MONASH University
Engineering

# Monash University
# Faculty of Engineering

# The Harold Armstrong Lectures

**Professor Yee Cheong Lam**
School of Mechanical & Aerospace Engineering
Nanyang Technological University, Singapore

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## ‘Seeing’ the Heat of Femto-Second ($10^{-15}$s) Laser Machining

**Tuesday 13th June 2006**
2 pm, Lecture Theatre E7, Building 72, Clayton

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## Turbulence In Micro-Channel Mixing?

**Thursday 15th June 2006**
2 pm, Lecture Theatre E7, Building 72, Clayton

Please contact Dr Leslie Yeo (leslie.yeo@eng.monash.edu.au; 99053834) for more information

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## 'Seeing' the Heat of Femto-Second ($10^{-15}$s) Laser Machining

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Femtosecond (fs) laser is attractive as a high-precision micromachining tool for materials processing because of its advantages, such as less thermal and mechanical damages to the surroundings, when compared to long-pulsed (nanosecond or longer) counterparts. It has been accepted that for long (nanosecond) laser pulses, the electrons and lattice (ion systems) are in thermal equilibrium during laser-materials interaction because the pulse duration is longer than the electron-phonon energy relaxation time (~1 picosecond). Therefore, significant heat conduction occurs during the interaction of long laser pulses with materials. In contrast, the interaction of fs laser with materials is not clearly understood. In general, it is believed that the incident laser energy is carried away by the ablated material leaving negligible amount of energy in the bulk. However, a number of recent studies have indicated indirectly the existence of significant residual thermal energy in the bulk substrate during fs laser ablation. Employing infrared thermography technique, we measured in situ directly the temperature fields of carefully prepared silicon and steel specimens irradiated by femtosecond laser pulses, and were able to quantify conduction within them. We discovered that two-thirds or more of the laser power was conducted away over a large range of laser powers for both crystalline silicon and steel specimens. The implication of this discovery will be briefly discussed.

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## Turbulence In Micro-Channel Mixing?

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Turbulent flow instabilities are recognized to be an effective mechanism for mixing and have been well studied for Newtonian fluids. To induce turbulence, e.g. for flow in a round pipe, the Reynolds number ($\mathrm{Re} = \rho\bar{V}d/\eta_o$ = ratio of inertia to viscous forces) must be around 2000 or more, implying relatively high flow velocity, low fluid viscosity and large characteristic dimension. However at a microscale characteristic dimension, viscous effects dominate resulting in laminar flow and it is no longer possible to induce turbulence through an inertia/viscous mechanism. Here we show the different fluid behaviors in microchannels as competition between different fluid properties, namely viscous/elastic, viscous/viscous and viscous/inertial. Turbulent mixing was achieved in a flow regime dominated by viscous and elastic forces (devoid of inertial forces). We employ low viscosity viscoelastic fluids, i.e. dilute polymeric solutions, where elasticity derived from long chain polymer. By employing an abrupt contraction microchannel, two different viscoelastic fluids were turbulently mixed at vanishingly small Reynolds number (Re < 0.1), but with enormous Peclet and Elasticity numbers (namely negligible diffusion and inertia effects). This viscoelastic mixing at microscale without diffusion was achieved over a short effective mixing length of less than 5 mm and a flow velocity of $10^0$ to $10^1$ mm/s.

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# Biography of Professor Yee Cheong Lam

Professor Lam obtained his Bachelor of Mechanical Engineering in 1979 from the University of Melbourne, and was awarded the Dixon Scholarship for Outstanding Academic Achievement. Subsequently, he obtained his Ph.D. in 1983 from the same University and was awarded the M.H. de Fina Memorial Prize for the Best Postgraduate Student.

He joined Monash University, Australia in 1984. Before leaving Australia for Singapore in 1997, he was the Head (Monash Node), of the Cooperative Research Centre for Advanced Composite Structure (CRC-ACS), a Director of the Far East Oceanic Fracture Society, and President of the Australian Fracture Group.

He is currently a Professor in the School of Mechanical and Aerospace Engineering, Nanyang Technological University. He holds joint appointment as Principal Scientist, Singapore Institute of Manufacturing Technology, and as Fellow, Singapore-MIT Alliance.

His current research focuses on microfluidics, laser machining, optimization of manufacturing processes, and numerical and physical modeling of material behaviours. He has published more than a hundred journal articles in these areas.

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# The Harold Armstrong Memorial Fund

The Harold Armstrong Memorial Fund was formally established in 1967 for the furtherance of the study and promotion of the applied sciences, having particular regard to the relationship of the sciences to industry in the broadest sense. The fund is therefore used to encourage and develop studies at Monash University in the field of production science and for the provision of facilities and equipment for such studies.