Micro and Nano Technology (MNT) Measurement Club

1-day meeting

The Measurement and Characterisation of MST Devices (MEMS)

Venue: National Physical Laboratory, Hampton Road, Teddington, Middlesex TW11 0LW

Date: Monday 27 February 2006

Overview of Meeting
The aim of this meeting is to raise awareness of and discuss the measurement and characterisation (M&C) needs, requirements and issues in the design, development and manufacture of Micro-Systems Technology (MST) devices. It will include presentations on some of the key techniques for the measurement and characterisation of MST devices and on current metrology research within the DTI's National Measurement System (NMS) Programmes supporting MST development. Areas where there are outstanding M&C issues and needs, not fully addressed by existing measurement techniques, will be highlighted. Presentations will also describe some of the key open access measurement and characterisation facilities available to R&D and manufacturing organisations operating in the MST field.

This meeting will be of interest to researchers, engineers, scientists and technical/quality control managers in R&D and manufacturing organisations who would like to find out more about measurement and characterisation issues, techniques, tools and facilities in order to improve their products and processes and to network with others working in the MST field.

PROGRAMME

09.15 – 10.15 REGISTRATION, COFFEE

10.15 – 10.20 Introduction to meeting – *Dr Richard Leach, National Physical Laboratory*

10.20 –10.45 'CEMMNT' Nano Metrology Programme – *Dr Gareth Francis, National Physical Laboratory*

10.45 – 11.10 Metrology challenges facing the fabrication of Micro System Technologies *- Chris Reeves, QinetiQ*

11.10 – 11.35 Metrology, MEMS and Electromagnetics – *Prof. Eric Yeatman, Imperial College*

11.35 – 12.10 Metrology challenges in micro and nanofabrication – *Dr Zheng Cui, Rutherford Appleton Laboratory*

12.10 – 13.20 LUNCH

13.20 – 13.45 A new European community for design and manufacture of MNT based systems : The FP6 Network of Excellence 'PATENT-DfMM' – *Prof. Andrew Richardson, Lancaster University*

13.45 – 14.10 Measurement issues in micro-fluidic devices – *Dr Tom Harvey, Epigem Limited*

14.10 – 14.35 An optical workstation for characterisation and modification of MEMS – *Dr John Hedley, Newcastle University*

14.35 – 15.00 COFFEE

15.00 – 15.25 Metrology of MST and microfluidic devices using white light interferometery and novel surface metrology characterisation – *Prof. Liam Blunt, Centre for Precision Technologies, University of Huddersfield*

15.25 – 15.50 Vibrometry measurements to determine cause of non-ideal angular rate sensor behaviour - *David Cowell, ETB Ltd*

15.50 – 16.15 Metrology for MEMS and MEMS for metrology – *Dr Richard Leach, National Physical Laboratory*

16.15 – **MEETING CLOSE**

Presentation Abstracts and Speaker Profiles

‘CEMMNT’ Nano Metrology Programme

CEMMNT is the Centre of Excellence for Metrology in Micro and Nanotechnology. It is a new partnership of UK MNT measurement and characterisation providers. Its mission is to accelerate the integration of micro and nano technologies into products and processes within the UK by strategically enhancing the UK measurement and characterisation supply chain to fill capability gaps, improve technology and increase access to existing capabilities to support the different levels of the MNT value chain. Companies involved in the CEMMNT partnership include NPL, QinetiQ, Taylor Hobson and the Systems Engineering Innovation Centre**.**

Speaker Profile - Dr Gareth Francis, National Physical Laboratory

Dr Gareth Francis is the Business Technology Sales Manager at NPL. He has a strong scientific and commercial background with 8 years experience of in the commercialisation of research and technology transfer at NPL. He has a research background in micro and nano technology, with a PhD. in nanotechnology from the University of Cambridge. He has lead the commercial development of NPL’s nano and nano-bio metrology capability, through the development of the London Bio-Nano Centre in collaboration with Imperial College and University College London and the Centre of Excellence for Metrology for Micro and Nanotechnology (CEMMNT).

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Metrology challenges facing the fabrication of Micro System Technologies

The fabrication of 3D Microsystems using a combination of surface and high aspect ratio micromachining requires the measurement of dimensional, material and functional properties. The verification of process parameters is key to controlling yield and the cost-effective manufacture of MEMS. A holistic approach is required to determine these parameters using both in-line and off-line metrology techniques, for example, the use of dynamic measurement to determine functionality. Case studies will be used to demonstrate how existing metrology tools can be used to determine some of these parameters and will highlight some of the challenges facing the metrology of MEMS.

