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**Group A, Session I**

**Behnam Bozorgmehr (Advisor: Prof. Murray)**

The Effect of Marangoni Number and Initial Contact Angle on the Evaporation Rate and Internal Flow Structure in a Sessile Droplet

The evaporation of a sessile droplet on substrate is a fundamental phenomenon that has a wide range of applications; in particular, printing processes where the deposition patterns are controlled by flow inside the drop. Surface tension driven flow may occur due to the temperature variation along the liquid-vapor interface. At the same time, the faster rate of evaporation near contact line creates a jet-like stream from the top of drop to the contact line. The competition between these two effects determines the nature of the flow inside the drop. A computational model is developed to investigate the evaporation rate and convective flows inside a sessile droplet with a pinned contact line. In order to calculate the evaporation rate, the diffusion equation is solved in still air domain around the drop. The evaporation rate influences the temperature field which impacts the Marangoni stress along the interface. The effect of the initial contact angle and the Marangoni number on the evaporation rate and internal flow structure is investigated. The results show that the evaporation rate is constant through the process and depends on the initial contact angle. The Marangoni number controls the strength of the flow which impacts the overall transport within the drop.

**Xiaoze Sun (Advisor: Prof. Singler)**

3D Particle Motion Visualization with Defocusing PTV Technique

Quantitative visualization of microscale flow is of great interest in biological and mechanical field. Particle tracking velocimetry is an essential tool for quantitative flow mapping and has been well applied but is limited to 2-dimentional (2D) measurements. In the present study, a 3-dimentional (3D) imaging technique for the purpose of visualizing flow motion inside a droplet or rivulet is described. In this technique an aperture mask with three pinholes which form an equilateral triangle is inserted into the light path of a microscope. When a target is defocused, an equilateral triangle is observed instead of a blurred dot. The third spatial dimension can be obtained by calculating the separation of defocused images generated by the aperture mask. Particle motion inside an evaporating sessile droplet is captured using a microscope equipped with a 20X objective lens. Preliminary tracking results will be shown.

**Mingfei Zhao (Advisor: Prof. Yong)**

Modeling nanoparticle-laden droplets on a solid surface using the free-energy-based multiphase lattice Boltzmann method

We present a free-energy-based multiphase lattice Boltzmann model to simulate particle-laden droplets on a solid substrate, which is of importance for providing a fundamental hydrodynamic insight of hybrid printing technique combining the inkjet printing and electrospray technique. This work focuses on 2D multiphase lattice Boltzmann model to investigate the influence of different wetting properties of solid surface on the nanoparticle-laden droplet. That means we will observe how nanoparticles change droplet wetting properties by initially putting nanoparticle-laden droplet with different static contact angles. We mainly study two different initial positions of nanoparticles within the interface and dispersing inside the droplet. The different numbers of nanoparticles are also taken into consideration. In fact, in our model, wetting properties of nanoparticles can be easily applied to see its influence on the distribution of nanoparticles.
Liang Liu (Advisor: Prof. Singler)

Experimentally observed convective particle self-assembly by inkjet printing liquid rivulet on engineered substrate surface

We report an experimental investigation of the particle self-assembly at the three-phase contact line via printing a polydopamine nanoparticle (PDA-NP) laden ink rivulet, due to the “coffee-stain” effect. The wetting behavior of the ink was controlled via engineering the surface of substrate by oxygen plasma treatment. The results suggested an intimate relationship between the wetting process and final particle deposition morphology, which can be explained by the convective transport of liquid suspension due to evaporation and the geometric restriction of liquid meniscus in the vicinity of the contact line. This technique is potentially applicable to the cost-effective fabrication of transparent conductive grids without sophisticated equipment, and a capacitive touch sensing device was demonstrated.

Shyi Qin (Advisor: Prof. Yong)

Electrostatic interactions in many-body dissipative particle dynamics using Ewald sum and Particle-Particle and Particle-Mesh method.

The electrostatic interactions between particles are common in real system. Thus we are interested in incorporating electrostatic interactions in many-body dissipative particle dynamics (MDPD) simulation. In this work, we try to use two different methods to model some charged systems such as bulk electrolyte and two ions immersed in water. The standard Ewald sum method with Slater-type charge distribution is applied to study a bulk electrolyte. The structure of the fluid is analyzed through the radial distribution function between charged particles. Although the standard Ewald sum method is easy to accomplish, it is hard to deal with local inhomogeneities in the electrostatic permittivity. Thus, we use an alternative method called Particle-Particle and Particle-Mesh (PPPM) method to calculate the electrostatis. Due to soft nature of the conservative forces in MDPD simulations, to avoid a collapse of oppositely charged particles onto each other in MDPD simulations, we smear out the charges on the MDPD beads into the grid points enclosed in a sphere of a certain radius. Rather than using Fourier transform to solve the Poisson equation, we use a real-space successive overdamped relaxations method to get the electric potentials. As a verification of the algorithm, we do a simulation with just two ions immersed in water to obtain a relation between forces and distances between two ions.

