Institution:	University of Northumbria at Newcastle
Unit of Assessment:	15 - General Engineering
Title of case study:	Development of novel low-ohmic thin film resistors for TT Electronics plc.

1. Summary of the impact

This research within the Unit was in collaboration with TT Electronics plc. to develop a novel low-ohmic thin film resistor for precision current measurement in power management applications. TT Electronics plc. is an international company with 6,000 employees worldwide and annual sales of over £500 million to multinational clients such as BMW, Daimler and BAE Systems. Since 2008 the benefits of this research to TT Electronics plc. include:

- a new product launched with a full scale new production line (4.8 million units per annum);
- confirmed new orders of £2 million over the next four years with 12 new international clients;
- 10% reduction in the production cost for existing thin film based resistor products;
- an increase of employees by two per cent at Welwyn Components Ltd (TT Electronics plc. plant in Bedlington, UK).

2. Underpinning research

With increasing environmental awareness and ever-rising energy prices, there is a growing market demand for the low-ohmic high precision resistors in the range of 0.1-10 Ohms (Ω). This is especially so for portable devices for the purpose of saving battery power. For this type of application, the more precise the resistor value, the more accurate the current measurement in power management. Prior to this work there were no suitable materials available to fulfil this requirement. Thick-film resistors can cover an extremely wide resistance or ohmic range, but with poor precision. Existing thin-film material systems, where the material is vacuum deposited, offered the required precision but were not suitable to manufacture resistors below 10 Ω.

Since 1999, the Unit's academic staff, Dr Penlington (Principal Lecturer, 1994 – present) and Dr Birkett (Senior Lecturer since 2011) have been working on the development of new electronic components (1, 2). These activities resulted in the Unit being approached by TT Electronics plc. to carry out research into the development of a new copper-aluminium-molybdenum (CuAlMo) alloy with low resistivity. The initial results obtained were encouraging and led to a successful grant application (£72,500, The Royal Commission for the Exhibition of 1851: Industrial Fellowship, 2006-2009). The research resulted in the development of a new low-Ohmic alloy with a resistivity value of 80 μΩcm and a temperature coefficient of resistance (TCR) of <15ppm/°C, which could be used to manufacture thin-film resistors in the range of 100 mΩ -10 Ω (3-6). The main outcome of this research was the successful integration of the low resistivity copper with the self-oxidising properties of the aluminium to improve the material's stability. Finally, in June 2008 a small quantity of molybdenum was added to the system to control the TCR level and further improve the material's stability. Having developed the film material the research moved on to optimise its composition for full scale production of a new range of surface mount current sensing resistors at TT Electronics plc. in 2010.

3. References to the research

1. Putrus, G. A., Ahmed, M. M. R., Ran, L., Xiao, L., Penlington, R., and May, S. (2001) 'Hybrid fault current limiting & interrupting device', Northumbria & Northern Electric Distribution Ltd, Patent No. GB2375902
2. Ahmed, M. M. R, Putrus, G. A., Ran, L., and Penlington, R. (2006) 'Development of a prototype solid-state fault-current limiting and interrupting device', *IEEE Transactions on*

Power Delivery, **21** (4), pp1997-2005. DOI: 10.1109/TPWRD.2006.874584

3. Birkett, M., Brooker, J., Penlington, R., Wilson, A., and Tan K. (2008) 'Electrical characterisation of AlCuMo thin films prepared by DC magnetron sputtering', *IET Science, Measurement and Technology*, 2 (5), 304-309. DOI: 10.1049/iet-smt:20070076
4. *Birkett, M. & Penlington, R (2012) 'Laser Trimming of CuAlMo Thin Film Resistors: Effect of Laser Processing Parameters', *Journal of Electronic Materials,* **41** (8), pp2169-2177. DOI: 10.1007/s11664-012-2103-9
5. *Birkett, M., and Penlington, R. (2012) 'Laser trim pattern modelling and optimisation for CuAlMo thin film resistors', *IEEE Transactions on Components, Packaging and Manufacturing Technology,* **3** (3), pp523-529. DOI: 10.1109/TCPMT.2012.2223468
6. *Birkett, M., Penlington, R., Wan, C., and Zoppi, G. (2013) 'Structural and electrical properties of CuAlMo thin films prepared by magnetron sputtering', *Thin Solid Films,* **540**, pp235-241. DOI: 1016/j.tsf.2013.05.145

***** denotes the references that best indicate the quality of the underpinning research

Grant award

The research was supported by a grant from the Royal Commission for the Exhibition of 1851 (Industrial Fellowship of £72,500 for the period of 2006-2009, PI- Dr. R. Penlington).

