



Technologies Available for Licensing: NANOTECHNOLOGY

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Index-tuned Anti-reflective Coating Using a Nanostructured Metamaterial

UMA 07-15; Yavuzcetin, Tuominen, Russell (Patent process initiated)

- **Description:** An anti-reflective film is created by nanostructuring the surface of the optical material into which light transmission is desired. This is achieved by etching the surface through a nanoporous polymer film etch mask, thereby transferring the porous pattern to the optical material. The resulting nanostructured layer is considered an optical metamaterial (also known as an effective optical medium) -- a material with structural features much smaller than the wavelength of light, the presence of which changes the effective index of refraction. The anti-reflection condition is satisfied by tuning the effective index of refraction by controlling the degree of porosity and the thickness of the porous layer. This method also results in an increase of the effective surface area of the top layer, enhancing results in a solar cell application.
- **Applications:** Solar cells; Anti-reflective and optical coatings
- **Advantages:** Simple fabrication process that is amenable to large scale manufacturing; Wider range of index of refraction as compared to typical deposited films; Applicability to a wide variety of solar cell materials or other optical materials; Better wear resistance than polymeric-based anti-reflectance coatings; Lower top contact resistance; Possibility for less pinhole defects than competing methods

BUMP: Buckled Microlens Patterns for Optics and Adhesion

UMA 07-12; Crosby (Patent process initiated)

- **Description:** A new method to produce microlens arrays based on confinement of surface wrinkles. A material is laterally confined in at least one dimension as a stress is applied, such as compression, swelling, photopolymerization or heat, which then generates surface "wrinkles" in the desired configuration. Previous chemical modification creates the necessary elastic moduli differences on the surface to control wrinkle formation.
- **Applications:** Tunable optical refractive devices; Compound lens for multi-angular light detection; Smart surfaces for adhesion control; True pressure-sensitive adhesives; Self-cleaning surfaces
- **Advantages:** Rapid generation of microlens arrays over macroscopic lateral dimensions; Low cost, efficient method; Ease of tuning microlens arrays through control of elastic moduli of materials and degree of lateral confinement; Ability to pattern microlens arrays over non-planar substrates; Optical properties are easily tuned and amenable to a wide variety of materials

Colorant-Free Color Filter

UMA 07-07; Kim (Patent process initiated)

- **Description:** This optical "colorant-free" color filter is based on a sub-micron scale wire grid polarizer, and another dielectric material formed on a substrate. The object is to provide polarization light and high transmission of color without using pigment. The wire grid polarizer only allows light waves of a certain rotation to pass through. The arrangement and incident angles are finely tuned - the ideal polarizer blocks one polarization light and passes another polarization through freely. Another object of this invention is to provide a polarizer matrix between color filter cells, which has a similar surface structure but different dimensional parameters. The intensity of the light arriving at the output of the display device is higher, resulting in a better image quality.
- **Applications:** LCD market – Liquid Crystal Display device – for use in TVs, monitors and other flat panel applications
- **Advantages:** The pigment-free process seeks to reduce cost (the pigment application process is quite wasteful) and simplify manufacturing, at the same time providing a display with brighter and better quality image

Method for Rapid Production of Large-Area Microstructures and Nanostructures

UMA 07-06; Kim (Patent process initiated)

- **Description:** This invention is an improved method and apparatus to control temperature and outcome during the roller embossing process. The method allows the variation of temperature at different locations on the surface of the embossing roll, achieved by the use of a high-frequency heating mechanism, and builds off the principle disclosed by the same inventors in their U.S. patent 6,846,445. This concept further refines the heating of film in the roller embossing process--from a large area heating--to a small area along the nip of paired embossing rolls using proximity heating using radio-frequency or high-frequency electrical current instead of induction. In the downstream position on the embossing roll, cooling mechanisms, either internal, external or both, are used to rapidly cool the area and effect a holding stage while the film is still in contact with the roller and under pressure, reducing the viscoelastic recovery of the film, after it exits the roll. The result is a more accurate replication of the desired surface features
- **Applications:** Polymer films of all sorts, where appearance, feel and various surface properties are of importance including optical, mechanical, electrical, and chemical properties.
- **Advantages:** The immediate cooling of the film after embossing to set the surface structures before the film leaves the roll, allows for smaller and better defined features in the finished product. Micro- and nano-structured features, once restricted to very small sample size sheets, can now be mass produced.

