Institution: University of Greenwich

Unit of Assessment: (UoA 13) - Electrical and Electronic Engineering, Metallurgy and Materials

Title of case study: Design for manufacture and reliability of microsystems

1. Summary of the impact

The Computational Mechanics and Reliability Group at the University of Greenwich has been developing design and materials modelling expertise and tools for electronic manufacturing and reliability since the late 1990s. This case study details economic and environmental impacts and impacts on practitioners. In particular it shows how our expertise has:

- substantially aided companies to assemble miniaturised electronic systems using environmentally friendly materials;
- aided companies to predict reliability of new electronic systems before physical prototyping providing significant cost savings;
- led to formation of spin out companies by our academic partners.

2. Underpinning research

The university uses computational reliability engineering and advanced materials analysis to assess the performance of complex microsystems components. It predicts how multi-component, multi-material systems will behave in myriad situations including variations in temperature, pressure, vibration, humidity, and over time. A central theme of the work is multi-physics process modelling and physics of failure reliability analysis of Microsystems (micro-electronics, power electronics, MEMS, etc).

A) Design for manufacture

Research began in 1998 when we developed multi-physics models to predict the assembly of semiconductor dies onto printed circuit boards - the so called flip-chip assembly process [3a]. Due to EU environmental legislation (Reduction of Hazardous Substances) there was an urgent need to extend our work to investigate lead-free solder assembly which we achieved for both Tin-Silver-Copper solders [3b] and Conductive Adhesives [3c]. These projects sought to enable high-volume production of the next generation of intelligent products, eg mobile phones, visual display equipment and medical devices, by providing industry with a process using appropriate microsystems technologies. We developed computational modelling techniques (eg through our multi-physics software tool PHYSICA) and advanced materials analysis which identified a *process route* to integrate microsystems-based components using low cost flip chip assembly, and adopt microsystems technology such as UV-LIGA to manufacture stencils with ultra-fine apertures in order to print solders and adhesive materials onto a substrate ant sub-100um pitch [3.1, 3.2]. These results were used by our industrial partners Henkel, Celestica, MicroEmmisive Displays, and DEK Printing Machines to implement the technologies.

Using our modelling expertise we have also worked with a number of companies to assess the impact of manufacturing processes and product design on the performance of electronic systems for the high reliability aerospace sector. Examples include the project ENDVIEW (http://bit.ly/1aXpPok) [3d] where we used our modelling techniques to predict optimal heat sink designs, and LED backlight designs for ruggedized displays for use in harsh sunlight environments. The results from our work have allowed GE-Aviation to optimise these new LED displays for cockpit environments. In addition to this we have been supported by the US Government [3e] and aerospace companies such as Selex-ES, Rolls Royce, Micross

Semiconductors, and General Dynamics (USA) to assess the performance of a robotic controlled process that refinishes lead-free components so that they are suitable for high reliability applications (eg submarines, avionics, etc) [3.3].

B) Design for reliability

Design for manufacture aims to ensure the microsystem developed from manufacturing is of high quality. The next step is to assess how reliable this component will be. We have used the physics of failure approach to predicting reliability of microsystems. For example with regards to lead-free solders and conductive adhesives, we have assessed the reliability of these interconnects particularly at sub-100um pitch [3.4]. This capability has led on to many consultancy projects with industry. For example consultancy work with Selex-Electronics Systems has used our expertise to predict the reliability of solder joints, and assessment of underfill materials for the radar signal processor used for the Eurofighter Typhoon aircraft [3.5].

Our expertise has also been used in developing physics of failure reliability models for power electronics components – particularly insulated-gate bipolar transistor (IGBT) modules. This started in 2005 through support from the Innovative Electronics Manufacturing Research Centre (IeMRC http://bit.ly/HbNs2Y) for the Flagship Project in Power Electronics [3h]. Here we developed a number of physics of failure reliability models for solders, wirebonds and bussbars and demonstrated how these can be adopted in a prognostics and health monitoring framework [3.6]. This work was also supported by Department of Trade and Industry project – Modelling Power Modules (MPM) [3i] which started the development of our software tool PowerLife which embeds algorithms to calculate the reliability and robustness of power modules. Working closely with our industrial partners such as SEMELAB and Dynex Semiconductors we have further advanced this tool through the EU project PEMREL [3j]. This tool is now used within both companies to optimise designs of power modules before physical prototyping.

