EXTREME TECHNOLOGY EXPLORES THE WORLD'S HOT-SPOTS

Prof Nick Wright
Newcastle University

Dr Alton Horsfall
Newcastle University

Interesting things very rarely happen in safe and secure circumstances – a maxim that is just as true for scientists as it is for explorers. Unfortunately, scientists have struggled for generations with the limitations of fragile equipment to take data outside a relatively limited environmental range. Recent developments in technologies that can withstand hostile environments may at long last allow scientists to explore fully the 90% of the Universe that lies outside the -55C to 125C range of conventional electronics whilst operating technologies under high pressure is of crucial importance for our understanding and safe exploitation of the oceans. Such interesting environments are of course of great importance not just for scientists but also for UK industrial sectors such as space, defence, energy and health.

The Extreme Technology program at Newcastle University has led the way in bringing together both academic and industrial expertise to extend the range of crucial technologies that can operate in such interesting places. An approach that is critical for society as well. For example, more than 600 million people worldwide live in the shadow of a volcano and many more can feel the effect of a major eruption. Recent headlines following the eruptions of Eyjafjallajökull (2010) and Grimsvotn (2011) in Iceland and Puyehue (2011) in Chile described the chaos caused to air travel, with over 500 flights cancelled in Europe within the last year. Between 1995 and 2010, the Soufriere Hills volcano on Monserrat destroyed half the island (including the capital, Plymouth, and the airport), killing 19 people and resulting in some 8,000 refugees being relocated in the UK.

Fortunately the prediction of volcano eruption has progressed since the Romans used the shape and texture of goat's entrails. A key breakthrough was the understanding (developed by David Johnston in the 1970s) that prior to eruption the components of the gas emitted from the volcano crater changes (Fig 1). This was demonstrated at the 1991 explosion of Mount Pinatubo in the Phillipines, where the flux of sulphur based gas changed by an order of magnitude in the days before the eruption.

Currently, the gas is evaluated using optical means, which requires equipment to be installed at the volcano site, or through the use of remote earth sensing. These techniques measure the content of the plume whilst in the sky, the readings are therefore diluted by the air and so highly sensitive equipment is required. Of course, once a volcano shows signs of activity, people are evacuated to a safe distance, limiting the possibility of further scientific study. There is therefore a requirement for a system which can be installed in the volcano and relay information relating to the concentration of key gas species to a remote location. The primary challenge is the conditions inside the volcano where the emitted gas is typically around 400°C and contains a high concentration of corrosive acids. These conditions are so extreme, that conventional silicon based electronics cannot function.

Fig 1 - a gas mixture of steam and acidic gases (typcially CO_2, SO_2, H_2S, H_2O and HF) venting from Mt Etna (photo courtesy of Dr A McGonigle, Sheffield University).

Within the Extreme team at Newcastle University and supported by the Engineering and Physical Sciences Research Council (EPSRC), we have demonstrated the key components of a system to monitor the concentration of gas in a volcanic fumaroles using an exciting new electronic material, an alloy of silicon and carbon – silicon carbide. The chemical and thermal stability of the carbon-silicon bond is greater than that of a silicon-silicon bond and this results in the ability to operate at higher temperatures (operation beyond 600°C has been demonstrated – Fig 2) and results in a material which is not affected by any known acid. Due to the relatively mature wafer and process technology, coupled with the excellent electrical and mechanical properties, silicon carbide is now the material of choice for the realisation of electronic sensor and control systems for deployment in aggressive environments.

Fig 2 - Silicon carbide electronics under a flame test in the Newcastle Laboratory (the insert at the bottom shows the construction of the sensor and associated electronics).

Over the last 10 years we have established at Newcastle University one of the world's leading academic groups in this field – collaborating with a whole raft of UK and international companies. This technology includes gas sensing arrays (capable for example of measuring gases such as hydrogen sulphide in the parts per million range), energy harvesting and power management systems, amplitude and frequency modulation transmission systems and instrumentation amplifiers, all capable of operation in such extreme conditions (Figs 2 and 3). The Extreme team thus stands at a unique threshold – we might at last be able finally to measure in real-time what is going on inside a volcano and realise the millennia-long hope of accurate eruption prediction.

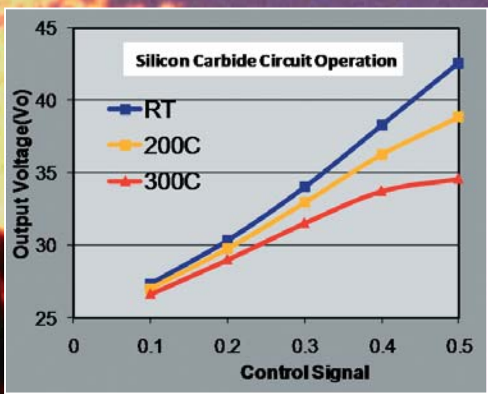

Fig 3 - Graph showing the comparative temperature stability of a silicon carbide electronic module.

In terms of UK research policy a key question is: how did we get to this exciting position? Firstly, we did not set out to study volcanoes – in the early days of our 10 year journey we were driven by simple curiosity and interest in the properties of new materials and their application to electronics. We felt that this would be useful (in fact we have advised dozens of prominent UK companies on such electronics over that period) but we were not quite sure where and how – our experience is inconsistent with the new requirements of research councils that academics must draw up so-called "impact plans" in advance of performing the actual research. We would contend that the most interesting applications of technology are rarely envisaged at the beginning – in fact not many people were even aware of volcanoes in Europe until the Icelandic eruptions of 2010. The work that we do is also highly multi-disciplinary and we could not have achieved the success that we have without close involvement with industry. In our direct experience, there is a lot of truly astonishing science and technology in UK companies – it has been very much a two-way knowledge exchange facilitated by fantastic schemes such as the Royal Academy of Engineering Industrial Secondments and consistent support from the EPSRC supplemented in recent years by our regional RDA, OneNorthEast.

And what of the future? Our colleagues in the Extreme Technologies program are also working on highly innovative technologies such as "through-metal communications", deep-water autonomous vehicles, and radiation-tolerant electronics. Driven by curiosity but inspired to apply our knowledge to lots of interesting places – check out our science and technology at http://www.ncl.ac.uk/eece/industry/extreme/or contact us at nick.wright@ncl.ac.uk