T H E E L E C T R O N

N E W S L E T T E R O F T H E I N S T I T U T I O N O F E L E C T R O N I C S

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AROUND THE JOURNALS

Welcome to the first Electron Newsletter of 2020, which finds us in difficult times as Covid-19 has led to much of industry under lockdown, with many events cancelled or postponed. We are pleased, however, to take the opportunity, as in the past, to thank all of the magazine publishers that have kindly granted us free subscriptions to their publications over the past year, and come to the rescue. In this issue, we have therefore selected a sample of the articles that have been featured for review, representing a diverse range of electronic topics.

ELECTRONICS INDUSTRY AWARDS 2019

The Electronics Industry Awards, organised by Data team Business Media and featured in *Computers in Electronics* (CIE) magazine, were first introduced in 2018 as an event for leaders in the industry to celebrate achievement and provide recognition in the form of an award to the highest achievers.

At the 2019 event, held at The Tower Hotel, London, on 21st. June, a total of eighteen awards were presented across three categories of Product Awards, Business Awards and Individual Awards. These are listed in the July/August issue of CIE.

Product Awards

The Product Awards were as follows:

* Aerospace/Military/Defence Product of the Year: STURA 7 Drone Detector and Disrupter (Eskam Electronics)

* Automotive Product of the Year: LT8708/-1: 80V Bidirectional Synchronous Buck-Boost DC/DC Controller (Analog Devices)

* Display Product of the Year: microLED Emissive Display (Plessey Semiconductors)

* Enclosure Product of the Year: Environmental Case System (Phoenix Contact)

* Engineering Development/Design Tool of the Year: Introspect ESP Software

* Interconnection Product of the Year: Fischer LP360 Connector

* Internet of Things Product of the Year: sensAI Stack (Lattice Semiconductor)

* Power Product of the Year: Yokogawa WT5000 Precision Power Analyzer

* Test, Measurement and Inspection Product of the Year: SV3C-DPTXCPTX Combo MIPI D-PHY/C-PHY Generator (Introspect)

* Embedded Solutions Product of the Year: microLED Emissive Display (Plessey Semiconductor)

Business Awards

The Business Awards were as follows:

* Distributor of the Year: Digi-Key Electronics

* Electronics Manufacturer of the Year: NCAB Group UK

* Excellence in Innovation: Xilinx

* Environmental Leadership: NCAB Group UK

* Best Customer Service: Intelliconnect

* Academic Support: RS Components

* Most Outstanding PR Agency: BWW Communications

Individual Awards

Just one Industry Personality Award was presented in this category and that was to Nick Foot of BWW Communications.

The Awards Process

The Product Awards were decided by combining a public vote with the scores from an expert panel of judges, whilst the Business Awards were decided solely by an online vote.

Winners' Profiles

In the May 2019 issue of CIE profiles are featured of two of the Award Winners, Intelliconnect and Yokogawa.

Cochlear Implant

The Intelliconnect profile relates to the development of a cochlear implant (surgically implanted device that enables a severely deaf person to hear again).

Having suffered multiple failures of standard connectors, a major manufacturer of cochlear implant technology approached Intelliconnect with a request to develop a quick disconnect waterproof connector:

'The internal transmitter, where a connector is required, transmits RF signals through to the implant via a magnetic connection to reduce the possibility of patient infection. The transmitter processes the RF signals from the microphones through the speech processor and then into the internal implant which connects to the cochlear allowing the person to "hear" the sound.'

The proposed connector was to be in the external transmitting/processing part of the device, and so had to be extremely rugged and reliable. This meant that the connector had to be waterproof, because they were used close to the skin, and capable of being used in normal domestic environments, such as swimming pools, showers, baths and high-humidity environments such as saunas and steam rooms. The design had to be small enough to fit into the transmitter equipment, but also sufficiently rugged to permit a push/pull connection style to be incorporated.

The brief required a new design of connector to be initiated since two important features i.e. waterproof integrity and a push-pull connection as against a coupling nut, were needed to allow ease of use and performance under severe environmental conditions.

The design was based around a modified MCX connector with the waterproof rating of IP68 in the unmated condition, equivalent to 10m immersion in water tested for a minimum period of four hours. In practice the connector had been tested to 60m without leaking, providing a safety factor of six.

The application required several thousand disconnects during the product lifecycle, which required a development programme that would ensure that the latching mechanism, spring forces, and engagement and separation forces would be consistent and qualified for the specified number of mating and unmating cycles:

'The connector needed to be capable of up to 3,000 mating cycles, and this was to be achieved by fine tuning the connector forces to an engagement force of 2.5 lbs maximum and 1.5 lbs minimum, and a disengagement force of 3 lbs maximum and 2 lbs minimum.'

The successful design is now in volume production.

Intelliconnect is currently the largest UK-based manufacturer of RF and waterproof connectors for specialised applications.

Precision Power Analyser

In 'A Power Analyser to meet Tomorrow's Challenges' Anoop Gangadharan of Yokogawa Europe points to changes in areas such as the automotive sector and the nature of the power grid to justify 'a versatile test platform that not only delivers reliable measurements today, but is also ready for the challenges of tomorrow':

'In the automotive sector meeting the demands of electric and hybrid vehicles for greater charging capacity, shorter charging times and greater travelling range requires thorough positive and negative cycle evaluations of battery charge and discharge characteristics. Similarly, tests on inverter signals need to account for the harmonic superimpositions from switching circuits. Minimising the interference from this switching noise requires isolated inputs, high-speed sample rates and measurement data gathered over long periods.

As pure sine-wave PWM signals become less common in motor applications, measuring instruments need to include the ability to carry out high-frequency measurements. With mean voltages increasingly differing from the fundamental voltage waveform, harmonic measurements are also are also needed to establish the values of derived measurements such as active power. Similarly, addressing the challenges of measuring parameters such as energy efficiency, harmonic content and power factor require both progressively greater accuracy and consistency in measurement over the specified ranges and conditions.

In the area of power transmission and distribution, new developments such as renewable energy stations, energy-positive buildings and infrastructures mean that electricity no longer has a unidirectional flow from the power station to the consumer. With a multitude of renewable and non-renewable power stations feeding the grid, engineers in charge of ensuring a balanced grid need robust testing and accurate measurements to reduce the impact of noise, distortions and harmonics from multiple sources.'

The WT5000 Precision Power Analyser addresses these challenges with a measurement accuracy of plus or minus 0.03 per cent combined with stability, noise immunity and plug-in modular flexibility:

'Seven built-in slots for user-swappable power input modules and diverse mainframe options enable users to expand or reconfigure the WT5000 as their applications and their requirements change.