Sepehr Maktabi (Advisor: Prof. Chiarot)

Electrohydrodynamic Printing of PEDOT:PSS on Flat and Uneven Surfaces

In materials printing applications, the ability to generate fine droplets is critical for achieving high resolution features. Other desirable characteristics are high print speeds, large stand-off distances, and minimal instrumentation requirements. In this work, a tunable electrohydrodynamic (EHD) printing technique capable of generating micron-sized droplets is reported. This method was used to print organic resistors on flat and uneven substrates. These ubiquitous electronic components were built using the commercial polymer-based conductive ink poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS), which has been widely used in the manufacturing of organic electronic devices. Resistors with widths from 50 to 500 µm and resistances from 1 to 70 Ω/µm were created. An array of emission modes for EHD printing was identified. Among these, the most promising is the microdripping mode, where droplets 10 times smaller than the nozzle’s inner diameter were created at frequencies up to 10 kHz. It was found that the ink flow rate, applied voltage, and stand-off distance all significantly influence the droplet generation frequency. In particular, the experimental results reveal that the frequency increases nonlinearly with the applied voltage. The non-Newtonian shear thinning behavior of PEDOT:PSS strongly influenced the droplet frequency. Finally, the topology of a 3-dimensional target substrate had a significant effect on the structure and function of a printed resistor.
Ali Davoodabadi (Adviser: Prof. Singler and Prof. Jin)

Thin Film Wrinkling

Thin films deposited on substrates can be triggered to decohere in various fashions; and one of them is injection of a liquid into the interface. Although this injection would typically be done manually, in this particular case we use a mercury (Hg) droplet which can self-deliver itself into a gold/glass interface via penetration through the on-glass deposited gold (Au) membrane. Continuous transport of the mercury to and its subsequent accumulation at the interface entails lifting of the film by forming a mercury-filled blister underneath. Strong stresses induced in this highly deformed region of the membrane trigger wrinkling instability which is quite common for thin films under tension. This instability forms corrugations in the elastic membrane all around the triple line which later evolve to fingers. These fingers then become susceptible to tip splitting and start branching as they grow farther from the central region.

Xiao Xiong (Advisor: Prof. Singler)

Evaporation induced rivulet flow and deposition of the binary solvents by inkjet printing

My research focuses on the fundamental study of the evaporation induced rivulet flow of the binary solvents by inkjet printing. For elucidating the formation of the Marangoni vortex and its relationship with the capillary pressure driven flow (Axial Flow and Reversal Flow), the image acquisition of the bottom and side views as well as the direct Particle Tracking Velocimetry (PTV) analysis would be adopted to obtain the flow profile. With different ink concentrations and interactions between substrate and ink, the transport phenomena inside the rivulet and the particle deposition would vary due to the evaporation process of the ink. In next step, the effects of these factors on the flow evolution of printed rivulet and particle deposition would be explicated. And functional nanoparticles would be added into the binary solvents and the effect of the flow pattern on the deposition of the particles would be discussed.

Group A, Session II

Li Lu (Advisor: Prof. Chiarot)

High-throughput Microfluidic Fabrication of Synthetic Asymmetric Vesicles to Support Membrane Biology Studies

Membrane vesicles are spherical structures comprised of a single lipid bilayer enclosing an aqueous cavity. Vesicles carry out many important functions in natural organisms. When preparing vesicles artificially, it is difficult to simultaneously control vesicle membrane asymmetry, size, unilamellarity, throughput, and monodispersity. Membrane asymmetry, where each leaflet of the lipid bilayer consists of a different lipid content, is of particular importance as it is a feature of nearly all natural membranes. In this study, we report on a novel microfluidic strategy to build monodisperse asymmetric vesicles with customized membrane composition, size, and luminal content at high-throughput. The microfluidic device consists of a triangular post region and two flow-focusing regions. The major steps of the vesicle fabrication process include: (1) assembly of the inner-leaflet, (2) continuous flow separation - replacing the inner-leaflet-lipid with the outer-leaflet-lipid, (3) assembly of the outer-leaflet, and (4) extraction of the intermediate oil layer. Membrane asymmetry and unilamellarity are confirmed using a fluorescence quenching assay and a membrane protein insertion assay, respectively. Our vesicle fabrication method can yield membrane asymmetries as high as 95%, which is maintained at a high-degree for over 30 hours. The effect of bilayer composition on the mechanical properties of the membrane and the role of small molecules on membrane architecture will be investigated.
Nicholas A. Brown (Advisor: Prof. Chiarot)

Characterization of Nanoparticle Printed Thin-Films

Electrospray utilizes a high electric potential to aerosolize conductive colloidal dispersions. These colloidal dispersions consist of nanoparticles suspended in a volatile solvent, acting as a printable ink. Due to the high volatility of the solvent, complete evaporation occurs while the generated droplets are in flight resulting in dry individual nanoparticles. The process of electrospray imparts excess charge onto the emitted nanoparticles. It is this charge which dictates the transport and ultimately the morphology of a printed deposit. The transport of the nanoparticles is a stochastic process governed by the electric charges on the nanoparticles. Due to this charge, there are three primary mechanisms that influence the deposition morphology: the influence of the global potential required to generate the electrospray, the mutual interaction between particles in flight and the interactions with particles that are deposited on the substrate. In this study, I shall characterize the structure of nanoparticle deposited printed via electrospray as a function of processing parameters.