Speaker - Chris Reeves, QinetiQ

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Metrology, MEMS and Electromagnetics

In electromagnetic applications, MEMS becomes increasingly valuable as operating frequencies rise and the degree of integration increases. In the radio frequency (RF) field, the MEMS RF switch provides advantages over solid state switches such as low insertion loss, and high bandwidth and linearity. The micro machining methods of MEMS create a number of opportunities for highly 3-dimensional structures, such as vertical inductors for high Q operation on lossy substrates. For microwave and mm-wave applications, additional possibilities for micro-machining arise, such as on-chip antennas and various resonant cavity devices. Finally, optical applications of MEMS have been highly successful, particularly in fibre-optic communications, and in sensing.

Many important metrology challenges in MEMS have yet to be fully addressed. For example, dimensional measurements are well established in microelectronics for in-plane dimensions, but methods for measuring out-of-plane are very limited. Consequently, 3D structures such as vertical inductors cannot be adequately measured. Surface quality is a vital issue for electrical loss and frequency response, and although excellent methods exist for characterising the upper surfaces (such as atomic force microscopy and imaging optical interferometry), equivalent techniques for

vertical surfaces are not available. The 3D nature of electromagnetic MEMS devices also creates difficulties for electrical testing, because of interactions among devices, and between them and the test equipment. Closely related to these measurement challenges are the limitations in truly 3D modelling and simulation. This talk will describe a number of electromagnetic MEMS devices, and discuss further the metrology challenges they present.

Speaker profile - Prof. Eric M. Yeatman, Dept of Electrical and Electronic Engineering, Imperial College

Professor Eric M. Yeatman has been a member of academic staff in Imperial College London since 1989, and deputy head of the Optical and Semiconductor Devices Group since 1996. He has published around 90 papers on integrated optics, MEMS and ultrasonics, and several patents, and is co-founder and chairman of Microsaic Systems Ltd., a MEMS product development company spun-out of Imperial College. He has been manager of two large European Union research collaborations, and principal or co-investigator on 12 research council and several industry supported projects. He has acted as a design consultant for several international companies, and technical advisory board member to two venture capital funds. His current research interests are in radio frequency and photonic MEMS devices, and energy scavenging for wireless sensor nodes.

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Metrology challenges in micro and nanofabrication

Metrology is an integral part of micro and nanofabrication processes. At the central Microstructure Facility we need various metrology tools to measure and characterize microstructures and thin film materials in almost every step of the fabrication processes, in order to keep the structures in correct dimension. With the development of microsystems and nanotechnology, there have been increasing demands in 3D metrology. In this talk, the normal practice of metrology in a microfabrication environment is introduced. The experience in 3D metrology for micromechanical systems is described. Some real case studies are presented to highlight the challenges current metrology is facing in manufacturing microsystems and nanostructures.

Speaker profile- Dr. Zheng Cui, Central Microstructure Facility, Rutherford Appleton Laboratory

Dr Zheng Cui has a PhD in Electronic Engineering in 1988, SERC visiting Fellow in 1989 at the Microelectronics Research Centre, Cambridge University. In 1993 he joined the Central Microstructure Facility, Rutherford Appleton Laboratory and is currently a Principal Scientist and group leader. His specialities are in micro-nanofabrication technologies, with applications in Microsystems and nanotechnology. He has participated in 7 European projects and a number of UKresearch council projects, including a EU project in partnership with NPL on "standardisation of Microsystem Technology (MEMSTAND)". He has published over 130 technical papers and recently a book "Micro-nanofabrication Technologies and Applications" (Springer, 2006).

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A new European community for design and manufacture of MNT based systems : The FP6 Network of Excellence 'PATENT-DfMM'

PATENT-DfMM www.patent-dfmm.org focuses on Design for Manufacture technology for Micro & Nano enabled systems. Its technical foundations are in response to the need to pull together test and measurement, reliability and packaging specialists with modeling and simulation experts to develop design solutions to back end manufacturing issues (cost, quality, reliability). 145 researchers and engineers from 24 institutions across Europe are actively engaged in the program. This presentation will brief the audience on the technical progress made, the capability of the

network and opportunities for the UK community to collaborate / interact with this community and its industrial partners.