Key features include the ability to use 5A or 30A input modules in conjunction with the split-screen touch display to compare multichannel measurements; simultaneous measurements on up to four motors; carrying out measurements under highly fluctuating input and/or load conditions; and custom measurements for added flexibility. The WT5000 also performs harmonic measurements including comparisons of two simultaneous measurements up to the 500th order.'

WORLD'S FIRST PERSONAL CAPNOMETER

In the December 2019 - January 2020 issue of *CIE,* Russell Overend, Managing Director of Wideblue, in his article 'The Challenging Environment of Medical Electronics', (p.14), describes how his company has achieved a world first with the development of the N-Tidal Personal Capnometer.

A capnometer is a device that is used to measure the amount of carbon dioxide in an exhaled breath in order to assess lung health. Traditionally it takes the form of a large bedside machine ordinarily only used in hospitals. In his article the author explains how, following an approach from Cambridge Respiratory Innovations Limited, Wideblue subsequently set about the task of designing a hand-held battery-powered version that could be used in a patient's home or by a general practitioner:

'An ergonomic study allowed us to develop the device for children and adults and left/right handed operation. We chose an infra-red LED tuned to the peak CO2 adsorption wavelength and developed some patented infra-red optics to measure the CO2 levels as the patient breathes in and out through the mouthpiece.'

Miniaturisation techniques enabled a sensor to be directly in front of the mouth, providing more accurate results:

'A replaceable breath tube with integrated infra-red widow means the device can be used by many patients and prevents cross-contamination. A simple traffic light system (red, amber, green) gives an indication of the lung health so that any remedial action can be taken quickly. Electronics within the device capture the data from the sensor and the breath record is transmitted wirelessly to a secure server. Not patient identifiable data is used. Additional engineering data is captured and transmitted to allow us to monitor the use of the device in service. We chose 2G comms as this service was most available in most of the target countries and the service is unlikely to be switched off due to the installed base of other 2G devices. The device uses an internal Li-ion battery charged through a USB connector. This had the added benefit during development and clinical trials of having direct access to the microprocessor and memory in the device.'

The N-Tidal Capnometer is currently undergoing clinical/user trials and has already produced "superb" clinical results. Subject to successful completion of these trials and regulatory approvals, the device is expected to go into commercial production in 2020.

WORLD'S LONGEST MULTILAYER FLEXIBLE PRINTED CIRCUIT

The April 2019 issue of *CIE* (p.35) describes how Trackwise has shipped a 26-metre long multilayer flexible printed circuit (FPC), believed to be the largest ever produced, for distributing power and control signals across the wings of a solar-powered unmanned aerial vehicle.

The FPC forms part of a complete interconnect system (power and signal) that provides an estimated total systems weight saving of some 60 per cent over the traditional wire harness:

'The FPCs are manufactured using Improved Harness Technology (IHT), a patented reel-to-reel manufacturing technique. Conventional FPCs are rarely more than two metres in length, primarily due to limitations of manufacturing processes. IHT overcomes these limitations, enabling FPCs of unlimited length to be produced.

The UAV's flexible circuit is based on a polyimide substrate. The planar structure of the circuit dissipates heat better than conventional wiring, enabling higher current carrying capacity for a given weight of copper conductor. Printed manufacturing ensures circuit consistency, fewer connection points are needed so reliability is enhanced and the FPC is easier to install than wire harnesses, reducing a vehicle's assembly time and cost.'

Philip Johnstone, CEO of Trackwise, is quoted as follows:

"There are many new applications emerging for long, lightweight FPCs, but aerospace is a natural fit- weight savings, high reliability and cost effectiveness are critical. We're also seeing growing interest from a variety of sectors including medical and automotive. For the latter, manufacturers are challenged to reduce vehicle weight to improve fuel efficiency at a time when there's an ever-growing array of electrical and electronic circuits on their vehicles. In particular electric vehicles are accelerating this trend."

CMOS TECHNOLOGY FOR FABRICATION OF GAN MICROLED DISPLAYS

The June issue of Commercial *Micro Manufacturing (CMM) International* (p.9) contains a short, but interesting, account how a French-based research institute for miniaturisation technologies (CEA-Leti) has developed a complementary metal-oxide-semiconductor (CMOS) technology for the fabrication of gallium nitride on silicon (GaN) microLED displays.

The technology is said "to overcome current microLED display size limitations and be suitable for applications ranging from smart watches to big-screen televisions".

The article states:

'MicroLED displays promise exceptional image quality and better energy efficiency than existing liquid crystal display (LCD) and organic light-emitting diode (OLED) technologies, but they face significant challenges on the road to commercialisation. One of the biggest challenges is improving the performance of their driving electronics, which require more power to deliver brighter images and more speed to support continuously increasing demands for high display resolution. Faster electronics are needed to power millions of pixels in a fixed-frame time, but existing thin-film transistor (TFT) active matrix technology cannot provide the necessary current and speed.

CEA-Leti's approach is to fabricate CMOS-driven, high performance GaN microLED displays via a simple transfer process that eliminates the use of the conventional TFT backplane. All-in-one red, green, blue (RGB) microLEDs are stacked directly onto a micro-CMOS driving circuit, and each unit is transferred onto a simple receiving substrate, or backplane. The microLEDs and backplane are then fabricated on a single wafer-scale semiconductor line.'

Benefits claimed for the process include increased power and driving speed that improve microLED display performance, and avoidance of several costly steps that would otherwise be needed to make electrical and mechanical contacts between the microLEDs and the receiving substrates.

Francois Templier, Strategic Marketing Manager for Photonic Devices for CEA-Leti, is quoted as follows:

"This new process paves the way to commercial, high-performance microLED displays. The CMOS-based approach provides higher brightness and higher resolution microLEDs, and is a gamechanger for very large TVs."

HERMETIC ALD ENCAPSULATION PREVENTS ELECTRONICS DEGRADATION

The April 2019 issue of CMM International (ref. p.8) explains how a collaborative project between Finnish-based Picosun and the European Space Agency has shown that Picosun's hermetic atomic layer deposition, or ALD, encapsulation method conclusively prevents electronics degradation.

The article 'Project shows Picosun's Hermetic ALD Encapsulation Method prevents Electronics Degradation' states:

'Picosun's ALD systems were used to develop hermetic ALD nanolaminate coatings, and these have proven to block tin whisker formation on printed circuit board assemblies (PCBAs) completely. During the observation period of over one month to three years, ALD nanolaminate coated samples showed no tin whisker growth at all, whereas on non-protected samples, tin whisker density of over 1,000 pcs per square centimetre was measured.