Mikhail Coloma (Advisor: Prof. Chiarot and Prof. Huang)

A Hydrodynamic Mechanism for Beta-Amyloid Clearance from the Brain

The lack of beta-amyloid clearance from the aging brain leads to its accumulation within the walls of arteries and to Alzheimer’s disease. However, the transport mechanism for beta-amyloid clearance is unknown. In this study, we propose a hydrodynamic mechanism for flow within the vascular walls in the cerebral arterial basement membrane. The transport mechanism consist of arterial lumen deformation induced by heart pulsations superimposed with reflected boundary waves. The arterial basement membrane is modeled as an annulus between deformable concentric cylinders with the flow conduit filled with an incompressible, single-phase Newtonian fluid. Our model predicts that while the overall arterial wave propagation is in the same direction as the blood flow toward the capillaries, a reverse flow in the basement membrane can be preferentially induced toward larger arteries. This has been suggested as a potential clearance pathway for beta-amyloid. We estimate the magnitude of the reverse transport through a control volume analysis which is validated by numerical solutions of the Navier-Stokes equations. Bench-top experiments to validate our computational models are presented.

Yaser Hadad (Advisor: Prof. Chiarot)

Numerical Modeling and Optimization of Warm-water Heat Sinks

For cooling in large data-centers and supercomputers, water is increasingly replacing air as the working fluid in heat sinks. Utilizing water provides unique capabilities; for example: higher heat capacity, Prandtl number, and convection heat transfer coefficient. The use of warm, rather than chilled, water has the potential to provide increased energy efficiency. The geometric and operating parameters of the heat sink govern its performance. Numerical modeling is used to examine the influence of geometry and operating conditions on key metrics such as thermal and flow resistance. This model also facilitates studies on cooling of electronic chip hot spots and failure scenarios. We report on the optimal parameters for a warm-water heat sink to achieve maximum cooling performance.
Fei Dong (Advisor: Prof. Cho)

Effects of Curing Conditions on Structural Evolution and Mechanical Properties of UV-Curable Polyurethane Acrylate Coatings

Tin whisker growth phenomenon which can lead to short circuit in the electronic industry becomes more serious in lead (Pb)-free electronics. One of the solutions to solve this problem is to use conformal coating. So a novel polyurethane acrylate (PUA) conformal coating which protect electronic components and boards from harsh environmental exposures was characterized to evaluate its potential in mitigating the tin whisker growth. Optimized mechanical properties, as well as the adhesion characteristics of the conformal coating on the tin surface, play a critical role in the mitigation strategies. In this project, the mechanical properties (tensile stress, elongation, elastic modulus and yield stress) and interfacial adhesion energy of conformal coating on tin (Sn) surface were measured through tensile test and four point bending test respectively. In addition, the curing step with different UV time (10min, 20min, 30min, 40min) and heating condition (80°C for 2h, 3h, 4h, 5h) after coating applying can have an effect on the mechanical properties of the coating. The curing condition and chemical structure of the coating were studied by Differential Scanning Calorimetry, Infrared Spectroscopy and Raman Spectra.

Tao Tao (Advisor: Prof. Cho)

Mechanism for nanorod growth of TiO2 in low supersaturated solution

Ceramic materials such as TiO2 and ZnO are recognized as a promising wide band gap semiconducting material for catalytic and solar cells applications due to their photo-responsive physical properties. These properties are strongly related to material nanostructures. In this work, we employed a hydrothermal method to deposit TiO2 thin film on FTO (fluorine doped tin oxide) glass substrate. Due to a thermodynamic selection reason, the TiO2 crystals grow in a vertically aligned nanorod form. The size, length and density of these nanorods are controlled by various hydrothermal conditions tailored toward specific applications. Our goal is to synthesis nanorods at low supersaturation ranges and shed a light on a possible mechanism responsible for the nanorod growth.

Preeth Sivakumar (Advisor: Prof. Singler)

Theoretical analysis of diffusion-controlled moving boundary interface at Au-Sn solder joints

Gold-Tin solder has been used in the telecommunications industry for several decades. In most of the cases, nickel has been used as a barrier layer material between solder and Printed Circuit Board (PCB), which acts as substrates. Intermetallic compound (IMC) is formed at the interface and subsequently nickel (barrier layer) is dissolved into the molten solder. The formation of the IMC is desirable for the joint to occur but excessive metal dissolution and uncontrolled growth of the IMC is detrimental to quality of joint. In the present study, numerical methods of finding transient solutions to diffusion problems, at isothermal conditions, in two distinct phases (barrier layer and solder) that are separated by a moving boundary (interface) are reviewed and compared. Finite difference equations are derived in such a way as to ensure that solute is conserved. The algorithm was run separately for two different moving interfaces Au-Sn solder/IMC interface and IMC/Ni barrier layer interface. The computational result showed that movement of solder/IMC interface is faster than IMC/barrier layer interface. The result also indicated that the growth rate of IMC, at AuSn / Ni interface, is very high during the early stage of soldering cycle (till 130 seconds) and then in later stage (after 130 seconds) it is almost constant. The efficiency of algorithms were implemented for different solder/barrier layer material interfaces in isothermal conditions that are available in literature.
Lianfeng Zou (Advisor: Prof. Zhou)

