Institution: 10007857 – Bangor University

Unit of Assessment: UoA 13

Title of case study: Laser Micromachining Limited (LML)

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

The innovative application of laser micromachining research has been effected through Bangor's spin-out company Laser Micromachining Ltd , LML (established in 2005). The versatile approach adopted by LML has enabled it, since 2008, to undertake of order 1000 commercial contracts for more than 280 industrial customers and 60 academic institutions. That work has contributed directly to product development and related economic growth in sectors including medical devices, biotechnology, energy, photonics, optoelectronics, aerospace, automotive and microelectronics. With an annual turn-over of circa £0.5M LML has created and sustained 5 full-time jobs. LML also contributes to training in laser micro-machining techniques on a European basis.

2. Underpinning research (indicative maximum 500 words)

In 1996 Pethig and Burt identified laser micromachining as a disruptive technology for realising their concept of a 'biofactory-on-a-chip ': a credit card sized micro-engineered device capable of separating and analysing bioparticles using AC electro-kinetic processes. Substantial BBSRC support gained in 1996 [G1] allowed Bangor, in collaboration with laser tool manufacturer Exitech Ltd, to acquire an S8000 excimer laser micromachining workstation - the first such machine in a UK university. This facility enabled a step change in micro-fabrication whereby complex multi-layered electrode structures could be used to advance research on the electro-kinetic manipulation of biological cells. Early demonstrations of the efficacy of the technology were reported in [P1]. Earlier research activity had relied on photolithographically-produced microelectrodes for studying di-electrophoresis [P2]. However, due to the combination of materials and the need for sub 10µm electrodes within 3-dimensional polymer fluidic channels, bio-factory-on-a-chip fabrication was not possible with photolithography.

In developing the biofactory technology, the S8000 excimer laser system was used extensively allowing a very broad understanding and expertise in laser micromachining to be gained at Bangor. The final biofactory demonstrator device consisted of over 6000 microelectrodes configured in 9 independent distinct processing regions over a 75mm x 50mm area [G1]. Within each region every fourth electrode was connected together to allow continuous travelling electric fields to be created for different forms of particle manipulation. This device used laser micromachining to directly pattern 5µm wide microelectrodes from 100nm gold films deposited on glass. Additionally, the interconnected nature of the electrodes required up to 6 layers of construction with busbars and layer interconnection through via holes in polymer insulating layers. Device reliability was achieved by developing laser methods for contouring the edge of via holes to improve metallisation. A number of developed machining processes were used for this including grayscale mask projection. Grayscale machining was extended to produce microfluidic manifold systems which allowed the smooth distribution of fluids between multiple channels within lab-on-a-chip devices [P3]. Additionally, the ability to machine difficult to etch materials with 3D profiles was used to produce micropumps with contoured membranes. The expertise in excimer laser micromachining developed between 1996 and 2002 has been used to support subsequent microfabrication activities including the development of polymer electronic devices by direct machining or photobleaching. In 2002 Bangor purchased an Exitech M2000F femtosecond laser micromachining workstation [*G2*], again, the first such tool in a UK university. Femto-second laser machining has also been used within a RCUK Basic Technology Programme in the development of optical biochips (2003-2007) where the ability to machine with no heat damage or debris has been used to machine active light emitting semiconductors to produce wafers containing microfluidic channels with integrated, custom shaped, light sources. The combined excimer and femtosecond laser micromachining capability enables the manufacture of biochips where femtosecond machining is used to cut composite materials and adhesives to form microfluidic features and the excimer laser has been used to pattern transparent indium tin oxide (ITO) electrodes [P4]

Key contributing researchers with their positions and time in Bangor are summarised here :

Lecturer/Reader/Professor R. Pethig (01/10/1971- 31/08/2008); Lecturer/Senior Lecturer J.Burt (1990-Present); Project Officer N. Rizvi (01/11/2003 -31/10/2005); PDRAs : A.Goater (01/10/1998 - 31/07/2006); C.Hayden (15/04/2002 - 31/08/2004). M. Talary (01/01/1995 - 30/11/2000) ; C. Dalton (01/02/2001 -1/08/2003).