As well as blocking tin whiskering, hermetic ALD nanolaminate coatings help to protect PCBAs against other key degradation phenomena such as various forms of corrosion and oxidation. The coatings work efficiently, even against moisture and gaseous sulphur in polluted atmospheres. Furthermore, due to their nanometre scale thicknesses, the coatings have no effect on PCBA functionality, mass or dimension, and they allow for PCBA reworking.

Tin whisker formation and corrosion can be disastrous in several high reliability electronics applications, including space, aviation, military, medical and industrial control systems.Picosun's ALD hermetic encapsulation method lengthens product lifetime and delivers long-term cost savings. The PICOSUN P-1000 and PICOSUN P-300B high-volume batch ALD systems allow for the realisation of fast, cost-efficient processing of large numbers of PCBAs.'

Dr. Jani Kivioja, Chief Technical Officer for Picosun, is quoted as follows:

"This is a new, potentially huge market for ALD. There has already been lots of interest in our turnkey coating solutions for large-scale PCBA protection from the corresponding industries. This shows again the versatility of ALD and its power to disrupt nearly all fields of today's industrial manufacturing."

[Reference: 'Picosun and European Space Agency (ESA) Project: Evaluation of Atomic Layer Deposition (ALD) Conformal Coating to mitigate Tin Whiskering' (4000113 005/14/NL/PA), 2015-2018.]

MICROSCOPE LENS ENABLES TEMPERATURE MONITORING OF ULTRA-SMALL COMPONENTS

Another short feature, this time in the August 2019 issue of CMM International, ref. p.9, describes how UK-based Micro-Epsilon has developed a microscope lens that enables the temperature monitoring of ultra-small components using its thermoIMAGER TIM thermal imaging cameras.

The article states:

'The lens has been specially developed for printed circuit board (PCB) temperature measurements, PCB assembly monitoring and micro-sized solder and weld joint inspection. However, it is also suitable in a wide range of other industrial and laboratory temperature monitoring applications.

In addition to overall temperature profile images and videos, detailed macro shooting of individual objects is possible in real-time, at up to 125 Hz and based on a spatial resolution of up to 28µm. The distance between the camera and the object to be measured can be up to 100mm. Scalable temperature ranges are from -20 to +100 degrees Centigrade, from 0 to 250 degrees Centigrade and from 150 to 900 degrees Centigrade. Due to the large working distances, temperature measurements of electronic components can be carried out during electrical parameter function tests.

The lens enables the display and rapid analysis of quickly changing temperatures as well as the recording of radiometric images and videos. The data can be evaluated using the thermoIMAGER TIM cameras' TIM Connect thermography software, however it can also be exported into and evaluated using other programs.'

DETECTING AND CLASSIFYING DEFECTS IN SEMICONDUCTOR MANUFACTURING VIA AUTOMATIC DEFECT REVIEW WITH ATOMIC FORCE MICROSCOPY

This article, by Sang-Joon Cho, Vice President and Director of the R and D Centre, Park Systems Corporation, and Ilka M. Hermes, Principal Scientist for Park Systems Europe, in the October issue of *CMM International* (p.40-45), outlines how, as semiconductor devices are becoming ever smaller, so called 'defects of interest', or DOIs, are also becoming smaller, presenting a challenge for defect analysis:

'Traditionally defect analysis in the semiconductor industry comprises two steps. In step 1 (called defect inspection), imaging methods that afford a high throughput but low resolution - such as automated optical inspection (AOI) or scanning surface inspection (SSI) - provide maps with the coordinates of defect positions on the wafer surface. However, due to their low resolutions, AOI and SSI provide insufficient information when characterising nanometre-sized DOI, thus necessitating the second step.

In step 2 (called defect review), high-resolution microscopy methods - such as transmission electron microscopy (TEM), scanning electron microscopy (SEM) or atomic force microscopy (AFM) - image smaller areas of the wafer surface to resolve the DOI using the defect coordinate maps from defect inspection. Utilising the coordinate maps from AOI or SSI minimises the scan area of interest and thus the measurement time of the defect review.

The electron beams of SEM and TEM can potentially damage the wafers, but AFM is able to scan surfaces non-invasively if a non-contact mode is employed. Furthermore, only AFM is capable of imaging defects at a high vertical resolution as well as a high lateral resolution. Therefore, AFM provides quantitative 3D information on defects required for reliable defect classification.'

The technology of AFM is described by the authors as follows:

'AFM achieves the highest vertical resolution among conventional imaging methods by mechanically scanning surfaces using a nanometre-sized tip on the end of a cantilever. As well as contact mode, AFM can be operated in a non-contact mode, meaning the cantilever oscillates above the surface; here, changes in the oscillation amplitude or frequency provide information on the sample topography. Non-contact mode ensures non-invasive imaging of surfaces at high lateral and vertical resolutions.

Recent developments in automated AFM have meant that its application has spread from academic research to industry sectors such as hard disk manufacturing and semiconductor manufacturing. Industry has started to focus on the versatility of AFM and its ability to non-invasively characterise nanostructures in three dimensions. Hence, AFM is evolving into a next-generation inline measurement solution for defect analysis.'

A major challenge for AFM-based defect review, however, is the transfer of defect coordinates from AOI to AFM:

'Originally, the user manually marked defect coordinates using an optical microscope in an additional step between AOI and AFM, then searched for these coordinates in the AFM. However, this additional step proved time-consuming and lowered throughput significantly.

ADR-AFM, on the other hand, imports the defect coordinates from the AOI data. This requires an accurate alignment of the wafer as well as the compensation of stage errors between AOI and AFM. An optical surface analysis tool possessing higher position accuracy than AOI can reduce the stage error in a quick intermediate calibration step. The ensuing ADR-AFM measurement comprises a large-scale survey scan at the given defect coordinates, a high-resolution image of the defect and the defect classification. Since the measurement is automated, the user does not have to be present and throughput increases by up to an order of magnitude. ADF-AFM is used in non-contact mode to maintain the nanometre-range tip radius and high resolution for multiple subsequent scans. This prevents tip wear and ensures a quantitative defect review.'