In situ atomic-scale imaging of the Cu2O/Cu interface conversion

Many processes and reactions such as the oxidation of metals, the reduction of metal oxides, and heteroepitaxial thin film growth can lead to the formation of metal/oxide interfaces. The resulting metal/oxide interface is a critical region for engineering the macroscopic properties, especially when the material systems approach to the nanometer scale, where the interface area is comparable to the bulk/surface region. However, directly probing the structural dynamics at the metal/oxide interface has been difficult due to the buried nature of the interface. Using environmental transmission electron microscopy (ETEM), we overcome this issue by forming Cu2O/Cu epitaxial interfaces via the oxidation of Cu. We probed the atomic processes of the Cu2O→Cu transformation at the Cu2O/Cu interfaces under a reducing H2 gas environment. The Cu2O→Cu conversion at the epitaxial Cu2O/Cu interface occurs in a layer-by-layer manner and through lateral ledge flow, thereby maintaining the epitaxy. However, the continued Cu2O reduction leads to the rotation of the Cu2O grain and thus the loss of the Cu2O/Cu interfacial epitaxy. Using DFT calculations, we find that the preferred occupancy of oxygen vacancies at the disconnections of Cu2O and Cu atomic planes along the Cu2O/Cu interface induces the initially ledge-flow-controlled Cu2O/Cu interfacial reduction while the accumulation of oxygen vacancies at the Cu2O/Cu interface weakens the Cu2O/Cu interface adhesion and induces the rotation of the Cu2O grain.

Qianqian Liu (Advisor: Prof. Zhou)

An STM Investigation of the Reaction of Hydrogen with Chemisorbed Oxygen on Cu(110)

The interaction of hydrogen with oxygen adsorbed on metal surface is widely studied because of its relevance to a wide range of technological processes such as heterogeneous catalysis, but the atomic processes leading to the transition of different oxygen chemisorbed phases are still poorly understood. In our work, Scanning Tunneling Microscopy (STM) is employed to study the evolution of oxygen chemisorption induced surface reconstruction of Cu(110) during the reaction of chemisorbed oxygen and hydrogen. The reduction is performed at 150 °C with hydrogen pressure varying from 1 × 10^{-8} Torr to 5 × 10^{-5} Torr on the chemisorbed-oxygen covered Cu(110) surface. Cu(110)-c(6×2) phase transits to the (2×1) phase along the step edges and then the (2×1) phase grows larger and finally covers the entire surface with higher hydrogen exposure. We show that the (6×2)→(2×1) transition occurs via the H2 induced loss of chemisorbed oxygen in the (6x2) phase, resulting on releases extra Cu atoms diffusing to the step edges and terraces. The STM observation of the atomic processes of the H2-induced (6×2)→(2×1) transition will be described in detail.

Group B, Session I

Jian Zhou (Advisor: Prof. Miles)

Title: Acoustic flow sensing by nanowires

We demonstrate that sound can be detected by nanowires. The inspiration comes from the hair-like ear structures of tiny animals, which detect minute fluctuations in the movement of air that occur in sound fields, in contrast to mammals, and essentially all microphones, which detect acoustic fluctuations in pressure. Taking advantage of ultra-long conductive nanowires with aspect ratio on the order of a thousand, the medium movement can be sensed with 100% velocity transfer ratio. We predict that this can be accomplished over a frequency range from infrasound to ultrasound. Experimental results obtained using natural and artificial nanowires support our prediction in a wide frequency range from 70 Hz~10 KHz. We also show the possibility to detect acoustic flow in um/s-range, which is identical to nm-range acoustic fluctuation. The developed acoustic flow sensing technology can be an extension to the current pressure and flow sensing technology, with promising applications such as communication, disaster warning, autonomous system, biomedicine, biology acoustic behavior, and flow related research.
Wei Yang (Advisor: Prof. Towfighian)

Nonlinear vibration energy harvesting based on variable double well potential function

Nonlinear energy harvesters have the advantage of a wider frequency spectrum compared to linear resonators making them more efficient in scavenging the broadband frequency of ambient vibrations. To increase the output power of the nonlinear resonators, we propose an energy harvester composed of a cantilever piezoelectric beam carrying a movable magnet facing a fixed magnet at a distance. The movable magnet on the beam is attached to a spring at the base of the beam. The spring-magnet system on the cantilever beam creates the variable double well potential function. The spring attached to the magnet is in its compressed position when the beam is not deflected, as the beam oscillates, the spring energy gradually releases and further increases the amplitude of vibration. We obtained two coupled partial differential equations by assuming the cantilever beam as Euler-Bernoulli beam considering the effect of the moving magnet. Method of multiple scales is used to solve the coupled equations. Making one magnet movable can create internal resonance that is explored as a mechanism to increase the frequency bandwidth. The effect of system parameters on the frequency bandwidth of the resonator is investigated through numerical solutions. This study benefits vibration energy harvesting to achieve a higher performance when excited by the wideband ambient vibrations.