Speaker profile - Prof. Andrew Richardson – Lancaster University
Prof. Andrew Richardson currently holds a personal chair in Microsystems Engineering within the Department of Engineering at Lancaster University. He is the Director of the Centre for Microsystems Engineering, Scientific Director of Dolphin Integration, Grenoble and the coordinator of the European Framework VI Network of Excellence in Design for Micro & Nano Manufacture (PATENT-DfMM). Prof. Richardson has published 120 journal, conference and workshop papers together and two books that cover work in the fields of mixed signal and analogue design-for-test, defect, fault and degradation modelling, MEMS modelling and test and design for micro and nano manufacture. Prof. Richardson has contributed to funded projects in all European IST programs since 1994 that includes the recently launched PATENT-DfMM Network of Excellence that involves 24 partners and over 140 researchers across 10 European countries. He is also a partner in the new QinetiQ led FP6 Program "Integrated MNT Platforms & Services" (INTEGRAMplus) and is a co-investigator and member of the management team for the new EPSRC Innovative Electronics Manufacturing Centre. Prof. Richardson is also a steering committee member for the NEXUS Association that represents European universities and industry working in the field of integrated MEMS.

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Measurement issues in micro-fluidic devices

Epigem makes polymer micro-fluidic devices and we require new methods to quantitatively measure the chemical and physical properties of both the micro-fluidic device and the liquid(s) flowing within it. Quantitative methods would be most useful at the device design stage, allowing direct comparison with modeling results. The measurements need to be made both locally, in a particular region of the fluidic circuit, and globally, over the whole circuit. Since the circuits are micro in their component parts and macro in their overall functional size, this task is not straightforward. Ideally, the measurements should be non-destructive as well as in-situ. The surface properties of the micro-fluid channels such as surface energy, chemical composition, charge, roughness for example, are of particular interest because they strongly effect such parameters as pressure, flow velocity and binding (of chemical species from the fluid stream). The chemical and physical properties of the liquid(s) flowing in the device need to be measured to assess its functional performance. The parameters of most interest would be pressure (especially differential pressure), flow velocity, composition (of different liquids to assess mixing for example), volume, pH and temperature.

Speaker profile - Dr Tom Harvey, Epigem Limited
Tom is one of the founders of Epigem Limited and is currently Chief Technology Officer. He is expert in the field of polymer micro-engineering, having spent many years developing micro-optic, micro-fluidic and/or micro-electronic products using novel micro-moulding or micro-replication techniques. He is also responsible for initiating and managing projects with customers and ensuring full characterisation of the performance (optical, electrical, mechanical etc) of Epigem's products and processes. He led the technology development of Epigem's range of microfluid devices, now commercialized under the trade name "Fluence™". His other current research interests include flexible displays (e-paper), high resolution flexible circuit boards and the preparation and use of magnetic nanoparticles in medical diagnostics. A physicist by training, Tom graduated from Heriot-Watt University in 1991 with a PhD in the non-linear optics of polymer materials.

An Optical workstation for characterisation and modification of MEMS

An optical workstation consisting of a surface profiler, laser vibrometer and a high power pulsed laser has been constructed for mechanical testing of MEMS. Through a series of static and dynamic measurements, the performance of a device is determined in seconds. For these measurements the device is induced to move by either using mechanical, electrostatic or optical actuation methods. In the latter case this is achieved by directing high power light pulses onto a silicon surface. The same laser can also be used to trim and frequency tune resonant devices. The workstation has been designed to incorporate single devices, wafers and packaged devices so that devices may be characterised at any stage of processing. The speed and non-contact nature of this workstation makes it suitable for industrial metrology. A variety of MEMS have been characterised, examples of which will be presented. The workstation has proved to be an invaluable tool for determining the cause of device failure. The limitations of the system to the advancement of MEMS / NEMS technology will be discussed.

Speaker profile – Dr John Hedley, Newcastle University

John Hedley received a PhD in atomic physics from the University of Newcastle in 1996. He was subsequently employed as a postdoctoral researcher in MEMS design, fabrication and testing. He is currently a lecturer at the University in the School of Mechanical and Systems Engineering. His research interests are in MEMS / NEMS metrology and biosensors and is currently principle investigator on an EPSRC funded project on dynamic Raman mapping of micro / nano sturctures and a Royal Society funded project on the integration of micro-sensor platforms, this being in collaboration with CNM in Barcelona. John co-directs the MSc in Biomedical Nanotechnology course at the University.

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Metrology of MST and Microfluidic Devices Using White Light Interferometery and Novel Surface Metrology Characterisation

The manufacture and fabrication of MST and microfluidic devices is now a hugely expanding technology with new applications stretching from electronics to biotechnology. A major technological hurdle for the mass production and development of these devices is the difficulties associated with the geometrical metrology and surface metrology. The difficulties lie around the ability to separate and quantify zones of differing planer height and then being able to analyse the metrology of the zones individually. Complicated surfaces pose particular difficulties in terms of establishing measurement datums and levelling data. These problems are further accentuated by the limited size of data sets available form the current metrology tools This presentation outlines the use of edge detection and areal pattern analysis techniques to establish a basis for improved device characterisation for both MST and microfluidic devices.