ADDITIVE MANUFACTURING IN THE FABRICATION OF MEMS WAFERS AND SENSORS

In the December 2019 issue of *CMM International* (p.20-26) Doug Sparks, President of 3D Printed Wafers, explains how his company, a subsidiary of M2N Technologies, has developed a patent-pending technology known as AM+MEMS, which combines additively manufactured wafers with microelectro-mechanical systems (MEMS) sensing circuits. The

wafer is polished flat and thin film layers are deposited on its surface to build the MEMS sensing circuits.

The author describes the technique as follows:

'Additive manufacturing of single metal sensors is still a relatively expensive option and, in many cases, only cost competitive with CNC, casting and welded assembly for low-volume prototyping. To overcome this cost disadvantage, multiple sensors can be produced during the same print operation. This is the same commercialisation path that was taken for MEMS sensors a decade ago. Additive manufacturing allows the engineer to move from a CAD file to a structured wafer without the cost and time of photomask fabrication. The AM+MEMS fabricated, 100mm diameter titanium wafer can produce multiple small sensors and leverage wafer fabrication lithography tooling for building up surface circuitry layers. The wafer was printed using the DMLS method.'

In his article Mr. Sparks emphasises the need for post-processing of additively manufactured MEMS wafers, for example due to cracks and warpage, drawing parallels with welded parts. Annealing, often conducted in an inert atmosphere or vacuum, is therefore applied either before or after the part is removed from the build plate. Trapped metal powder from a DMLS or SLM print may also need to be shaken out of cavities.

Advantages

A number of important advantages are highlighted for this technology:

'A significant advantage of metal additive micromanufacturing of complex MEMS and microfluidic structures is that it can reduce the number of wafer processing steps required by traditional silicon MEMS fabrication methods. The most time-consuming of these methods are typically deep reactive ion etching (DRIE) and wafer-to-wafer bonding, which only allow one or two wafers to be processed at a time and can each take more than an hour. Furthermore, DRIE is somewhat limited in etching direction, specifically straight down or at a slightly fixed angle into the silicon or glass wafer; and wafer-to-wafer bonding to form

channels can result in problems with hermeticity at the bond interface and be prone to burst failure. In general, silicon has low-fracture toughness and is prone to rupturing under pressure or shock compared with metals such as stainless steel and titanium.

Not only can additive micromanufacturing reduce the step counts of traditional MEMS fabrication methods by hundreds, but it can form wafer features that are not possible using traditional silicon-based micromachining.

In the past MEMS wafer-to-wafer bonding has been required to begin the sensor packaging process by enclosing fragile sensing elements into a particle-free vacuum or inert gas-filled chip-scale package. Now, optically transparent plastic and metal wafers with cavities and bond pad openings can be additively micromanufactured using Kovar and titanium for wafer-level packaging.'

Another major problem that is overcome is the need in silicon and glass fluidics for the chip to be epoxied or soldered to the system package:

'This weak link in the silicon packaging step has resulted in chip attachment failure when the epoxy fails under high temperature or pressure or after chemical exposure over time. A CSFP that can be laser welded for metal or solvent welded for plastic to the package affords a significant improvement in reliability for microfluidics in aggressive applications.'

Another problem that is addressed is the need with sensors to have an electrical interface on the sensor wafer:

'Traditional MEMS integrate the electrical interface for sensors using wafer fabrication processes, leveraging integrated circuit fabrication technology. By using wafer fabrication photolithography tools, the minimum feature dimensions for metal traces can go down from 5 to 2µm for proximity tools and from 2 to less than 0.09µm for stepper lithography tools.'

Leveraging the existing MEMS wafer foundry infrastructure is envisaged to enable rapid commercialisation of AM+MEMS:

'Many traditional silicon MEMS foundries that do not produce complementary metal-oxide semiconductor (CMOS) or bi-polar CMOS (BiCMOS) wafers have allowed the processing of sodium-containing wafers such as Borofloat 33 borosilicate glass and titanium. This opens up the possibility for not only AM+MEMS fabricated wafer prototypes but high-volume manufacturing. Some MEMS foundries are processing 100, 150 and 200mm diameter metal and glass wafers, and it is these that would benefit from the commercialisation of AM+MEMS technology.'

ELECTRON ENHANCED MATERIAL PROCESSING

In semiconductor fabrication the traditional approach to dry etching has been to utilise radiofrequency plasma to bombard the surface of the wafer with positive ions in order to remove material between masking layers, but this method does not provide the precise, sharp nano-sized structures and pathways needed for present next-generation devices. It also generates considerable excess heat that can damage underlying material layers and, in the case of compound semiconductor materials such as gallium nitride (GaN) and silicon carbide (SiC), can also change surface atomic ratios.

In the February 2020 issue of *CMM International*, Samir Aziz and Stewart Nando, Co-founders of VelvETch, Michael Barden, Head of Research and Development for PVA TePla America, and William A. Goddard III, Professor of Chemistry, Materials Science and Applied Physics at the California Institute of Technology (p.12-17) in their article 'Electrons are able to deliver exceptional Plasma Etching of Nanoscale Semiconductor Devices' describe how the emerging technology of Electron Enhanced Material Processing, or EEMP, is overcoming modern-day challenges by using the power of electrons, rather than ions, to remove material much more precisely at the nano-level.

The authors state:

'It is a common misconception that electrons are not capable of etching, but this is based on the assumption that the process in question involves electron beam scanning.

In EEMP, precisely controlled waves of electrons are accelerated to the surface of the material at specific voltages to create chemical reactions that release the surface atomic bonds, allowing the material at the surface to be gently lifted away. A full-scale immersion by electrons allows the item being processed, such as a wafer, to be completely etched at a rate comparable to RF plasma etching.

EEMP is flexible, allowing various factors to be precisely controlled to essentially etch any material, including thin nano-layers and quantum well structures. It can also be fine-tuned and controlled to achieve atomically smooth surfaces, thus enabling the fabrication of quantum computing devices.'

At The California Institute of Technology it was discovered that electrons in a discharge, with sufficient energy, can remove an electron buried deep inside an atom, which in turn is replaced by an electron from a bond, whilst simultaneously knocking a second electron out of a bond. If two electrons are lost from a bond it breaks, creating what is known as the Auger Effect. It is this theory that forms the basis of this new technology:

'This system utilises a proprietary bias waveform signal that pulls the electrons down to the surface being processed. The bias waveform signal is applied across the whole surface of the wafer and this is the mechanism that accelerates a wave of electrons towards the whole surface. As electrons have little mass, there is no impact damage to the surface and only nominal heat is generated as a result of the chemical reaction, thus the wafer remains at room temperature.'