Mark Pallay (Advisor: Prof. Towfighian)

MEMS Cantilever with Repulsive Force Actuation

Micro-Electro-Mechanical Systems (MEMS) are a necessity for the operation of many high-tech electrical devices. MEMS resonators are a class of MEMS devices that are used extensively in sensing, energy harvesting, signal filtering, and many other applications. Typical resonators use electrostatic, piezoelectric, magnetic, or external forces to actuate a beam or plate into resonance. The most popular actuation method is through attractive electrostatic fields, however there are some drawbacks to this method. If the attractive forces between the electrode and beam become too large they can collapse (pull-in), which can damage and/or destroy the device. The resonator outlined in this presentation uses electrostatic fringe fields to generate a net repulsive force between a cantilever micro-beam and electrode. The repulsive force eliminates the risk of pull-in, which is a major limiting factor in many electrostatic MEMS devices. A 2D COMSOL simulation was performed to determine the force profile, which showed results in close agreement with a previous analytical calculation. The beam is modeled through Euler-Bernoulli beam theory and solved numerically in MATLAB. Static and dynamic analyses of the micro-beam are presented. The resonator will be fabricated through MEMSCAP to determine the accuracy of the theoretical model results and forcing profile.

Mahdi Farahkia (Advisor: Prof. Su)

Studying Human Head Acoustics using Finite Element Analysis in ANSYS

In order to improve the performance of hearing aids, an understanding of optimal placement of microphone arrays or directional microphones on a human head is necessary. That is due to the capability of directional microphones to enhance the sound that must be heard, while eliminating background noise. These microphones work based on acoustic pressure gradient which can be translated to particle velocity. Although many have studied the sound pressure around human head, not much research has been done on understanding pressure gradient.

In this presentation, current work on obtaining acoustic pressure gradient around an object due to an incident sound wave using ANSYS is discussed. These results are verified using numerical and analytical methods to ensure the accuracy of the Finite Element Model. Necessary steps to conduct an accurate and efficient Finite Element Analysis of an acoustic model in ANSYS and extracting data presented. Finally, future steps for this project are explained.
Durability Analysis of Total Elbow Replacement (TER) Using Computational Techniques

Total elbow replacement (TER) is a common treatment for end-stage elbow joint arthritis or fracture. Although TER results in joint motions similar to the natural joint, bearing wear, excessive deformations or early fracture might affect the final outcome of the replacement. The current study aims to develop explicit finite element computational models of TER implants in order to simulate the effects of different loading patterns on bushing contact stresses and to predict possible failure mechanisms. Model results were compared directly with corresponding experimental data using micro computed tomography (µCT) imaging techniques. Comparisons were made between the possible sites of failure based on the numerical simulation and the experimental results. The results represent high localized contact pressures on the bushings which can be a reason for poor outcomes due to wear or early fracture of the TER implants. Numerical results demonstrate acceptable correlations with experimental data based on the location of deformation and creep on bushings after experimental tests. The numerical model developed can be further used to simulate the effects of different loading patterns on the implant (e.g., chair-rise) and to evaluate the outcome of optimized TER designs. Furthermore, by the manipulation of the data provided by FE simulation and the application of a wear criteria, the volume of material removed due to wear can be evaluated which leads to better understanding of critical sites of failure on the implant.

Development of Clinically Relevant Constraint Measurement of Total Knee Replacements

Despite over four decades of development, there is still no established and universal method for the design, evaluation, and comparison of total knee replacement (TKR) designs. The intrinsic constraint of a TKR system is an important metric for determining the stability, and there are standardized techniques for measuring these properties (e.g. ASTM F 1223-14). These standards describe the resistance to anterior-posterior (AP) and medial-lateral (ML) displacements, and internal-external (IE) rotation under an axial load between the femoral and tibial components at discrete flexion angles. Such tests, however, do not necessarily map directly to any physiologically relevant loading scenarios; thus, comparisons of TKR systems based on these techniques may provide misleading results. Recent advancements in the development of force-controlled joint motion simulators have allowed more physiological in-vitro joint loading, including the contributions of virtual soft tissues. We hypothesize that a function-based technique for measuring TKR constraint may yield a different classification of TKR systems in terms of constraint, as compare with the long-standing discrete-angle measurement technique. Therefore, the objective of this study is to develop an alternative, function-based means of assessing TKR constraint.
Yuling Niu (Advisor: Prof. Park)

In-Situ Warpage Characterization of BGA Packages with Solder Balls Attached During Reflow with 3D Digital Image Correlation (DIC)

The getting smaller interconnections leave limited tolerance of allowable warpage range. Understanding the packages behavior during reflow process becomes the most important task in assuring reliability. As a non-contact optical method, 3-D DIC is capable to measure deformations with high sensitivity and wide ranges. The in-situ capability allows to understand packages’ behavior during reflow process. When electronic packages are deployed to customers, solder joints are attached to the substrate. The spherical shape of a solder ball cannot correlate from two cameras. To measure warpage of the substrate, DIC requires removing the solder balls. However, these test results are questioned about the effect of solder joints elimination. There is no evidence available to demonstrate the consistency of warpage results with or without solder joints, since there is not an effective tool readily available for in-situ warpage characterization with solder balls. In this regard, a 3D DIC method, which can measure the warpage with solder joints on the surface, was proposed and investigated.

