Institution:
University of Cambridge

Unit of Assessment:
UoA15

Title of case study:
Cambridge Semiconductor (CamSemi)

1. Summary of the impact (indicative maximum 100 words)

Research on high-voltage power devices by the University of Cambridge Department of Engineering (DoEng) was commercialised by its spin-off company, Cambridge Semiconductor Limited (CamSemi), which, in the REF period, has:

- shipped more than 450 million power-management chips
- secured private investment of over GBP35M
- continued to employ 50-60 staff.

CamSemi chips are more efficient than traditional linear power supplies. The CamSemi chips that were produced before the end of the REF period are estimated to save of the order of 100GWh of electricity and 50,000 tonnes of CO_2 emissions per year in total.

2. Underpinning research (indicative maximum 500 words)

Gehan Amaratunga joined the DoEng in 1987 as a Lecturer and formed the DoEng Power Electronics Group. He led research in high-voltage semiconductor power devices. Amaratunga was the Principal Investigator (PI) for fundamental research on Trench IGBTs by Florin Udrea (Research Fellow in the DoEng from 1995 to 1998, appointed as a Lecturer in the DoEng in 1998 and promoted to Professor in 2009). Prior to this research, the main advantage of the Trench IGBT was thought to be better utilisation of silicon area due to the device's geometry and orientation. The DoEng research not only built unprecedented understanding of these devices, but also discovered the phenomenon of Inversion Layer Injection and how to exploit this phenomenon to enhance device performance. Amaratunga and Udrea published their seminar paper on Trench IGBTs in 1995 (Ref 1).

Amaratunga saw the advantages of integrating IGBTs and CMOS (Complementary Metal Oxide Semiconductor) control electronics in a single integrated circuit in terms of potential performance and cost. In his experiments, he chose to use lateral IGBTs, rather than the standard vertical IGBTs, because they do not require processing on both sides of the silicon substrate, but are produced only on one side, in the same way as normal CMOS circuitry, making them ideal for monolithic integration. Amaratunga and his team, through experiment, elucidated the influence of a Lateral IGBT on the latch up characteristics of an adjacent CMOS ("latch up" is an uncontrolled state which must be avoided). The work was published in 1995 (Ref 2).

Bill Milne (appointed as Lecturer in the DoEng in 1976 and promoted to Professor in 1996) led the DoEng Power Electronics Group, when Amaratunga left for a Professorship in Liverpool in 1995. Milne was the PI for the EPSRC grant "New silicon on insulator (SOI) high-voltage devices", which ran from 1997 to 2000. Udrea, as a Research Fellow, took the technical lead. This project used theoretical studies, simulations in two and three dimensions (2D and 3D) and experiments to propose novel REduced SURface Field (RESURF) SOI devices. Through detailed understanding of device physics, novel geometries in both 2D and 3D were proposed, allowing these devices to achieve higher breakdown voltages and current densities than previously possible. Udrea and Milne published the first international journal paper on a superjunction device (3D RESURF) in 1998 (Ref 3).

Udrea collaborated with Amaratunga on his return to the DoEng as Professor in 1998. This drew together their original DoEng work on IGBTs, integration with CMOS and 3D RESURF. Their research produced a novel high-performance high-voltage SOI device. They used a CMOS-compliant deep back-etch process step to selectively remove the silicon substrate under the buried oxide beneath the high-voltage power components, thus creating an ultra-thin silicon membrane. The use of the membrane greatly increased the breakdown voltage capability while at the same time significantly reducing the capacitance between the Anode and substrate, which led to ultra-

fast switching performance. This was the first time that process steps normally associated with MEMS had been used to enhance the performance of an active electronic device. This technology was capable of delivering more than five times higher current density (50A/cm^2 for a 650V-rated device operating at 500kHz) of state-of-the-art power IC technologies (SOI or Junction Isolation). Amaratunga and Udrea founded CamSemi in 2000 to commercialise their research. CamSemi applied for patents in 2000 with Udrea and Amaratunga as inventors. CamSemi sanctioned academic publication of the concept when the patents were granted in 2004 (Ref 4).

