Conference report - SPIE Microtechnologies 2017

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The 8th SPIE Microtechnologies conference took place between 8-10th of May 2017 in Barcelona, Spain, conglomerating four symposia in the fields of Smart Sensors, Actuators and MEMS; Bio-MEMS and Medical Microdevices; Nanotechnology; and Integrated Photonics: Materials, Devices and Applications.

The conference featured several plenary talks, an interactive poster session, and between three to ten sessions per symposium, with ten invited papers throughout the conference. The large scale and international representation at this conference provided a unique experience and an excellent opportunity to present my own work: a cathodoluminescence study of InGaN/GaN core-shell nanorods structures for optimising next generation LED devices. This presentation was given as an example case of the work I do as part of the ManuGaN project, a collaboration between the Universities of Sheffield, Bath, Bristol and Strathclyde to harness multidisciplinary experience in III-V material research to create the foundation for a new manufacturing industry. Discussion from the presentation began with exploring the potential of investigating quantum dots using such a set up as was presented, and came to focus around the potential of future core-shell nanorod-based LEDs against current planar-based designs. The varied backgrounds of the audience proved very beneficial, making it possible to glean the perception of our work from scientists with less specific knowledge, and appreciate the figures of merit they look for as comparison points, which then allows us to plan out future work to reflect their feedback and hence bolster the project as a whole.

Similarly, the wide variety of topics covered allowed for a greater appreciation of the latest work occurring around the world. A selection of these works is presented below, along with the name of the speaker and the institute they represented.

Plenary talks

MEMS Microphone Innovations Towards High Signal to Noise Ratios

Alfons Dehé, Infineon Technologies AG

Dr Dehé presented a very informative introduction and background to the field silicon microphone research, a field I had little prior knowledge of, including the history of the devices and the key parameters for improving them: signal-to-noise ratio, the acoustic overload point or maximum tolerable sound pressure, and the size of the device. He presented some of the innovations he had introduced to the field and which have since become ubiquitous in devices which feature silicon microphones, including most modern smartphones – which can use up to 16 such microphones per handset, including several on the back of the phone to subtract environmental noise and improve the signal at the operational end. Such innovations included perforating the backplate of the device with holes of varying density and diameter to control the high frequency response of the microphone, and introducing a second such perforated plate on the other side of the active membrane, thus realising what he referred to as a 'true differential dual backplate MEMS'. Such a configuration allowed for a higher pull-in voltage, leading to a greater possible bias and thus a stronger signal from the microphone. The presentation was concluded with a prediction that future devices will be capable of a signal-to-noise ratio on the scale of 80 and less than $3mm^2$ in size, and a discussion of other potential applications of the dual backplate MEMS, in for example speakers or as photoacoustic CO_2 sensors with 50ppm resolution.

Graphene Technologies for Bioelectronics and Neuroprosthetics

Jose A. Garrido, Institut Català de Nanociència I Nanotecnologia (ICN2)

Professor Garrido's talk was on the topic of neural interfaces, such as cochlear implants, spinal cord stimulators, retina implants, etc., and specifically the unique ways in which graphene technology could advance research in this field. He identified some of the key requirements necessary for several example devices, and associated properties of graphene which could aid their functionality; for example: *in vivo* neural interfacing is currently done using 'spike pads' – rigid multielectrode arrays which penetrate brain tissue to record the action potential between neurons. There is a technology challenge available here to integrate high-end electronics capable of detecting these very small neural signals ($<10\mu V$) with flexible substrates on the scale of $10x10\mu m^2$. A design for such a device was presented, featuring graphene as the source and drain component of a field-effect transistor utilising the electrolytes present in brain tissue as gates. The talk concluded with an analysis of the electron transport properties of chemical vapour deposition grown graphene, to propose that advancements here present an opportunity to further this design to multifunctionality – capable of stimulation as well as recording.