In this work, three main parameters of 3-D DIC (camera angle, facet size and facet step) are studied on the effect of data integrity. Solder ball diameter and image pixels will be combined together with facet sizes and steps to form a guidance for conducting nondestructive warpage measurement. Several samples will be measured to check the consistency of warpage behavior when the solder joints are bonded or removed mechanically.

Charandeep Singh (Advisor: Prof. Park)

Measurement of Dynamic Response Parameters Of an Underdamped System

The dynamic behavior of a system is highly influenced by the energy dissipation due to its damping. To clearly understand dynamic behavior, an accurate measurement of damping is very important. One of the most commonly used methods for evaluating damping coefficients is the measurement of decay of free vibrations. The purpose of this study is to introduce a new experimental technique, a pluck test coupled with High speed Digital Image Correlation (DIC) [1] technique, to analyze the dynamic response of underdamped systems. It is further validated comparing the results from this test with those of obtained from the existing techniques such as using laser vibrometer and by using a general purpose single-axis accelerometer. Using the pluck test, an initial displacement is introduced into the system and the response with time is measured using DIC. High speed DIC employs two synchronized high speed digital cameras. Images captured at a high frame rate by high speed cameras are analyzed using 3D DIC software and therefore, a full field dynamic response of the test subject is captured. The parameters such as natural frequency and damping ratio are obtained from the measured time history of the displacement using logarithmic decrement method [2]. The test vehicles used in this study to implement this technique are different liquid crystal display (LCD) modules used in commercially available smart phones and Corning® Gorilla® Glass that is used as cover glass in the same.
Group B, Session II

Wenyang Qu (Advisor: Prof. Ke)

Friction Characteristics of Boron Nitride Nanosheets

By using atomic force microscopy (AFM), we show the velocity-dependent friction and temperature-dependent friction characteristics of different layer boron nitride nanosheets (BNNSs). In addition, the temperature-dependent adhesion characteristics was also studied. Mechanical exfoliation is an effective, simple and inexpensive method to make thin layers BNNSs of high quality. And the BNNSs sample was deposited on a flat Si wafers with 290 nm oxide thickness. The number of layers of BNNSs were identified by Raman spectroscopy and AFM contact mode. In the velocity-dependent friction experiment, an AFM tip that was applied compressive load range from 0.05 to 25 nN sliding against the boron nitride film. And the scan velocity was controlled to increase from 250 to 2000 nm/s. The results show that, for monolayer four-layer and six-layer BNNSs, friction force between BNNSs and AFM tip increases as the scan velocity increasing from 50 to 2000 nm/s. Additionally, the friction force, starting from monolayer, decrease as number of layers increasing. Compared with the results of friction force, the adhesion force does not exhibit a prominent dependence on the number of layers.

In the temperature-dependent friction experiment, the friction force tests were conducted at sample surface temperature of 20, 30 and 40 °C, respectively. From the results, the friction force decrease as the temperature increasing from 20 to 40 °C. However, the pull-off (adhesion force) force increase as temperature increasing.

Chenglin Yi (Advisor: Prof. Ke)

Z-shape Folding of Graphene on Flat Substrate

Graphene folding is an essential process in the design and manufacturing of graphene origami. Here we report the nanomechanical z-shape folding of single graphene sheet on a flat substrate by using atomic force microscopy techniques. The quantitative nanomechanical measurements reveal that reversible out-of-plane buckling delamination of graphene occurs in its early stage folding process, enabling graphene to deform into a stable self-folded z-shape conformation. The research findings are useful to the study of active and controllable folding of graphene and in the pursuit of graphene origami with intricate geometries.
Huayan Wang (Advisor: Prof. Park)

Abstract title: In-Situ Nano Scale Strain Measurement Using 2D DIC with Scanning Electron Microscope (SEM)

As demand of the smaller dimension with multifunctional devise has been increased, different interconnect method such as TSV and Cu pillar has been widely studied. FEA are often used for stress analysis on those interconnect. But to obtain reliable analysis from FEA, empirical results must be correlated with simulation. However, measuring thermal strain of the local structures such as TSV or Cu pillar are challenging. The objective of this study is to achieve local strain measurement data of package interconnection under thermal loading which has the dimension in area of interest smaller than 30µm. To achieve this specific requirement, Digital Image correlation (DIC) technique using Scanning Electron Microscope (SEM) images is proposed. For the BGA size of interconnects 2D DIC technique with optical microscope has been used in previous studies however since sensitivity of the DIC is directly related to the field of view size and number of pixels, optical microscope cannot achieve the high magnification to measure the strain of micro structure. To implement SEM to 2D DIC, effect on the different type of SEM mode has been studied to mitigate the error induced from random noise and time drift. Also customized heating system is built to able to control and monitor the sample inside of the SEM vacuum chamber. This method enables to measure local strain of the package and also to validate the FEA simulation of the micro-scale structure such as micro bump and TSV for the further analysis.