Strengthening PLA-PEO-PLA Hydrogels with Nanoparticles

UMA 06-36; Tew and Bhatia

- **Description:** This tissue engineering invention builds on UMA 04-18 "Designing Stiff Hydrogels from Biodegradable and Biocompatible Polymers," and seeks to improve the structure and strength of copolymer hydrogels by the addition of "Laponite XLG" particles (Laponite XLG is a synthetic layered silicate produced by Southern Clay Products, Inc.), PLA (polylactic acid), PEO (poly ethylene oxide) and gold nanoparticles. The resulting hydrogels are stiffer with increased elastic moduli, named "HydroMatrix" by its co-inventors. The addition of nanoparticles produces a strong, bioactive, bio-resorbable matrix which stimulates migration and growth of healthy cells, and provides a suitable medium for repair of cartilage and other soft tissues, providing a scaffold for new cell growth. HydroMatrix is self-assembling, with the advantage of being "tunable" to match the mechanical properties of surrounding tissue, is mostly made of water and therefore can be injected. Research is being carried out to further develop the components and formulation, and to test HydroMatrix in vitro for biocompatibility with chondrocytes (cells that produce cartilage) and other relevant cell lines, prior to testing in animal systems.
- **Applications:** HydroMatrix, a nanostructured polymer, targets the veterinary and human medical fields for repair of injuries and degenerative conditions.
- **Advantages:** Compared to competitor products, HydroMatrix retains its composition under high pressure water flow in arthroscopic surgery, and uses polymer blocks already approved by the FDA. The advantage is a less costly, less invasive, and less likely to be rejected, way to spur natural growth of cartilage.

Functionalizing Nanoporous Membranes for Protein Separation (FnMPS)

UMA 06-27A; Thayumanavan, Krishnamoorthy, Nesan

(Patent process initiated)

- **Description:** A straightforward platform technology has been developed to functionalize nanoporous membranes. The versatile technology allows one to tune the pore size (capability to obtain 6nm) as well as the functionalities inside the pore. This versatility allows for separation of molecules based on size, charge, and specific functionalities.
- **Applications:** Molecular filters for separation of molecules and proteins; Proxy for 2-D electrophoresis; Separations of all molecules (>6nm) based on size, charge and hydrophobicity; Separate proteins to pinpoint culprit for causing disease, or the catalyst for physiological process; Improve efficiency of biomarker discovery, protein research and pharmaceutical development.
- **Advantages:** Enhanced proteomic research through enhanced accuracy and sensitivity; Overcomes major shortcomings of 2-DE; Scalability of the technology facilitates mass production of inexpensive devices; Wide range of selectivity in separation; Short fabrication time; Stability across full pH range of 1–14 allows application in a variety of solutions; Use of environmentally friendly modification process; Versatile functionalization with broad range of inexpensive commercially available materials; Fine tuning of pore size with nanometer precision; Flexibility of membranes enhances tolerance to stress; No electrical double layer complications; No receptor clustering

Method of Imparting Nanoscopic Topography to Materials

UMA 06-08 McCarthy (Patent process initiated)

- **Description:** This is a new method to impart water repellency to material surfaces by introducing nanoscopic (tens-of-nanometer) length scale topography to solid or fibrous objects that are smoother (have no topographic features) than this length scale. The object is treated with solutions of an organosilicon halide or mixtures of organosilicon halides and subsequently treated with a non-solvent for the resulting attached polymer, extracting the organic solvent and causing phase separation at the nanoscopic length scale. The results are a nearly hydrophobic surface (i.e. totally water repellent). It may have further implications beyond water repellency such as non-reflective coatings.
- **Applications:** It is applicable to many materials, organic or inorganic, of all shapes and sizes, where water repellency is of importance or desirable.
- **Advantages:** The method is very simple and straightforward, and can be applied to smooth surfaces over large areas.

Anti-fouling Graft Copolymer Coatings on Commercial Membranes

UMA 06-31; Emrick (Patent process initiated)

- **Description:** Hydrolytically stable, amphiphilic, and photoactive graft copolymers have been synthesized and applied as coatings to commercial membranes materials.
- **Applications:** The graft copolymers of this invention can be applied to commercial membranes as sub-micron coatings to prevent fouling. For example, poly(vinylidene fluoride) ultrafiltration (PVDF-UF) membranes undergo little-to-no fouling in cross-flow filtration experiments with an oil-in-water emulsion feed. Conversely, the commercially available uncoated membranes foul readily under identical conditions.
- **Advantages:** The graft copolymer coating provides a clear advantage over the commercial material by preventing membrane fouling. The graft copolymer synthesis is of interest for the ability to readily tune properties, including hydrophilicity, graft length and density, and relative degree of cross-linking functionality on the polymer backbone.