In commercialising the process VelvETch and PVA TePla America adopted direct current (DC), as opposed to making it RF-based, in order to obtain low temperature plasma:

'DC plasma (DCP) allows for a controlled positive column that is extremely rich in low energy electrons, thus enabling the EEMP plasma etching system to provide a high level of reliability.'

SCIENTISTS 3D PRINT ALL-LIQUID LAB-ON-CHIP

In 2018 a new technique was devised for the printing of various liquid structures within another liquid and in the May-June 2019 issue of *Med-Tech Innovation News* the article 'Bridge over Coupled Waters' (p.32) describes how this innovation was later extended to enable liquid printing to be used to fabricate a fully-functioning device.

The concept involved printing liquids in defined channels and then flowing contents through them without destroying them, and the article describes how Wenquian Feng, a post doctoral researcher in Berkeley Labs' material sciences division, designed a specially patterned glass substrate to facilitate this:

'When two liquids - one containing nanoscale clay particles, and another containing polymer particles - are printed onto the substrate, they come together at the interface of the two liquids and within milliseconds form a very thin channel or tube about 1mm in diameter.

Once the channels are formed, catalysts can be placed in different channels of the device. The user can then 3D-print bridges between channels, connecting them so that a chemical flowing through them encounters catalysts in a specific order, setting off a cascade of chemical reactions to make specific chemical compounds, and when controlled by a computer, this complex process can be automated "to execute tasks associated with catalyst placement, build liquid bridges within the device, and run reaction sequences needed to make molecules".

The multitasking device can also be programmed to function like an artificial circulatory system that separates molecules flowing through the channel and automatically removes unwanted by-products while it continues to print a sequence of bridges to specific catalysts, and carry out the steps of chemical synthesis.'

The next stage of development is electrification of the walls of the device using conductive nanoparticles in order to expand the types of reactions that can be explored. It is envisaged that all-liquid circuitry will then be created.

LIGHT PULSES ENABLE SUPERFAST COMPUTING

The June 2019 issue of *Data Centre Review Magazine* (p.6) describes how an international team of scientists, including Dr. Rostilav Mikhaylovski of the University of Lancaster, has successfully deployed light pulses in place of electricity in order to provide superfast data processing. This uses magnets to record computer data, consuming virtually zero energy, so solving the age-old dilemma of how to create faster data processing speeds without the accompanying high energy costs:

'The team demonstrated this new method by pulsing a magnet with ultrashort light bursts (the duration a millionth of a millionth of a second) at frequencies in the far infrared, the so-called terahertz spectral range.

However, even the strongest existing sources of the terahertz range did not provide strong enough pulses to switch the orientation of a magnet to date. The breakthrough was achieved by utilising the efficient interaction mechanism of coupling between spins [tiny magnets] and terahertz electric field, which was discovered by the same team.

The scientists then developed and fabricated a very small antenna on top of the magnet to concentrate and thereby enhance the electric field of light. This strongest local electric field was sufficient to navigate the magnetisation of the magnet to its new orientation in just one trillionth of a second. The temperature of the magnet did not increase at all as this process requires energy of only one quantum of the terahertz light - a photon - per spin.'

Dr. Mikhaylovski is quoted as follows:

"The record low-energy loss makes this approach scalable. Future storage services would also exploit the excellent spatial definition of antenna structures enabling practical magnetic memories with simultaneously maximal energy efficiency and speed."

Future plans include research at the University of Lancaster which will utilise the university's new ultrafast laser together with accelerators at The Cockcroft Institute that can generate intense pulses of light to allow switching magnets and to determine the practical and fundamental speed and energy limits of magnetic recording.

NEW ENGINEERING INSTITUTIONS FOR CHILDREN

In his Editorial for the July issue of *Smart Machines and Factories* Aaron Blutstein says how he was "lucky enough" to have attended the launch of two new engineering institutions for children, namely The Institution of Primary Engineers and The Institution of Secondary Engineers, at The House of Lords in June.

He notably agrees with the comments of Professor John Perkins CBE FREng, author of *The Perkins Review of Engineering Skills*, that "the Institutions will provide the framework for bringing together STEM initiatives and education into a single cohesive journey for children that will track and celebrate their progress as they move through the education system."

Pages 8 to 9 provide a more detailed account of the launch and quote Dr. Susan Scurlock, Founder of The Primary Engineer and creator of the two new Institutions as follows:

"The primary school children of today will, within the next quarter of a century, be the original thinkers, problem solvers and collaborators that change the world. The Institutions of Primary and Secondary Engineers will empower children to navigate a pathway to work while identifying, building and supporting engineers in the making. This is the beginning of a cycle that will embed fundamental skills in children from a very young age providing them with the foundation for their and our future.

The Institution of Primary Engineers and The Institution of Secondary Engineers have been a long time in research and development and today signal a major turning point in the identification and development of fundamental skills at an early point in a child's education. They are a modern tool, based on age-old professional membership organisations which seek to support, nurture and acknowledge best practice. Too often, children who are excited by engineering skills and project-based learning are unable to pursue them consistently through their educational journey, and many able students lose the thread into STEM related careers. We've now bridged the gaps between each phase of their education and will give school children an idea of what belonging to a professional body in a highly professional environment feels like."

The two Institutions have been designed to help pupils and teachers structure skills, both personal and those closely related to engineering, and the wider STEM curriculum continuously throughout a pupil's educational journey. Delivered via an online portal they allow teachers to create, access and evaluate projects while keeping track of the skills their school delivers.

More information is available from www.onedotall.com

NORTH WEST BENEFITS FROM DIGITAL PILOT TECH PROGRAMME

Nine companies based in Greater Manchester, Cheshire, Lancashire and the Liverpool City Region have become the first in the UK to benefit from the £20 million government-funded Made Smarter regional pilot, which is designed to enhance productivity through the use of 'smarter' manufacturing technologies.

Under the scheme the nine companies will introduce a total of twelve advanced manufacturing technologies, including Artificial Intelligence, The Industrial Internet of Things (IIoT), 3D-Printing and robotics. This is expected to generate around £5.5 million in gross value added, or GVA, for the North West economy. Ultimately it is hoped that the scheme will engage with over 3,000 SMEs in the North West and create GVA in the region of around £115 million.

In addition to the programme, up to 600 North West firms will also qualify for more in-depth support that includes mentoring from senior industry figures, a leadership and management programme designed to support leaders in implementing digital change, and additional grants for new tools and equipment.

The Made Smarter initiative comes as a result of the Made Smarter Commission, a partnership between the Department for Business, Energy and Industrial Strategy (BEIS) and the private sector, and includes representatives from 17 leading UK manufacturers, technology companies and business representative bodies.

