with the Technical University of Madrid through the MIT

Climate rewind: Scientists turn carbon dioxide back into coal

New technique can efficiently convert CO_2 from gas into solid particles of carbon

February 26, 2019

Scientists have harnessed liquid metals to turn carbon dioxide back into solid coal, in research that offers an alternative pathway for safely and permanently removing the greenhouse gas from our atmosphere. The new technique can convert carbon dioxide back into carbon at room temperature, a process that's efficient and scalable. A side benefit is that the carbon can hold electrical charge, becoming a supercapacitor, so it could potentially be used as a component in future vehicles.



The research team led by RMIT University in Melbourne, Australia, have developed a new technique that can efficiently convert $CO_2$from a gas into solid particles of carbon.

Published in the journal *Nature Communications*, the research offers an alternative pathway for safely and permanently removing the greenhouse gas from our atmosphere.

Current technologies for carbon capture and storage focus on compressing CO_2 into a liquid form, transporting it to a suitable site and injecting it underground.

But implementation has been hampered by engineering challenges, issues around economic viability and environmental concerns about possible leaks from the storage sites.

RMIT researcher Dr Torben Daeneke said converting CO_2 into a solid could be a more sustainable approach.

"While we can't literally turn back time, turning carbon dioxide back into coal and burying it back in the ground is a bit like rewinding the emissions clock," Daeneke, an Australian Research Council DECRA Fellow, said.

"To date, CO_2 has only been converted into a solid at extremely high temperatures, making it industrially unviable.

"By using liquid metals as a catalyst, we've shown it's possible to turn the gas back into carbon at room temperature, in a process that's efficient and scalable.

"While more research needs to be done, it's a crucial first step to delivering solid storage of carbon."

How the carbon conversion works

Lead author, Dr Dorna Esrafilzadeh, a Vice-Chancellor's Research Fellow in RMIT's School of Engineering, developed the electrochemical technique to capture and convert atmospheric CO_2 to storable solid carbon.

To convert CO_2, the researchers designed a liquid metal catalyst with specific surface properties that made it extremely efficient at conducting electricity while chemically activating the surface.

The carbon dioxide is dissolved in a beaker filled with an electrolyte liquid and a small amount of the liquid metal, which is then charged with an electrical current.

The CO_2 slowly converts into solid flakes of carbon, which are naturally detached from the liquid metal surface, allowing the continuous production of carbonaceous solid.

Esrafilzadeh said the carbon produced could also be used as an electrode.

"A side benefit of the process is that the carbon can hold electrical charge, becoming a supercapacitor, so it could potentially be used as a component in future vehicles."

"The process also produces synthetic fuel as a by-product, which could also have industrial applications."

The research was conducted at RMIT's MicroNano Research Facility and the RMIT Microscopy and Microanalysis Facility, with lead investigator, Honorary RMIT and ARC Laureate Fellow, Professor Kourosh Kalantar-Zadeh (now UNSW).

The research is supported by the Australian Research Council Centre for Future Low-Energy Electronics Technologies (FLEET) and the ARC Centre of Excellence for Electromaterials Science (ACES).