Production of Reduced Fat Foods using Gelled Biopolymer Particle Double Emulsions

UMA 06-12; McClements, Decker, and Weiss (Patent process initiated)

- **Description:** This invention is a new method based on the utilization of gelled biopolymer particles in double emulsions (sometimes called multiple emulsions) for producing reduced fat food emulsions or for development of novel encapsulation, stabilization and release systems. The method produces stable water-in-oil-in-water (W/O/W) emulsions that would be suitable for use within the food industry, based on the creation of gelled biopolymer particles in the water-in-oil (W/O) emulsion.
- **Applications:** Applied science applications of this novel invention: (1) Creation of low-calorie fatty food products that have similar physicochemical properties and quality attributes as conventional full fat products. (2) Emulsion-based food products where conventional fat droplets would be replaced by fat droplets containing gelled biopolymer particles, (e.g., in mayonnaise, dressings, yogurts, deserts, sauces, soups, dips, beverages, meat products, creamers, pet foods). (3) All ingredients used to make the double emulsions could be food-grade; therefore, not need FDA approval.
- **Advantages:** This invention has several key advantages from the usage of gelled biopolymer particles in the W/O emulsion. (1) Greater mechanical rigidity and cohesiveness than non-gelled water droplets. (2) More stable to the extremely high mechanical stresses experienced by the water droplets when the initial W/O emulsion is homogenized with an aqueous solution to form the W/O/W emulsion. (3) Can be prepared using all food grade ingredients (e.g., proteins, polysaccharides and minerals). (4) Can be prepared using simple food processing operations (e.g., mixing, heating and homogenization).

Snapping Surfaces for Sensors and Adhesion Control

UMA 06-06; Crosby (Patent process initiated)

- **Description:** This invention involves creating shape transition at responsive interfaces or surfaces by employing simple features such as shells, plates or columns, that are integrated into a material's surface or interface through simple processes of molding or self-assembly. Upon application of a given stimulus (e.g. weight, light, chemical, thermal) the structures will spontaneously transform their shape due to the onset of elastic instability. This instability is a "snap-through" event which induces the shape transition of the material surface.
- **Applications:** The applied science that will result from this work can utilize the novel shape transition to serve several purposes. For example, it can cause the immediate de-bonding of a coating that is applied above these structures; it can activate an electrical signal to trigger a warning signal; it can change the reflectivity of a surface;

or it can simply change the adhesion quality of a surface, among many other applications. Potential commercial uses include on-command release of coatings, chemical sensors for packaging or coatings, anti-fouling coatings, tunable adhesives, "smart" adhesives, true pressure-sensitive adhesives, and release strategies for tissue engineering.

- **Advantages:** This invention has several key advantages for stimuli-responsive surfaces. (1) Sensitivity - the dimensions of the buckling structures and the residual stress built into the material surface can cause buckling to occur under a very small change in environmental conditions. (2) Speed - an example of the spherical shell illustrated a transition that occurs within 0.01 seconds. (3) Magnitude of change - the changes in adhesion or signal to noise for sensors can be very high due to the defined speed and force with which these buckling instabilities occur. (4) Versatility - structures can be designed on several length scales, using a wide-variety of materials for a wide-range of applications. (5) Ease of Development - processes already exist for covering surfaces with similar structures and new processes can be developed in a straightforward manner.

Novel Procedure for Creating Nano-Laminated Edible Films

UMA 05-27; McClements and Decker (Patent process initiated)

- **Description:** Edible films or coatings can be used to prevent food exposure to a host of conditions that can cause changes in food quality and safety. Current edible films have limited uses because of their physical characteristics. For example, lipid-based films have good moisture barriers but contain no mechanical strength. This invention overcomes these shortcomings by engineering edible films with multiple functional layers. The novel aspect of this invention is that it would be possible to engineer the properties of edible films and coatings in a much more controlled fashion than is possible using conventional technologies. In particular, by controlling the chemical composition, thickness, number and order of the various thin films used to make the laminate, it is possible to control the rheology, permeability, and stability of the overall film. In addition, it is possible to engineer unique functional attributes into the film by incorporating active agents, such as anti-microbials, anti-browning agents, anti-oxidants, enzymes, flavors, colors, etc.
- **Applications:** Food coatings, films, protectants, enhancements.
- **Advantages:** This invention has several key advantages over existing edible film technologies: (1) It permits the physical properties and functional attributes of edible films and coatings to be engineered using nano-scale and/or micro-scale techniques; (2) It is independent of any specific material, allowing the invention to leverage new materials advances; and (3) It uses all food-grade materials (GRAS) and existing inexpensive production techniques.