Udrea continued research as PI for two grants: an EPSRC ROPA grant which aimed to take forward Udrea's research on 3D semiconductor devices using SOI technology (2000-2002) fabricating proof-of-concept devices; and the EC ROBUSPIC project which sought to research smart power integrated circuits using not only SOI but also, the more conventional, Lateral IGBT (LIGBT) on bulk silicon (2003-2007). CamSemi was a partner on the EC project and sponsor for a series of other projects in the DoEng led by Udrea as PI from 2000-2013. CamSemi needed research to achieve high performance from less expensive manufacturing processes than originally proposed. Udrea's team used their research findings above on IGBT device physics, the effect of LIGBTs on CMOS latch up characteristics, RESURF physics and simulations to develop novel, fast-switching Lateral IGBT on bulk Si suitable for integration with CMOS control blocks. The team made four breakthroughs that were patented from 2009 to 2011 and published in 2013 (Ref 5):

- the creation of a floating n+ region in front of the Anode in a Lateral IGBT to make the device operate up to 10 times faster
- optimisation for latch up protection based on use of alternate p+ and n+ regions at the Cathode of the LIGBT
- use of backside p+ implant to prevent onset of a parasitic Schottky thyristor
- use of lowly doped p+ layer for the Anode of the LIGBT.

3. References to the research (indicative maximum of six references)

1. F. Udrea and G.A.J. Amaratunga (1995), Theoretical and Numerical Comparison between DMOS and Trench Technologies for Insulated Gate Bipolar Transistors (IGBTs), IEEE Transactions on Electron Devices, Vol 42, No 7, pp1356-1366. ISSN 0018-9383. DOI:10.1109/16.391221
2. A.Q. Huang and G.A.J. Amaratunga (1995), The Influence of an LIGBT on CMOS Latch Up in Power Integrated Circuit, IEEE Transactions on Electron Devices, Vol 42, No 10, pp1873-1874. DOI: 10.1109/16.464404
3. *F. Udrea, A. Popescu and W.I. Milne, (1998) "The 3D RESURF Double-gate MOSFET: A Revolutionary Power Device Concept", IEE Electronics Letters, Vol 34, No 8, pp808-809. DOI:10.1049/el:19980504
4. *F. Udrea, T. Trajkovic and G.A.J. Amaratunga (2004), Membrane High Voltage Devices - A Milestone Concept in Power ICs, Electron Devices Meeting, 2004, IEDM Technical Digest, IEEE International, pp451-454. DOI: 10.1109/IEDM.2004.1419185
5. *T. Trajkovic, V. Pathirana, N. Udugampola, G. Camuso, F. Udrea, and G. Amaratunga, "800V LIGBT in Bulk Si for Low Power Compact SMPS Applications," in ISPSD, Japan, 2013, pp. 401-404

* Papers that best represent the quality of the underpinning research.

Amaratunga was elected a Fellow of the Royal Academy of Engineering in 2004. In 2007, he was awarded the Royal Academy of Engineering Silver Medal which recognises an outstanding and demonstrated personal contribution to British engineering, specifically for "his pioneering development of special silicon chips with built-in high voltage power-switching devices". Udrea was awarded an EPSRC Advanced Research Fellowship 1998-2003 and promoted to Professor in 2009.

4. Details of the impact (indicative maximum 750 words)

Amaratunga and Udrea founded CamSemi in 2000 to commercialise their research on high-voltage power devices. The University of Cambridge assigned the DoEng intellectual property (IP)

to CamSemi, provided GBP250k in seed funding from the University's Challenge Fund and took shares in the company. CamSemi has since attracted investment of over GBP35M in several rounds of funding. (Ref 6)

In 2004, CamSemi appointed David Baillie as the CEO. Baillie invested CamSemi funds in a strategic programme to develop dedicated controllers for AC to DC power supplies. The controllers provided distinctive capability and had an immediate impact in the market. CamSemi's total annual sales have risen from GBP1M to just under GBP10M from 2008 to 2012. (Ref 6)

The controllers are manufactured and packaged by subcontractors and sold to customers. This "fabless" business model meant that CamSemi was able to grow its sales faster than its growth in staff numbers or physical assets. The employee headcount rose quickly in CamSemi's first seven years to establish the business and, in 2013, is around 60 people. The majority of CamSemi's staff are based in the UK, but there are offices in Taiwan, China, Hong Kong and Korea. (Ref 6)

[Text removed for publication]

Between 1 January 2007 and June 2013, nearly 500 million power control chips have been shipped by CamSemi to their ODM customers. 500,000 power supplies are now manufactured every day with CamSemi chips with about 175,000 of these employing the high voltage technology referred to here (Ref 6). [Text removed for publication]