Nanotechnology symposium talks

Carbon nanotubes as transparent charge collectors for hybrid perovskite photovoltaics

Anvar Zakhidov, University of Texas

The ability to paint photovoltaic material would be extremely useful and applicable in many parts of the world, reducing global reliance on unsustainable fuels to meet ever rising energy requirements. Perovskites are cheap and promising solar cell materials, not widely manufactured but showing a remarkably steep curve when plotting efficiency vs research/development time. This is primarily because perovskite solar cells are capable of thermalisation of hot carriers, resulting in charge separation by means of exciton diffusion. Carriers in perovskite solar cell materials benefit from high diffusion lengths and balanced carrier mobilities, however there are instability issues due to ionic motion and interfacing, making formation of essential p-i-n junctions difficult.
Professor Zakhidov's invited paper presented his approach to have a grating of perovskite material, and also replace the standard Au cathode interface with carbon nanotubes. The gratings are made by nanoimprinting to leave the desired grating structure. One of the images of this process shown in this presentation was of one of these structures which had broken during manufacture, but interestingly is had broken as a single solid, suggesting they are single crystal. The replacement of the cathode material with carbon nanotubes was decided on as they have strength above 35GPa, higher thermal conductivity than diamond, and are hugely conductive. A dry draw process was used to produce so-called 'carbon silk', with smoke-like density (see video). It was found that replacing the cathodes with this material lost efficiency (2%) compared with Au cathodes, but gained stability. Future work for the group includes using ionic liquid dipping to form an electrochemical double layer, charging the nanotubes and improving conductivity - increasing voltage across the ionic liquid gate has the effect of raising the energy of the carbon nanotube Fermi level to LUMO, turning on the device and having the IV curve resemble that of a solar cell. It would also be possible to open holes in the nanotube weave, increasing optical transparency but lowering the sheet resistance, making the device opaque to microwaves – i.e: inbuilt electromagnetic shielding.

Microfield emitters: characteristics and applications

Hidenori Mimura, Shizuoka University

Robotic investigation of the Fukushima disaster site in 2017 found an ambient background radiation of 650Gy/h, which was traced to fuel debris trapped in basement floors. In context, full body exposure to a dose of 5Gy can be lethal. Unfortunately, current imaging cannot withstand such harsh conditions – 200Gy will degrade a CCD, and while much hardier, a CMOS will degrade with exposure to 1kGy. In order to precisely locate the buried debris, there is then demand for an image sensor tolerant to gamma ray radiation in excess of 1MGy. In this presentation, Prof Mimura proposes a design based around use of a volcano-structured double-gate Field Emitter Array (FEA) and some photoelectric film – by systematically activating separate elements in the array, each of which can independently focus an electron beam and extract secondary electrons, an image can be created by recording the reaction between them, the photoelectric film, the sunlight, and an object.

Production of silver nanoparticles by the diatom *Phaedactylum Tricornutum*

Asher Wishkerman, Ruppin Academic Center

Diatoms are a type of eukaryotic algae with cell walls composed of SiO_2 which reproduce in a 'petri dish-like' geometry – overlapping shells are developed and then separate to leave 2 daughter diatoms. Interestingly, the species *phadactylum tricornutum* can reproduce even in the absence of a Si biomaterial environment. Dr Wishkermann used his presentation to demonstrate work taking advantage of *P.Tricornutum*'s ATPase pump-like mechanism in a silver nitre environment to have them produce silver nanoparticles.