Novel Procedure for Improving Encapsulation of Particulate Materials

UMA 05-22; McClements and Decker (Patent process initiated)

- **Description:** Many industries use micro-encapsulation to convert liquid oil-in-water emulsions into powders containing particles that consist of oil droplets embedded in a solid wall material. The most common industrial technique used to accomplish this conversion is spray drying. The efficient production of high quality spray dried product depends on selection of the most appropriate spray drier design, operating conditions, and feed material. This invention improves the composition of the feed material used in spray drying, by improving the final properties of the powders produced and/or reducing the amount of solids required in the materials. This novel invention improves the feed material by covering each individual oil droplet (or other type of particle) with a multilayer biopolymer membrane that is relatively thick and resistant to rupture prior to carrying out the drying process. These interfacial membranes can be designed to improve the economic, physicochemical and functional properties of the spray dried material.
- **Applications:** Industries such as drug, food, beverage, supplement, and personal care report problems associated with micro-encapsulation of functional ingredients, e.g., poor dispersibility, chemical degradation of functional ingredients, high product losses during production.
- **Advantages:** Several features of this invention improve upon conventional spray dried material: (1) Reduces the amount of wall material required to create stable systems, which reduces the cost of the spray drying process; (2) Prevents destabilization of the material within the droplets during storage and application, e.g., lipid or flavor oxidation, which increases the shelf-life of the powder; (3) Prevents oil droplet aggregation before, during and after micro-encapsulation, which improves the quality of the powder; and (4) Improves dispersibility of the powders.

Patchy Surfaces for Selective Adhesion, Sensing and Separations

UMA 05-10; Santore (Patent process initiated)

- **Description:** This invention presents a new method of selective particle separation, sensing, and adhesion control, based on particle size, characteristic curvature, and surface chemistry, including lengthscales of heterogeneities in surface chemistry. The invention describes the preparation and use of detection / adhesion surfaces that contain nanoscale domains which are fundamentally adhesive while the rest of the surface is

fundamentally repulsive to some portions of the surface of some external objects. These surface features can be recognized by external objects and molecules, the surface pattern being the sensing element. Patterns can adhere single molecules or objects up to at least one micron, and being a completely artificial construct, achieve selectivity without the use of fragile and costly biological molecules, if applying this method to analysis of biological materials.

- **Applications:** For the separation and / or sensing of molecules and particles from classical chemical separations to pharmaceutical and biomedical applications. Can be used to analyze very small volumes, as a substitute for, or to enhance, chromatographic separation. Can be used in combination with other methods such as electrophoresis and flow field fractionation; can be used in linear flow chambers (on chips and sensors) and with gentle shearing flows; appropriate for biological cells to separate them from proteins, different types of cells or viruses.
- **Advantages:** This method follows the concept of biological pattern recognition, but on a scale of nanometers instead of angstroms, without the use of fragile biological molecules. The selective adhesion surface features can be economically applied to planar or other geometries such as fibers (for increased throughput).

Geobacter sulfurreducens Conductive Pili as Biological Nanowires and Uses Thereof

UMA 05-09; Lovley, Reguera, McCarthy, Tuominen (Patent process initiated)

- **Description:** The present invention reports the conductive properties of *Geobacter sulfurreducens* pili (geopili) and their use in nanotechnology applications. More specifically, the present invention provides methods for culturing cells of *G. sulfurreducens* to produce conductive pili, as well as methods for their isolation and for their modification in order to produce biological nanowires or biological/inorganic hybrid devices with different functionalities. The invention provides applications for cells expressing native or modified pili, as well as for the isolated native or modified pili.
- **Applications:** Geopili, the pili produced by *Geobacter sulfurreducens*, may be applied in any application where nanowires are required. These include but are not limited to nanowires with electronic properties ranging from metallic to semiconducting for use in control of electron charge in nanodevices, and electrically-based biological and chemical biosensors.
- **Advantages:** Geopili can easily be mass-produced and they are naturally conductive, thus reducing manufacturing costs, and they can be altered using common genetic manipulations to make nanowires with different functionalities.