4. Details of the impact

TT Electronics plc. is a global electronics company supplying the world's leading manufacturers in the automotive, defence, aerospace, telecommunications, computing and industrial electronics markets. They have average annual sales of over £500 million and employ over 6,000 people worldwide at manufacturing, engineering and sales support facilities in North America, Europe, the UK, Mexico, Barbados, Malaysia, Japan, Singapore, Hong Kong, India and China, with sales to major OEMs including BMW, MAN Trucks, Daimler, BAE Systems, Selex, Smiths detection, Thales, Boeing, Airbus, Schneider, Hager, Philips Medical and GE Medical.

The outcome of the Unit's research is the novel CuAlMo alloy film material. This has had the following economic and commercial impacts for TT Electronics plc.:

- Launched a full scale production in January 2010 (4.8 million units per year) and satisfied market needs for the precision low current measurement in power management applications with a large number of clients across the globe.
- Invested £750,000 in a new production line in 2007 to manufacture 4.8 million resistors per year, which in turn generated new production jobs.
- Created new full time jobs for the new production facility, in September 2009, thus increasing the number of employees by 2% at Welwyn Components Ltd. (TT Electronics plc. plant in Bedlington, UK).
- Increased the competitiveness in a new electronic component market (since 2010 till present) and won additional contracts with 12 new clients in the power management market sector, estimated to be worth £2 million over the next four years.
- Incorporated the newly developed material into the manufacturing of existing resistor products (24 million units per year) in March 2010, which reduced the production costs by 10%; through savings in resources such as equipment, power and material consumption and labour. The additional income generated as a result of using the new material for the production of existing resistors is currently at £120,000 per annum
- Reduced the number of vacuum deposition machines from five to two in November 2010, which led to a significant reduction in corresponding overhead costs related to the electricity and gas consumption and the maintenance by 60%. Since the developed thin film is also thinner, it is therefore easier to cut through at the subsequent laser trimming stages, which in turn has reduced the time from production to the market

This impact is corroborated in the following statement from the Global Product Line Director at TT Electronics plc.:

"The development of this new low resistivity thin film resistor material has been of significant benefit to TT electronics. The research collaboration between Northumbria University and TT electronics focussed on the development of a new precision resistor material which is used to satisfy a gap in the global market for precision current measurement in power management applications.

The end result of the research was in the form of a material composition of CuAlMo which not only satisfied this requirement but also allowed a wider range of resistor values to be manufactured at lower costs, providing savings in material, labour and overheads. This work has also been instrumental in the setting up of a new £750K surface mount thin film chip resistor production line at TT Electronics plc. This line now produces around 5 million resistors per annum and has created new jobs for full time production operators.

In summary the research work of a group of academics at Northumbria University on the development of a new precision current sense resistor material has been vitally beneficial for TT Electronics commercial activities in targeting a new growing market and generating new business and also in reducing cost of production of existing products."

5. Sources to corroborate the impact

Reports, reviews and web links or other documented sources in the public domain

Information on TT Electronics plc. http://www.ttelectronics.com

Low-ohmic Product Specification Sheet: http://www.welwyn-tt.com/pdf/datasheet/PCF.pdf

The following web link illustrates the link between Dr Martin Birkett and his research with TT Electronics plc.
Emerald Publishing (2007) 'Promotion for Electronics Talent', *Microelectronics International*, 24 (2) http://www.emeraldinsight.com/journals.htm?issn=1356-5362&volume=24&issue=2&articleid=1602741&show=html&PHPSESSID=6qgd5u94nakolm0q3ufdire2s1

The following web link reports on the development of the film for Welwyn Components Ltd. (TT Electronics plc.'s plant in Bedlington, UK).

Bush, S (2009) 'Copper-based Metallic Film Improves 0R1 to 10R Chip Resistors', *Electronics Weekly*
http://www.electronicsweekly.com/news/design/power/copper-based-metallic-film-improves-0r1-to-10r-chip-resistors-2009-05/

Individual users/beneficiaries who can be contacted to corroborate claims

The Global Product Line Director for TT Electronics plc. has provided a statement and can corroborate all of the impacts claimed in this case study.