Speaker profile – Prof. Liam Blunt, Centre for Precision Technologies, University of Huddersfield

Professor Liam Blunt has worked since 1986 in the areas of Surface Metrology and Precision Engineering. He now the director the Centre for Precision Technologies (CPT) at the University of Huddersfield. In 2002 he was awarded the prestigious Taylor Hobson Chair in Surface Metrology in recognition of his research work and collaborative research with Taylor Hobson. Prof Blunt's specific areas of research include; surface metrology, nanoscale metrology, bio technology, the development of standards for 3D surface measurement, precision manufacturing processes and precision environment design. In 2005 the CPT and was awarded the prestigious status of CIC (Centre for Industrial Collaboration) by the regional development agency Yorkshire Forward in recognition of their knowledge transfer activities with industry. Recent research success has included obtaining completion and coordination of a large multinational EC funded project dealing with the development of written standards in 3D surface topography, where the University of Huddersfield as well as coordination investigated nanoscale surface finishes produced on orthopaedic implant bearing surfaces. Prof Blunt has worked in a number of UK academic institutes including Coventry University, Warwick University and Birmingham University in research areas covering metrology, tribology and processes. Prof Blunt has published over 130 papers.

Vibrometry measurements to determine cause of non-ideal angular rate sensor behaviour

Performance characterisation of a vibratory piezoelectric angular rate sensor revealed a systematic error suspected of being responsible for unpredictable sensor performance. Attention was focussed on the axisymmetric resonator, which is piezoelectrically driven at resonance into a planar mode of operation. In-house measurements of the resonator indicated a deviation from the idealised operational mode shape. ETB approached NPL under the Measurements for Innovators Program and the potential sources of non-ideal behaviour discussed. A plan of action was agreed which centred around vibrometer measurements of the axisymmetric resonator. Initial out-of plane measurements did reveal that the modal response was more complex that had initially been suspected. However, the observed out of plane motion did not explain the anomalies observed in-house. Furthermore, the mode of operation of the vibratory gyro is planar, something that laser vibrometry cannot measure easily. In an attempt to measure the in plane response, an unconventional approach was adopted whereby the resonator was inverted and measurements taken around the circumference of the disc. This method has proved technically challenging and is ongoing.

Speaker profile - David Cowell ETB

David Cowell studied Mechanical Engineering at university and began his career working in a production environment. He later undertook an MSc in Computer Aided Design, after which he became a Teaching Company Associate in conjunction with the University of Hertfordshire and European Technology for Business (ETB). During that period, he was responsible for the theoretical analysis of ETB's design for a novel piezoelectric angular rate sensor. David stayed with ETB after completion of the TCS and has been involved in the development and testing of the rate sensor ever since. He is in the final stages of submitting an MPhil, based on his work at ETB.

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Metrology for MEMS and MEMS for metrology

It is now fully appreciated that metrology will play an integral role in the successful development and commercialisation of micro- and nanotechnology. To this end the UK Government, through the National Measurement System, funded several groundbreaking projects in its 2002 – 2005 Programme for Length. This review will briefly describe the background of the research, concentrating on the technical details of the projects. The Programme for Length normally only funds work into dimensional metrology but this funding cycle also funded work into low force metrology as this area is crucial to most mechanical probing techniques. The projects described include a traceable areal surface measuring instrument designed to calibrate areal transfer artefacts and hence offer traceability for industrial areal instruments, the production of the areal transfer artefacts, a primary low force balance with a force resolution of 50 pN and the development of methods for measuring complex micro-scale structures. The talk will also discuss the current research projects into this area.

Speaker profile – Dr Richard Leach, National Physical Laboratory

Dr Richard Leach is an internationally recognised principle research scientist with sixteen years research and project management experience at NPL in various aspects of micro- and nanometrology. His main areas of research have been the measurement of surface texture, 3D metrology of microstructures and low force measurement. Richard gained a BSc in Applied Physics from Kingston University, an MSc in Industrial Measurement Systems from Brunel University and a PhD in Surface Metrology from University of Warwick. He is a member of BSI, ISO and SEMI committees and runs the Surface Texture special interest group for the UK's Dimensional Metrology Awareness Club (DMAC). He has authored over 60 technical publications in the field of nanometrology including four keynote addresses