Talks from other symposia

Powering a leadless pacemaker using a piezoMEMS energy harvester

Nathan Jackson, Tyndall National Institute

This talk was part of the Energy Devices session of the Smart Sensors, Actuators, and MEMS symposium. In pacemaker development, use of implanted capsules as a power source has recently overtaken use of epicardial leads, however these have a battery lifetime of ten years. This could be more than doubled by taking advantage of energy harvesting, however such a structure would need to be small enough to fit alongside the other devices within the capsule, and would only have a limited power allowance to avoid depriving the rest of the pacemaker. There are many options for energy harvesting, broadly categorised as solar, RF, thermal, and mechanical, however being limited to being implanted in a body only the latter of these is reasonable, and even then there are challenges which must be met. The energy harvesting device must be capable of low frequency operation, within the 20-28Hz range, and it must be able to cope with non-continuous vibrational sources, namely a regular heartbeat, which is more a series of impulses the waveform of which varies depending on the individual, the condition of the heart, and the placement within the heart. Previous efforts have included piezoelectric ribbons, but these are invasive and require leads. Dr Jackson presented an approach combining MEMS microfabrication methods with CMOS compatible thin-film piezoelectric materials to scale down whilst maintaining the necessary high power density. The proposed device would take advantage of shock-induced off-resonance vibration, a method previously used in energy harvesters in tyres to monitor pressure. The average acceleration force in a human heart is $(1.22 \pm 0.2)g$, however the proposed method requires about 10x that, so development is currently focussed on achieving the amplification by means of increasing the sensitivity of the device by utilising a multiple cantilever system.

Integrated photonics for infrared spectroscopic sensing

Juejun Hu, Massachusetts Institute of Technology

This invited paper was part of the Optical Sensing session of the Integrated Photonics – Materials, Devices and Applications symposium. IR spectroscopy is widely regarded as the leading method for fingerprinting gases and chemicals, however usually relies on the sample in question being brought into a lab environment due to the equipment required. Ideally, all of the discrete elements of bulky FTIR devices would be integrated into a single 'holy grail' mid-IR sensor-on-a-chip. Chalcogenides present an excellent opportunity in this regard, as in glass phase (ChG) they are transparent to a broad range of IR wavelengths, suitable for spectroscopic sensing, and in a polycrystalline-led phase they are capable of MIR photodetection. Their monolithic, epitaxy free deposition makes them compatible with Si substrates, and at low temperatures this means less disruption to crystal properties. By forming a spiral waveguide, Prof Hu *et al.* propose that it would be possible to booth the optical path length without increasing the surface footprint of a device, but increasing its sensitivity. A design was given for a high Q factor ChG micro-disk resonator capable of dual-mode detection, with refractometry and absorption spectrometry on-chip. This design utilised polycrstalline Pb(Sn)Te to deliberately introduce grain boundaries which could separate charge carriers and enhance oxygen diffusion to give a strong MIR responsivity, even at growth temperatures < 150°C. Results were shown from such a prototype device grown on Si, giving a detector with a quantum efficiency of 55%.

Micro-resonator-based electric field sensors with long duration of sensitivity

Amir Ali, The German Uni. In Cairo

This invited paper was part of the Biomedical Sensors and Microfluidics session of the Bio-MEMS and Medical Microdevices symposium. This paper involved monitoring the phenomenon of micro-photonic whispering gallery modes (WGM) for electric field detection. WGMs are also referred to as morphological dependent resonances, as tracking WGM shifts can allow for the determination of morphological changes of a physical object. To that end, Prof Ali's experiments were based around measuring the transmission spectra for a laser beam being projected through an optical fibre past a silica sphere, to couple the light into the sphere. The optical fibre was heated and stretched to thin it out to improve coupling at the point of contact with a 300µm diameter sphere to improve coupling, and the sphere itself was mounted between two capacitive plates such that the electrostrictive force could manipulate deformation of the sphere in a controllable way. The device proved to be capable of detecting electric fields on the scale of $100Vm^{-1}$. To increase sensitivity of the sphere to electric fields the silica was 'poled' – exposed to a 1MV potential for 4 hours, 'cured' - coated with dielectric, and mounted on a cantilever. It was found that the sensor's sensitivity had decayed exponentially 10 minutes after the poling stage, however could be sustained almost 150 times longer if the curing process occurred concurrently with the poling stage, referred to as 'curing while poling' (CWP). The reason was determined to be due to a change in the thermal expansion coefficient of the silica.

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