The June issue of *Industrial Technology* (p.6) lists the nine companies as follows:

* EnviraSystems (Preston)

* Abbey Group (Knowsley)

* DT Engineering North West Limited (Widnes)

* Graham Engineering (Nelson)

* T and R Precision Engineering (Colne)

* The Nursery Kitchen (Birkenhead)

* Fusion Implants (Liverpool)

* Mackinnon and Saunders (Altrincham)

* Applied Nutrition (Liverpool)

AI BOOSTS MACHINE UPTIME

The article 'Making Sense of Sounds: How AI can boost Machine Uptime' by Sebastian Christian, AI Engineering Director at Analog Devices, in the November/December issue of *Industrial Technology* (p.24-25) explains how his company has developed a system called OtoSense that learns sounds and vibrations from a machine and then evaluates their meaning in order to detect abnormal behaviour and perform diagnostics:

'The process by which humans make sense of sounds can be described in four familiar steps: analogue acquisition of the sound, digital conversion, feature extraction, and interpretation.

Analogue acquisition and digitisation in OtoSense is performed by sensors, amplifiers and codecs. For feature extraction OtoSense uses a time window that Analog Devices calls "chunk", which moves within a fixed step size. OtoSense shows a graphical representation of all the sounds or vibration heard, organised by similarity, but without trying to create rigid categories. This lets experts organise and name the groupings seen on screen without trying to artificially create bounded categories.

A feature is assigned an individual number to describe a given attribute/quality of a sound or vibration over a period of time (the time window or chunk). A portion of the OtoSense platform's two to 1024 features describe the time domain. They are extracted either right from the waveform or from the evolution of any other feature over the chunk. Some of these features include the average and maximal amplitude, complexity derived from the linear length of the waveform, amplitude variation, the existence and characterisation of impulsions, stability as the resemblance between the first and last buffer, skinny autocorrelation avoiding convolution, or variations of the main spectral peaks.

The features used on the frequency domain are extended from the FFT. The FFT is computed on each buffer and yields 128 to 2048 individual frequency contributions. The process then creates a vector with the desired number of dimensions - much smaller than the FFT size, but that still extensively describes the environment. OtoSense initially starts with an agnostic method for creating equal-sized buckets on the log spectrum. Then, depending on the environment and the events to be identified, these buckets adapt to focus on areas of the spectrum where the information density is high, either from an unsupervised perspective that maximises entropy or from a semi-supervised perspective that uses labelled events as a guide. This mimics the architecture of our inner ear cells, which is denser where the speech information is maximal.

Two different strategies are used to evaluate the normality of an incoming sound or vibration. The first is called "usualness" where any new incoming sound that lands in the feature space is checked for its surrounding, how far it is from any baseline points and clusters, and how big those clusters are. The bigger the distance and the smaller the clusters, the more unusual the new sound is and the higher its outlier score is. When this outlier score is above a threshold as defined by experts, the corresponding chunk is labelled unusual and sent to the server to become available for experts.

The second strategy is very simple: any incoming chunk with a feature value above or below the maximum or minimum of all the features defining the baseline is labelled as extreme and sent to the server as well. The combination of unusual and extreme strategies offers good coverage of abnormal sounds or vibrations, and these strategies perform well for detecting progressive wear and unexpected, brutal events.'

The technology is said to have "shown good performance" in situations that once required human expertise and in those involving embedded applications, especially on complex machines.

SMART AIR SPRING FOR PREDICTIVE MAINTENANCE

The February 2019 issue of *Industrial Technology* (p.16) describes how technology company Continental has developed a new air spring with integral sensor technology that provides hitherto unachievable continuous operational status information in real-time. This is particularly useful in the construction sector where machines have to continually deliver peak performance in a harsh environment.

The article 'Smart Air Spring provides Status Info for Predictive Maintenance' quotes Carsten Klages, Sales Manager for Industrial Applications at Air Spring Systems, as follows:

"The purpose of the integrated-sensor air spring system is to make a globally established system such as the air spring even safer, simpler and more efficient for customers - and thus also all the associated operations and processes, particularly in the fields of control and monitoring.

The greatest challenge in incorporating the sensor system really lay in integrating the fine wiring of the electronics in the product such that the air spring properties are not changed and the electronic system is not damaged."

In order to overcome this difficulty the experts at Continental produced a specially developed adapter, which ensures that there is a reliable connection between the air spring and the sensor system. With this two cables are used, one to connect the air spring control system and the other for the data connection. The sensor is therefore enabled to measure the mechanical status of the air spring completely automatically. The resulting information is then transmitted to the machine controller.

Herwig Peters, Head of Industrial Applications of Air Spring Systems for Continental, says:

"This development is a milestone in air spring technology. We're ushering in the next stage in digitisation. The air spring has been made smart, enabling it therefore to communicate with the user."

More information is available at www.contitech.de

AUTOMATING THE AEROSPACE SECTOR

This article in the October issue of *Industrial Technology* (p.10) is an Aerospace Report that describes how Astech Projects, part of the Schauenburg International group of companies, and a major supplier of robotics and automation solutions across many industry sectors, was approved by a leading UK aerospace company to build a bespoke automated masking system to mask complex areas of aircraft components to avoid precious metal coverage during manufacturing.

The system was required to have the capability to mask 14 component variants, while offering the functionality to add additional variants in the future, and although masking and coating is a common application, automation of it is not.

For this development Astech turned to the expertise of adhesive and coating specialist Intertronics, who had already established that its Dymax 717-R SpeedMask resin product was effective in protecting precious metal during the manufacturing process. With the masking resin selected, they worked on establishing the success of the preeflow eco-PEN450 as the dispensing mechanism. This was chosen for its high accuracy (plus or minus 1 per cent, 99 per cent of the time), and because the system has no fluctuation in the volume of resin dispensed with any change in viscosity. Intertronics also supplied the appropriate curing equipment, including high-intensity UV lamps, so the resin could be cured quickly in twenty to thirty seconds:

'The fully-automated system incorporates a 3-axis cartesian robot and two 6-axis robots working in synchrony according to one robot program. It also includes a high-definition vision system, masking dispensing system, and UV curing station. On a batch-by-batch basis, the system can correctly identify and orientate 14 types of part against the preeflow eco-PEN450, which accurately dispenses the Dymax 717-R SpeedMask product. The part is then taken to a curing chamber, where it is illuminated with high-intensity UV. Once the process is complete, the component is returned to its original input location. The process repeats itself until the entire batch of components has been processed.'