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

Bangor authors are in boldface. Citations are from Web of Science (November 2013)

Publications

P1 **Pethig, R**., **Burt, J P H**, Parton, A., Rizvi, N., **Talary, M S., Tame, J A.** (1998). Development of Biofactory-on-a-Chip Technology using Excimer Laser Micromachining. J. Micromech. Microeng. 8 57-63; DOI**:** 10.1088/0960-1317/8/2/004; (Parton with: Genera Technology, Newmarket, UK ; Rizvi with Exitech Ltd, Oxford, UK) :The first report of the application of laser micro-machining to the fabrication of biofactory-on-a-chip devices. **77** Citations.

P2 **Talary, M S., Burt, J P H**, **Tame, J A. Pethig, R**. (1996). Electro-manipulation and separation of cells using travelling electric fields, J Phys D 29,2198-2203; DOI**:**10.1088/0022-3727/29/8/021: Demonstrated the limitations of trying to use relatively simple photolithography to create multilayer electrode arrays. **109** Citations.

P3 **Hayden C.J.** (2003) Three dimensional excimer laser micromachining using greyscale masks. J. Micromech. Microeng. 13 599-603; DOI: 10.1088/0960-1317/13/5/310: Showed the use of laser machined greyscale masks to manufacture 3D structures. **13** Citations.

P4 **Burt, J.P.H., Goater, A.D., Menachery, A., Pethig, R., Rizvi, N.H**. (2007) Development of Microtitre Plates for Electrokinetic Assay. J. Micromech. Microeng. 17 250-257 DOI: 10.1088/0960-1317/17/2/010: Demonstration of the use of multiple laser micromachining processes to create biochips using wide range of materials. Established that laser micromachining can be used for complete device manufacture and allows use materials that cannot easily be patterned using lithography or conventional processes. **6** Citations.

Grants

G1*.Development of Biofactory on a Chip Technology, BBSRC/DTI Innovative Manufacturing Initiative [*IMI06337] *1996 – 1999, total value £1,480,000 (circa £ 700k BBSRC grant to Bangor together with matched funding from project partners)*

G2 *Femtosecond Laser Micromachining for Multidisciplinary Microsystems EPSRC JREI [GR/R61987/01] 2002 – 2005 £192,000*

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

The extensive research which led to the demonstration of 'bio-factory on a chip' functionality allowed Bangor to acquire a deep appreciation of the capabilities of laser micromachining. The unique combination of both excimer laser and femto-second laser micro-machining at Bangor provided a strong platform on which to broaden the use of a technology which allows cost-effective high resolution and accurate manufacturing using an almost unlimited range of materials.

Developmental activities pre-2008

A three-stage process was followed to utilise insights gained via research to create industrial impact of Bangor's laser micromachining expertise. In 2001 the activity was included in the Institute of Biological and Molecular Microsystem (IBMM) Centre of Excellence for Technology and Industrial Collaboration, CETIC (2001-2008) established at Bangor with £600k Welsh Government funding. Dr N. Rizvi joined IBMM in 2003 having an innovative profit-sharing salary package which incentivised the provision of machining services to outside clients. In 2005, Bangor gained £1.8M support from the DTI Micro and Nanotechnology (MNT) Programme to host the UK Laser Micromachining Centre (UK-LMC) providing open-access service provision to industry and academia. UK-LMC was set up in 2005 to run financially independently from the university through the Bangor-created company Laser Micromachining Ltd (LML). This independence was essential in allowing UK-LMC to provide confidential services within very short time frames.

In July 2007 LML was also awarded the IMechE's Manufacturing Excellence 'MNT Quality Mark'. The award helps the company attract clients due to the external, nationally competitive, recognition of the quality of LML work attested by the MNT Quality Mark. Initially LML made use of the laser tools at Bangor, then in 2007 an independent facility was created at St Asaph Business Park, north Wales. Impact through knowledge transfer occurred through the movement of Rizvi and Goater to LML with Burt on a long term 70%-time secondment to the company since 2008.