Key staff: Professor Chris Bailey – Director of the Computational Mechanics and Reliability Group and project manager; group members include Dr Stoyan Stoyanov (Reader), Dr Hua Lu (Reader); Dr Chunyan Yin (Lecturer), Dr Nadia Strusevich (Lecturer), Dr Tim Tilford (Lecturer), Dr Pushpa Rajaguru (Lecturer). Dr Sabuj Mallik, Lecturer in Engineering, collaborated on the MAT21 project, providing material analysis expertise.

3. References to the research (REF1 submitted staff in **bold**, **REF2 Output)

3.1 Glinski, G. P., Bailey, C., & Pericleous, K. A. (2001). A non-Newtonian computational fluid dynamics study of the stencil printing process (Vol. 215, pp. 437–446). Presented at the Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, SAGE Publications. http://dx.doi.org/10.1243/0954406011520869

3.2 Durairaj, R., **Mallik, S., Seman, A., Marks, A., & Ekere, N. N. (2009). Rheological characterisation of solder pastes and isotropic conductive adhesives used for flip-chip assembly. *Journal of Materials Processing Technology*, *209*(8), 3923–3930. http://dx.doi.org/10.1016/j.jmatprotec.2008.09.013

3.3 Stoyanov, S., Bailey, C., Alam, M. O., **Yin, C., Best, C., Tollafield, P., et al. (2013). Modelling methodology for thermal analysis of hot solder dip process. *Microelectronics Reliability*, *53*(8), 1055–1067. http://dx.doi.org/10.1016/j.microrel.2013.02.018

3.4 Stoyanov, S., Kay, R., Bailey, C., & Desmulliez, M. (2007). Computational modelling for reliable flip-chip packaging at sub-100µm pitch using isotropic conductive adhesives. *Microelectronics Reliability*, *47*(1), 132–141. http://dx.doi.org/10.1016/j.microrel.2006.01.004

3.5 Stoyanov, S., Bailey, C., Mackay, W., Jibb, D., & Gregson, C. (2004). Lifetime assessment of electronic components for high reliability aerospace applications (pp. 324–329). Presented at

the Electronics Packaging Technology Conference, 2004. EPTC 2004. Proceedings of 6th, IEEE. http://dx.doi.org/10.1109/EPTC.2004.1396627

3.6 Lu, H., Bailey, C., & **Yin, C. (2009). Design for reliability of power electronics modules. *Microelectronics Reliability*, *49*(9-11), 1250–1255. http://dx.doi.org/10.1016/j.microrel.2009.07.055

Research/consultancy grants:

3a EPSRC (GR/M09292), 1998-2000, £168,000 - *Modelling solder joint formation in the flip-chip process*

3b EPSRC (GR/N14095), 2000-2002, £110,000 - *Lead-Free Soldering for Flip-Chip Assembly Applications*

3c EPSRC (GR/R09190 and GR/R09206/02), 2001-2003, £243,463 - *Microsystems Assembly Technology for the 21St Century – MAT21*

3d TSB (TP-AF005K), 2008-2010, £81,284, *ENDVIEW*

3e US Government (H94003-04-D-003-0056), 2011-2014, US$320,000

3f Selex Galilleo, (Consultancy), 2002 & 2008, £40,000, Modelling Reliability of BGA's

3g EPSRC/IeMRC (FS/05/01/01), 2005-2009, £185.615 - *Power Electronics Flagship*

3h DTi (TP/3/DSM/6/I/16796), 2006-2009, £230,962 - *Modelling Power Modules (MPM)*

3i EU Clean Skies (Grant No. 271788), 2010-2013, 200,000 euros - PEMREL

4. Details of the impact

Economic impact

The value of the electronics manufacturing industry worldwide is ~US$2tn; Europe accounts for ~20% of this. Advances in electronics components and systems technologies underpin much larger markets which include industrial sectors, eg aerospace, automotive, energy generation, medical devices etc, and service sectors, eg internet, games, broadcasting, telecoms etc, which account for approximately 10% of world GDP.