Matthew Baseley, Technical Sales Office Supervisor for Intertronics, states:

"The main drivers behind the project were to accurately and repeatedly mask the component. The final result dispenses to an accuracy of 100 microns, a great achievement. Astech Projects' bespoke system offers the client a significant labour saving and increases throughput with the client now channelling 60 per cent of its components through the system."

5G MMWAVE: AN OPPORTUNITY TO REVOLUTIONISE ON-TRAIN CONNECTIVITY

This article, by Simon Holmes, Group Head of Digital (Engineering) at First Group, in the April-May 2019 issue of *Rail Technology Magazine* (RTM), p.88, describes how First Group and its partners have pioneered a 5G millimetre Wave (mmWave) that now offers connectivity that previously would have been impossible.

With the help of partners, notably Blu Wireless and Network Rail, First Group has worked to harness the 5G mmWave spectrum to achieve over one gigabit per second throughput to and from high-speed trains, that is a connection powerful enough to enable HD video streaming as well as reliable access to the cloud-based applications that many passengers use.

The author states:

'This project is breaking down barriers of commercial viability and technical feasibility that previously seemed intractable. During 2020 we plan to roll out this technology on our South Western Railway (SWR) franchise to create the first "gigabit railway", with work already underway. The technology we are implementing can process volumes of data 100 times greater than is possible on current mobile deployments, vastly increasing the consistency and quality of the wi-fi that our passengers will enjoy on their journey throughout this rail network.

The system is based on Blu Wireless' "mmWave" communication technology, which does not require the complex and expensive infrastructure of mobile systems. We believe that the combination of gigabit level data throughputs with cost-effective and ultra-low power operation will be instrumental in delivering First Group's customers with best-in-class on-train wi-fi services.'

NETWORK RAIL LAUNCHES INTELLIGENT INFRASTRUCTURE (II) PROGRAMME

2019 saw the launch of Network Rail's Intelligent Infrastructure (II) programme, a five-year Control Period 6 programme to deliver information derived from data that will inform the routes precisely where their assets are, how they are performing, how they are degrading and when they are likely to fail. This aims to assist engineers to prioritise and plan their opex and capital work bank and reduce the number of things that they have to respond to urgently.

In the December 2019 - January 2020 issue of *RTM*, Network Rail's Jonathan Schofield, in his article 'The Age of Intelligent Infrastructure' (p.22-23) explains:

'Working directly with the routes, the II programme will help the routes move from time-based, fix-on-rail maintenance to information-led predict and prevent regimes; capture, analyse and exploit asset data to help the routes prioritise the most critical work and to drive a 10 per cent service affecting failure improvement. This will be achieved through the development of automated network monitoring, advanced data analytics, aerial surveys and integrated decision support tools. The programme's workstreams include Track Signalling, Ellipse (Network Rail's central data base) Planning, Civils and Operational Property.

The first significant output from the programme is the Enhanced Track Decision Support Tool (eTDST). Delivered in November 2019 as a prototype, it is now being evaluated by engineers in the routes.

Containing a range of key data sets, it presents information via a maintenance dashboard underpinned by decision support capability for track geometry (TG). It aligns with TG outputs from Network Rail's fleet of measurement trains, identifying rates of degradation and highlighting sites at risk of reaching Alert Limit (AL) and Immediate Action Limit (IAL). This allows engineers to filter information by TG parameters, engineers' line references, track ID, start and end mileage, sleeper type and track category. The tool highlights where deterioration rates indicate a section of track will reach an AL within a 90-day window. This allows front line staff to have enough time to plan the right intervention at the right place at the right time allowing the business to shift from reactive to proactive regimes.

An algorithm developed internally within the II programme aligns trace data from the measurement trains to provide maintenance teams with run on run trace that can be used to analyse and demonstrate asset deterioration over time. This replaces the current paper trace method of viewing and analysing track geometry data. The tool is mobile responsive on both android and iOS devices, allowing engineers access to the data they need from any location at any time across the network.'

The article quotes Western Infrastructure Maintenance Engineer Dan Collins as follows:

"The aeronautical industry has data management systems that tell engineers how long a wing or fuselage component will last. They know exactly when they should intervene and that's precisely the level of knowledge and evidence the rail industry should work to if we want to meet the current challenge let alone future rail growth. Up until now we've relied exclusively on our engineering knowledge to arrive at timescales when building a Risk-based Maintenance Regime, but too often it involves making some assumptions and our current data sources are very difficult and time-consuming to use for trend analysis.

With the enhanced predict and prevent capability the II programme is looking to deliver, and by exploiting the potential of decision support tools like the eIDST, we are reaching a point where we can trust the information given to us to carry out predictive maintenance to actively fix faults before they impact our customers."

AUTONOMOUS VEHICLES DRIVE DATA CENTRE REQUIREMENTS

In *Electrical Review* (January - February 2019) Natalie Sauber, Market Intelligence Lead for Arcadis, in her article 'Shifting Gears' (p.24-26) focuses on the prediction that by 2025 autonomous and connected vehicles will generate over $200 billion in annual global revenue for automotive manufacturers and others, but underpinning this is the requirement for these vehicles to transmit over 100 petabytes of data to the cloud every month. She reminds us that a petabyte is over a million gigabytes and that this is equivalent to digitising around half of the printed material ever published. Looking further ahead, she estimates that by 2050 the data volume between vehicles and the cloud will need 10 exabytes a

month, which is some 10,000 times the present volume, an exabyte being around a thousand petabytes and equivalent to 250 million DVDs of data.

The author states:

'Connected and autonomous vehicles [CAVs] will soon communicate in real-time between each other (V2V) and vehicle-to-everything (V2X) for enhanced safety and convenience. For CAVs to operate safely and efficiently, reliable ultra-low latency vehicle-to-infrastructure (V2I) communication is critical.

As it stands today, the 4G cellular network can facilitate management of certain tasks back to the CAV, such as weather and road conditions and real-time information on accidents. However, providing high definition maps and identifying obstacles and objects moving near the vehicle requires constant reliable processing with low latency.

Far better is the 5G network currently being rolled out, which processes data up to 1,000 times faster than the existing 4G networks. The 5G cellular base station network will support connectivity and control for the CAVs, as the V2I wireless system will be capable of managing all the different tasks required by the AV, while at the same time operating under constant network connectivity.