Shuai Shao (Advisor: Prof. Park)

Die Stress in Stealth Dicing for MEMS

Wafer dicing is a necessary and important process in the microelectronics fabrication. Emerging technologies of IC semiconductor have been utilizing silicon-on-insulation (SOI) wafers. These wafers have made wafer dicing quite challenging. Compared to conventional blade dicing, stealth dicing has advantages such as debris-free and dry process. MEMS dies that are fabricated on a SOI wafer and then undergo stealth dicing is studied in this paper. Cracks were found around the edges of the membrane in the MEMS dies after stealth dicing. The failure causes are to be determined. Three processes in the stealth dicing are studied: IR laser scanning, tape dicing and peeling process. Effects of these three processes on the die stresses were investigated. It is the first time that die stresses in a membrane-structured MEMS on SOI wafer in stealth dicing are analyzed. Thermal/structural stress contours are obtained by finite element analysis. Die stresses caused by these three processes are compared.
Melissa Mansfield (Advisor: Prof. Willing)

Computational Modeling for Design Optimization of a Rate Responsive Knee Brace

Athletes who sustain ACL injuries are at much greater risk of developing early onset osteoarthritis and chronic pain, even if they undergo ACL reconstruction surgery. This is especially pertinent to female athletes who are much more likely to sustain a major knee injury than male athletes when competing in the same high-risk activities. Current prevention techniques, including neuromuscular training and conventional knee bracing have limitations. I propose developing a rate responsive knee brace that allows for unrestrained knee motions under low loading rates, but stiffens up to increase knee stability under high loading rates known to cause ACL injury. This type of brace would provide protection during neuromuscular deficits, as well as provide superior comfort and knee stability to current prophylactic knee braces, especially under high loading rates that normally elicit ACL injury. My objectives are to 1) develop and validate a computational model of a human knee for use in design optimization to develop a rate responsive knee brace, 2) determine the effect of gender on optimal knee brace design, and 3) compare commercially available knee braces and the optimized rate responsive knee brace. The optimal knee brace design is the one having maximum performance as defined by: minimizing knee displacements at high loading rates and minimizing the difference in displacements between the braced and unbraced conditions at physiological loading rates in all directions.

Van Lai Pham (Advisor: Prof. Park)

Warpage effect on CTE estimation using DIC technique

In electronic packaging, the measurement of in-plane displacement or strain is a significant resource in evaluation of the package reliability and material properties for validating finite element model. Among the various measurement methods, three-dimensional (3D) Digital Image Correlation (DIC), a non-contact optical technique, has been widely applied. This method documents both in-plane and out-of-plane deformation simultaneously with the accuracy as great as 1:30000 of the field of view. The basic principle of DIC is to track the movement of the surface patterns and correlate the movement between left and right camera. The strain measurement assists to learn the CTE mismatch among different layers of components and build the effective model under thermal loading. However, it comes to a critical issue since the occurrence of warpage influence on CTE calculation. Based on the fact that DIC can only determine the strain on the surface, the out-of-plane deformation (warpage) generates bias on quantifying in-plane strain. Issues related to warpage effects on bi-layer and tri-layer materials have been studied recently, yet proposed solutions to eliminate warpage effects on estimating CTE with DIC technique is quite limited. In this research, a study using analytical methods determining CTE under considering bending of thick materials will be presented and experiment results is planned to perform for validation purposes.
Measurement of Perception of Ego-Motion in a Ground Vehicle Simulator

Ego-motion is perceived through various physiological receptor systems. Perception of ego-motion due to visual stimuli alone is calledvection. The reported research aims to establish whethervection is evoked in a fixed base simulator. Optokinetic nystagmus (OKN) is a type of involuntary eye movement that is induced when the eye tracks a moving object and it begins with the eye fixated on a specific point. It is measured using a technique called electrooculography (EOG). In EOG the resting potential between the cornea and retina, also called as corneoretinal potential is measured. This potential varies with the position of the eye (with the head fixed), as the eye moves to track a moving object or a visual scene. In order to measure this potential, a data acquisition (DAQ) system is designed and fabricated. Experiments consist of measuring the speed (change in resting potential) of eye while tracking a computer generated signal at a fixed frequency and simulating the OKD in a dark enclosure using an LCD projector. Eye movements are recorded and the measurements are analyzed to find out if the subject experiences the sensation of ego-motion or not.