Flip-chip assembly, originally developed by IBM, is seen as a route to solve the challenge of reducing the amount of real estate taken up by a semiconductor package on a printed circuit board, but unfortunately the adoption of flip-chip assembly resulted in reliability problems. Our work in collaboration with Henkel, DEK Printing machines, and Heriot-Watt University has provided a route to adopt the flip-chip process at sub-100um pitch interconnections using both lead-free solder pastes and conductive adhesives. The project helped to establish MicroStencil Ltd, a spin-out company formed to commercialise the low cost and high precision electroforming technology developed from the project. MicroStencil has recently moved to Singapore to be closer to its customer base and entered a partnership with DEK Printing Machines Ltd, a world leading stencil printing equipment manufacturer, to produce a new brand of stencils.

The university's work supported the successful implementation of Ball Grid Array (BGA) semiconductor packaged components for Tranche 2 of the radar signal processor for the Eurofighter Typhoon aircraft. Each processor had a value of £300k with a total European buy of 200 processors of which 66% were exported to Italy, Spain and Germany. These went into production in 2008.

Our work in optimising the refinishing process of electronic components for use in high reliability aerospace applications has been funded by the US Department of Defense and industry, and has developed a methodology to dramatically reduce the amount of physical testing required to prove integrity, where normally such testing can cost upwards of £100,000 per component.

Environmental impact

European legislation such as Reduction of Hazardous Substances (RoHS) and Waste Electrical and Electronic Equipment (WEEE) have posed significant challenges for the electronics industry in finding replacements to a number of materials used in electronics manufacturing – including lead-based solders. Our work in assessing the manufacturing processes and subsequent reliability of electronic components using material replacements such as Tin-Silver-Copper solders has helped our industry partners meet these challenges, as well as avoid the placement of harmful materials such as lead in landfill. Although RoHS only applied to certain sectors (eg high reliability sectors have an opt-out), the use of commercial lead-free components in high reliability systems means that most sectors have had to abide with the RoHS legislation. Our work on power electronics modules and the use of our tool – PowerLife – by industrial partners is providing a route for the adoption of power electronics modules in a wide range of applications including aerospace, rail and automotive. For example our work on glob-top materials clearly identified this as a process to increase the reliability of wirebond interconnects in harsh environments. The adoption of power electronics has the potential for energy savings of $400bn annually and the UK is well placed to benefit from innovations in this area.

Impact on practitioners

A number of companies are using design rules, which have resulted from our work, to ensure that quality and reliability requirements of their components are met. Examples include Henkel Technologies Ltd, manufacturer of solder pastes and adhesives, who have adopted our results for implementation as part of a quality assurance (QA) tool in its production plant, and Selex Electronic Systems who are using our modelling technologies as part of their qualification process for avionics electronics. In addition to this our expertise in reliability of electronic components is contributing to the new IEEE Standard P1856 (http://bit.ly/1a2eZy0) – Prognostics and Health Management of Electronic Systems. Our modelling expertise has also contributed to the 2013 International Electronics Manufacturing Initiative Roadmap (http://bit.ly/1ea0Hjk). We work closely with the National Microelectronics Institute and the IEEE (where Professor Bailey is UK&RI Chapter Chair for IEEE components and manufacturing, and reliability societies) in disseminating our research outputs to practitioners.

5. Sources to corroborate the impact

1. Director of Product Development, Henkel Technologies (UK), Beneficiary, can provide a statement on the impact our work has had on new solder and adhesive materials development.
2. CTO, Selex-Electronic Systems, Beneficiary, can provide a statement on the impact of our work for predicting the reliability of avionic electronic systems.
3. R&D Manager, Dynex Semiconductors Limited, User, can provide a statement on the impact of our work for predicting the reliability of power electronics modules.
4. Business Development Manager, GE-Aviation (UK), Beneficiary, can provide a statement on the impact of our work for predicting performance of ruggedized displays.
5. Engineering Director, Micross Semiconductor Limited, Beneficiary, Can provide a statement on how our work on the robotic refinishing process has helped optimise the process.
6. Microstencil website, http://www.microstencil.co.uk/, details how our modelling work in developing a stencil for sub-100um pitch flip-chip assembly has been commercialised through this spin out company by our academic partner Heriot-Watt University.
7. IEEE Standard P1856 (http://bit.ly/1a2eZy0) – Standard Framework for Prognostics and Health Management of Electronic Systems, Chair is Professor Michael Pecht (pecht@calce.umd.edu), University of Maryland. University of Greenwich based on its research in reliability of electronics systems is a member of the working group.