The transfer into hyperscale cloud facilities for big data analytics and management precedes a fully integrated (V2X) ecosystem. However, delivering that data to the data centre is challenging with estimates suggesting that approximately $1 million needs to be spent on each data centre infrastructure for each AV.'

Ms. Sauber therefore points to "a dire need for new approaches on data centres to meet the demands of the new mobility value chain from data ingest to deep learning and simulation capabilities" and "a definite need to increase network capability between vehicles and the cloud by implementing edge computing and more efficient network designs".

She then devotes the latter part of her article to some of the initiatives that are now underway in response to this demand, pointing notably to car manufacturers Toyota, BMW and Ford:

'In 2016 Toyota announced plans to build its Data Centre for Connected-Car Data. Meanwhile BMW is planning to use IBM's cloud infrastructure to deploy its new platform for collecting data from connected cars. In 2017 Ford announced plans to build a $200 million data facility centre to store connected car data in Detroit. The American manufacturer predicts that their data storage requirements will rise from today's 13 PB to an astounding 200 PB by 2021.'

In the UK the West Midlands Combined Authority is set to receive up to £20 million to allow the Warwick Manufacturing Group to set up a UK Mobility Data Institute, which will be a focused research centre designed to collect, process and analyse transport data generated by autonomous vehicles, along with smart charging of electrified vehicles.

IMPLEMENTING BLOCKCHAIN AT CATERPILLAR

The technology of blockchain has previously been reported in *The Electron*. In this issue we present a case study from Vol. 22 Issue 9 (November 2019) of *The Manufacturer*, outlining how construction equipment manufacturer Caterpillar has worked with the Institute for Manufacturing at the University of Cambridge in a pioneering application of the technology in order to realise a range of improvements to the company's supply chain.

The article 'Blockchain: Driving Productivity, Traceability and Customer Experience in Supply Chains' by Dr. Veronica Martinez of the Institute for Manufacturing, and Caroline Burstall and Andrew Noblett of Caterpillar (p.42-45) is also reference as Martinez, V., Zhao, M., Bhydea, C., Han, X., Neely, A. and Albores, P., 'Blockchain-Driven Customer Order Management', *International Journal of Production and Operations Management*, 4th. July 2019.

The pilot project described focuses on a part of Caterpillar's business which sells diesel and gas engines that are customised to meet each customer's individual needs. Managing the customer orders has tended to be manual, with modifications to the customer's specification coming in through traditional channels such as phone, fax and email. These requests were then checked by Caterpillar's production team in order to ensure that they were deliverable.

There followed a back and forth process of specification and negotiation that could last for several days, involving six employees with information being stored in different formats, in different places by different people. This process was notoriously inefficient and prone to quality problems.

Blockchain was subsequently identified as a possible solution for the streamlining of the process, with the potential to make it more efficient, as well as preserving secure and accurate information:

'The technology's characteristics matched the business needs, offering "traceability of transactions" - tracking who, what and when an order was placed or modified. Furthermore it secures "irreversibility" of records, offering a safe bridge of "trust" between the customers and suppliers.

Our mission was to build and use blockchain to automate the interactions between the customer (demand) and the manufacturing site (supply).'

The project had two key elements, namely programming the blockchain and simulating the business process:

'With no prior experience our first task was to decide which technologies to use, bearing in mind that one of Caterpillar's requirements was to keep everything as simple as possible so that its employees could learn how to do it themselves. We reviewed the options and picked the most basic applications: Hyperledger Composer for the backend (building the blockchain) and React for the user interface. Both applications happen to be free.'

It took four people six weeks of study, mainly from online videos, to write and debug 5,000 lines of code. The other part of the process then required mapping the complexity of the existing system, i.e. identifying all the touch points between the firm and its customer, and where the data was being stored, and to specify a more streamlined blockchain enabled approach. The end result was a real-time method of sharing and managing data in a single record:

'Once we had our blockchain in place and had tested it with one of Caterpillar's customers, we carried out a "before and after" analysis to show what we had achieved. By automating the process, we had reduced the number of storage points from 20 to two, we had reduced the time taken to produce a new order by two thirds and we had halved the number of people needed to carry out the task. And we had a very positive response from the customer who was now using a bespoke user interface, which we had co-designed with its procurement team.'

The article presents the following full list of benefits:

* Reduction of the number of operations needed to place or amend orders, consequently making the customer order management process simpler and leaner - blockchain reduced the process for placing orders from 21 to six operations.

* Reduction of the average time of orders in the system by more than eight hours (493.3 minutes saved for placing orders).

* Display of traceability of orders through the user interface via dashboards.

* Improved visibility to various supply chain participants through the written rights set on blockchain.

* Consolidation of a single point of entry for the placement and amendment of orders.

* Removal of multiple checkpoints such as MRC, EDI, customer portal and emails.

* Reduction of manual input into the orders.

* Elimination of duplications of report status such as Excel sheets.

* Lowering of the number of storage points.

* Reduction of the number of account coordinators from six to three.

* Reduction of the number of errors and mistakes in the system.

The article concludes:

'Our research is the first to demonstrate that blockchain improves the efficiency of the processes involved in our pilot project: it reduces the number of operations, reduces the average time of orders in the system, reduces workload, shows traceability of orders and improves visibility to various supply chain participants.'

The pilot showed that it is possible to implement blockchain in-house on a small scale and manage its growth in a way that provides quantifiable benefits without introducing massive disruption and cost.

BITCOIN THREAT TO CLIMATE CHANGE

The small feature 'Not Coins of the Realm' in Vol. 253, No.6 (June 2019) of *Electrical Review* (p.8) highlights a study at the University of Hawaii Manoa that warns of "a catastrophic escalation of climate change" as a result of the increasing use of Bitcoin and other cryptocurrencies.

Researchers analysed the power efficiency of computers used in the administration of Bitcoin and estimated that the activity was responsible for the production of 69 million metric tonnes of carbon dioxide in 2017. Projecting this forward they concluded that if Bitcoin is taken up at similar rates to other new technologies it is likely to raise global temperatures by two degrees in the next 16 to 22 years.

Bitcoin purchases create encrypted transactions that are recorded and processed by a group of individuals known as 'miners' who group each Bitcoin transaction executed during a given timeframe into a 'block', which is then added to an online 'chain'. The study suggests that the electricity demands for the mining verification process are "very high indeed" and the study's Lead Author Professor Camilo Mora is quoted as follows:

"We cannot predict the future of Bitcoin, but if implemented at a rate even close to the slowest pace at which other technologies have been incorporated, it will spell very bad news for climate change and all the people and species impacted by it."