Jing Wang (Advisor: Prof. Park)

Non-linear finite element analysis on stacked die package subjected to integrated vapor-hygro-thermal-mechanical stress

This study examined the comprehensive effects of vapor pressure, hygroscopic swelling and thermal expansion on the reliability of stacked die package during soldering reflow by the finite element analysis. First, the moisture concentration distributions were obtained for preconditioning at MSL 1 as well as desorption at the reflow process. For the diffusion modeling, existing normalization approaches are only valid under constant temperature/humidity condition and cannot be extended to the reflow process which contains time-varying thermal loading. In this study, the internal source approach was adopted to overcome the concentration discontinuity at material interfaces during solder reflow. A micromechanics based vapor pressure model was used to predict the vapor pressure distribution. Second, a comprehensive nonlinear finite element model was proposed to study the vapor pressure, thermo-mechanical stress and hygro-mechanical stress with consideration of the non-uniform moisture distribution and the viscoelastic behavior of mold compound. The individual and integrated effects of vapor pressure, hygroscopic swelling and thermal expansion on the warpage and stress distribution were investigated. Finally, a fracture mechanics based approach was used to study the thermal-moisture impact on the delamination of the stacked die package.
Finding Optimum Gains for the NASA Motion System Full-State-Feedback Control Law

The subject of the research is the Cockpit Motion Facility (CMF) flight simulator motion system. The objective is to make the CMF platform behave like the ideal system. The CMF motion platform dynamics can be simulated as a second order linear model with poor performance and a low bandwidth. Introducing position, velocity and acceleration feedback with optimum gains can help increase the current state of the bandwidth and improve the system performance.

Before introducing the optimum gains, it was necessary to derive a linear model which can mostly match the CMF motion platform behavior. To derive the model, the recorded data from the NASA CMF motion platform was used. Then the full-state-feedback control law was introduced. The proposed control law has four gains which must be identified and optimized. It is desirable to minimize the error between ideal system and actual system. So the Newton-Raphson approach can be applied to obtain the optimized gains.

A MATLAB code was written to implement the Newton Raphson iterative technique. After the results converge to the criterion, the latest values of the gains can be seen as the values of the optimum gains. Time and frequency responses of the closed loop transfer function with the new gains are plotted to illustrate if the actual system has a similar bandwidth and time response as the ideal system. The presentation will discuss the Newton Raphson approach and the results.

Molding Compound/Underfill Interfacial Adhesion Strength

We observed delamination between micro-bump underfill and epoxy molding compound spacer during the aging test of an FPGA product, in which long-term exposure to sub-Tg temperature led to severe shrinkage of organic packaging materials and degradation of mechanical properties. We utilized finite element modeling for investigating the relationship between crack driving force and amount of shrinkage and estimated the failure time based on the simulation data. The cohesive critical strain energy release rate was used as fracture criterion. The failure time for aging at 125 °C is estimated to be around 5500 hours while more severe cases could arouse early failure.

However, the interfacial delamination critical strain energy release rate also needs to be tested to mimic the actual scenario in this work. Four-point bending method was performed, and the test method has been implemented for testing the adhesion strength between micro-bump underfill and epoxy molding compound. The interfacial adhesion strength under different temperatures and aging conditions could, therefore, be obtained. Test results showed a much smaller value of interfacial adhesion strength compared to the cohesive strength, which indicated an even earlier delamination failure than previous estimations.
Chaochao Zhou (Advisor: Prof. Willing)

Shape optimization of a transforaminal lumbar interbody fusion cage featuring an I-beam cross-section

Transforaminal lumbar interbody fusion (TLIF) using an implanted cage is the gold standard surgical treatment for disc diseases such as disc collapse and spinal cord compression, when more conservative medical therapy fails. Titanium (Ti) alloys are widely used implant materials due to their superior biocompatibility and corrosion resistance. However, subsidence or loosening of high stiffness Ti cages due to stress concentration and shielding is a concern. A new Ti TLIF cage concept featuring an I-beam cross-section was recently proposed, with the intent to allow bone graft paste injection and perfusion secondary to cage implantation. Design optimization is a systematic and iterative technique for designing components which perform optimally with respect to one or more performance metrics. In the cage design, we desire a clear pathway for bone graft to be injected into the implants, and perfused into the surrounding intervertebral space as much as possible. Therefore, we have employed shape optimization to maximize the sizes of cage windows (and decrease cage stiffness as well), subject to maintaining stresses below a threshold where fatigue or yield failures occur. Five cage dynamic tests (extension/flexion bending, lateraling bending, torsion, compression and shear compression) described in ASTM F2077 were simulated in each optimization iteration, such that the optimal cage design is sufficiently reliable in the long term (107 cycles) under all loading scenarios.

Meysam Daeichin (Advisor: Prof. Towfighian)

Nonlinear dynamics of micro-beam under electrostatic fringing field excitation

Electrostatic actuation is used widely in MEMS sensors and actuators because of its high efficiency and simplicity relative to other actuation methods like piezoelectric or magneto-electric. This concept is used in Micro-mirrors and accelerometers mostly with parallel plate configuration which suffers from pull-in instability. To overcome the limitation imposed by the pull-in instability, we use electrostatic fringing field actuation. In this case there is no pull-in instability as the electrostatic force is repulsive. We consider a clamped-clamped microbeam with mid-plane stretching effect as our structural element. Electrostatic force distribution is calculated numerically using finite element method and also analytically using the concept of conformal mapping. Since the analytic expression for the electrostatic force is very complicated, curve fitting is used to obtain a polynomial function. Next, Using Galerkin’s technique reduced order model of the beam is obtained. The static problem is solved to perform stability analysis. Expanding the beam deflection into dynamic and static components, using the stable static solution, the linearized nonlinear frequencies of the beam are obtained. These results will be used in dynamic simulation of the beam with shooting method in order to calculate the maximum steady state deflection of the beam.