Industrial impacts of LML services

Since 2008 LML has commissioned 8 different laser workstations covering deep UV to infrared, nanosecond to femtosecond pulses, mask projection and direct write machining methods. These facilities have enabled LML to process a wide range of materials including metals, polymers, glasses, ceramics, semiconductors and more diverse materials such as aerogels, diamond and elastomers [6,7]. LML's contract portfolio ranges from making modestly- priced prototypes (often delivered within days of receiving the order) through to multiple production of intricate structures. This versatility has enabled LML service the requirements of a wide customer base. LML Managing Director Dr. Rizvi confirms that since 2008 LML has undertaken over 984 contracts for more than 280 different enterprises ranging from SMEs through to multinational corporations [1, 3-5]. While most of its clients are UK- based around 20% are international. LML works with a diverse set of industries including medical (31%) biotechnology (6%) energy (9%) photonics and optoelectronics (13%) and microelectronics (8%).With an annual turn-over of circa £0.5M, LML has created and sustained 5 full-time jobs. LML has also regularly provided training to over 150 pan-European researchers and industrialists in laser micro-machining via FRSM, Neuchatel, Switzerland [1].

LML's commercial services also enabled academic research with 36 UK, 11 European, 8 USA and a further 8 worldwide universities using its services since 2008. Of the QS World University Rankings 7 of the top 10 universities are LML clients, 29 clients are ranked in the top 100 universities.

The following specific examples illustrate the significant economic impact and the wide reach of LML activities. Because of confidentiality, examples of specific impacts below are provided without disclosing company names.

Company A is a global organisation originally with roots in consumer electronics. While developing a new biomedical cell sorting product, during 2011/2 company A made use of LML's expertise to produce sacrificial masters of the complex, core, disposable consumable of the product. This allowed full system automation and miniaturisation by 33%. These masters, comprising a network of microfluidic channels of differing depth, dimensions and blended cross-sectional shape machined to micron precision and sub-micron surface quality, were used in an electroforming process to produce metal mould tools for the large scale production of the company's product which, since early 2013, has been on sale worldwide.

Company B and **Company C**, working in partnership to create products to reduce energy wastage by domestic appliances, tasked LML in 2010 to produce the critical component of their products. Understanding of machining processes along with the development of bespoke metrology solutions allowed over 4 million parts to be produced for incorporation within the final commercial product with sub-micron reproducibility in aperture size.

In 2012 **Company D**, a long established globally recognised name in IT and electronics, contracted LML to investigate the machining of candidate polymer display materials. This work used knowledge in laser/material interaction along with process control for machining quality and thermal management to study how a range of possible display materials, both as pure materials and composite structures, could be patterned using laser micromachining. In this work Company D commissioned an extended research activity drawing on LML's practical machining, process development and data analysis capabilities.

Industry and Customer Feedback confirms satisfaction with the service provided by LML :

" Having followed LML's growth with interest it is clear that the company now operates at the

highest levels of service provision and is very highly regarded for its offering."[2]

"Knowing well the challenges that the MNT centres faced in developing their own commercial propositions, the position which LML has established for itself within the UK and international micro-manufacturing community in such a short time is to be commended."[3]

" The laser tools available in LML enable the company to process an almost unlimited range of materials and this allow LML to use its capabilities in fields from medicine to microelectronics. It is a testament to the deep and wide-ranging expertise resident within LML that such a small, young business has been able to compete in the international arena at such a high level. "[4]

"LML is to be congratulated for having the agility to sustain and grow its operations over the past few years to a level where it has a reputation for excellence far outside of the UK. Given the increasing emphasis on micro and nano-technologies in many industrial sectors it can be expected that LML will be able to use its expertise to support users in industry, commerce as well as in the research community. "[5]

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

Letters of support from LML Industry partners and Customers

1) Project Manager, FRSM, Switzerland http://www.fsrm.ch/doc/c248.php
2) Executive Secretary, Association of Laser Users (AILU), UK
3) Managing Director, INEX,UK
4) Managing Director, MSOLV,UK
5) Product Development Manager, MiniFAB,Australia

Scope and significance of LML activity

6) UK Nanotechnology Directory http://www.thedirectory.eu.com/search/Profile.aspx?OrgID=2216
7) http://www.lasermicromachining.com .