CamSemi products are attractive to manufacturers of electrical goods (e.g. mobile phones and laptop computers that require chargers), because they are lightweight, low cost and reduce power consumption both in active use and in standby mode. CamSemi chips enable system solutions, which make chargers up to ten times lighter than traditional units with obvious benefits to end users, who often need to carry chargers when travelling. The saving in weight relates to the dramatic reduction in the size of inductive components and in the number of additional discrete components. Given the high price of copper and other metals, this reduces costs greatly too. In active use, adapters built with CamSemi's initial products are typically over 85% efficient compared with linear power supplies which can achieve only 50-60% efficiency (Ref 6). In standby mode, CamSemi products consume almost no power, which addresses a problem highlighted in a report by Intertek for DEFRA, DECC and the Carbon Trust – UK homes typically waste 47-81W of electrical power as a result of devices being left on standby, which equates to 9-16% of domestic electricity consumption (Ref 7).

Reductions in CO_2 emissions through the use of CamSemi technology provide broader environmental benefits. CamSemi has sold nearly 500 million chips between 2007 and 2013 (Ref 6). Savings of the order of 100GWh of electricity and 50,000 tonnes of CO_2 emissions per year can be estimated given the following assumptions: 5% of units sold are in use at any one time, each unit saves 0.5W of electrical power versus a traditional linear power supply whether on standby or active, and 0.45kg of CO_2 is released per kWh of electricity (UK energy mix).

In 2012, Udrea was awarded the Royal Academy of Engineering Silver Medal, which is an award given to British engineers who "have achieved significant commercial success in their fields and are recognised for advancing the cause of engineering in this country". The Royal Academy cited Udrea's role as founder of CamSemi. (Ref 8)

The Company itself won the following awards:

- "Start-up of the Year 2008" in the National Microelectronics Institute (NMI) annual awards (Ref 9)
- Finalist in the 2008 EDN 18th Annual Innovation Awards (Ref 10)
- Carbon Trust Innovation Award (buildings category) in 2009 (Ref 11)
- Listed in Global Cleantech 100 in 2009 (Ref 12)
- "University Spin-out of the Year" in Rosenblatt New Energy Awards 2009 (Ref 13)
- International Trade Prize in the Business Weekly East of England 2011 Business Awards (Ref 14)
- 29th place in the 2012 Sunday Times Hiscox Tech Track 100 listing of the UK's fastest-growing

private companies and the fastest growing semiconductor company in that list (Ref 15).

5. Sources to corroborate the impact (indicative maximum of 10 references)

6. CEO at CamSemi
7. Powering the nation - household electricity-using habits revealed, Report CO332, Energy Saving Trust, Department of Energy and Climate Change (DECC) and Department for Environment, Food and Rural Affairs (Defra), 26 June 2012, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/208097/10043_R66141HouseholdElectricitySurveyFinalReportissue4.pdf
8. "Academy awards four Silver Medals for outstanding commercial success", press release, Royal Academy of Engineering website, 20 June 2012, http://www.raeng.org.uk/news/releases/shownews.htm?NewsID=765
9. Ten Startups to Watch in 2009, EE Times website, 16 February 2009, http://www.eetimes.com/document.asp?doc_id=1255985
10. EDN's 18th Annual Innovation Awards 2008, EDN website, 1 February 2008 http://www.edn.com/electronics-news/4327581/EDN-s-18th-Annual-Innovation-Awards
11. CamSemi's power management ICs collects 2009 Carbon Trust Innovation Award, EE Times website, 15 December 2009, http://www.eetimes.com/document.asp?doc_id=1256149
12. Camsemi - 2008 contender makes it to the 2009 Global Cleantech 100 list, The Guardian website, 2009, http://www.theguardian.com/globalcleantech100/camsemi
13. Rosenblatt New Energy Awards 2009, Cleantech Investor website, 2009, http://www.cleantechinvestor.com/portal/cleantech-awards/1995-rosenblatt-new-energy-awards-2009.html
14. International Trade Award for CamSemi, Business Weekly, 24 March 2011, http://www.businessweekly.co.uk/business-awards/awards-news/11584-international-trade-award-for-camsemi
15. 2012 Tech Track 100 league table, Fast Track website, 2013, http://www.fasttrack.co.uk/fasttrack/leagues/tech100leaguetable.asp?siteID=3&yr=2012&area1=99&sort=num&x=29&y=14