Amphiphilic Monomers and Polymers Derived Therefrom

UMA 05-01; Thayumanavan (Patent process initiated)

- **Description:** The present invention demonstrates that incorporation of amphiphilic functionalities within the same monomer unit affords assemblies that are micelle-like or inverse micelle-like in solutions. The amphiphilic polymers exhibit very low critical micelle concentration (CMC), the assembly adapts itself to its environment (micelle-like in water, inverted micelle-like in apolar solvents), multiple functionalities could be directed in the interior of these nanoscale assemblies, and the invention offers the ability to compact incompatible functionalities by creating amphiphilicity using a third functionality.
- **Applications:** This invention may be applied to a variety of applications. This may include chemical decontamination of sensitive equipment, smart adhesive, controlled drug release, controlled release of pesticides or insecticides, targeted delivery to specific cell types, targeted gene delivery, and as compatibilizing agent for incompatible polymer blends.
- **Advantages:** It is an object of the present invention to provide a polymeric compound having invertible micellar capability at low critical micelle concentration, as compared to small molecule surfactants of prior art. The current amphiphilic polymers can be exemplified by the ability to perform phase transfer catalysis in fluorocarbon solvents. The polymer has the capability to sequester both lipophilic and hydrophilic compounds and confine them together in a nanoscale environment.

Emitting Quantum Dot Nanoparticle – Poly(phenylene vinylene) Composite Materials

UMA 04-24; Emrick (Patent process initiated)

- **Description:** The composite materials prepared in this unique approach allow the properties of quantum dots (CdSe nanocrystals) to be exploited in electronic polymer materials, using only a very low loading of quantum dots relative to conventional approaches. The effective dispersion of quantum dots within electronically active polymers, such as poly(para-phenylene), results in extensive interfacial contact between the quantum dots and polymer. This generates an efficient energy transfer between the two components that cannot be achieved in conventional blends, where quantum dot aggregation prevents such efficient transfer. Key to this invention is the strategic use of organic functionality in both the nanoparticle growth step and the subsequent polymerizations that provide the composite materials.
- **Applications:** Fabrication of light-emitting devices such as light-emitting diodes, solar cells, photon counters, sensor materials, materials for flat panel displays.

- **Advantages:** There are significant cost advantages, as well as environmental benefits, associated with the use of lower weight percentages of quantum dots in the composite materials.

Designing Stiff Hydrogels from Biodegradable and Biocompatible Polymers

UMA 04-18; Tew and Bhatia (Patent process initiated)

- **Description:** Triblock copolymers of poly (L-lactide) (PLLA) and poly (ethylene oxide) (PEO) have been processed to form stiff hydrogels which display elastic moduli in the range of 1000 – 18,300 Pa at ambient and physiological temperatures. These elastic moduli are in the same range as soft tissues (human and animal).
- **Applications:** Drug delivery systems; Drug eluding medical implants; Tissue engineering; Gels for rheological processing, cosmetics, etc.
- **Advantages:** Biodegradable and Biocompatible; Controlled Modulus.

Porous Hydroxyapatite Networks for Synthetic Bone Material by Spinodal Decomposition

UMA 04-14; Hyers (Patent process initiated)

- **Description:** A synthetic porous bone graft material produced through a spinodal decomposition process. The porosity can be modified by varying the initial composition, while the pore size can be changed by varying the time-temperature history. The resorption rate may be controlled through solution treatment. Control of these process variables would allow the implant material to be tailored to the specific application.
- **Applications:** Bone grafts for human and animal use.
- **Advantages:** Costs less to produce than currently available materials. Is a resorbable, porous, biomaterial of calcium phosphate. The rate of resorption, pore size, and porosity can be tailored to each specific application (injury, etc.). Stronger than currently used materials. Can be made to match the natural elastic modulus of natural bone. Eliminates the need for surgery to remove bioinert materials. Eliminates the need for autograft or allograft natural bone and the associated complications.

Encapsulation of Oils Using Three-Layered Interfacial Membranes Produced from Emulsifiers and Biopolymers

UMA 04-12; McClements and Decker (Patent process initiated)

- **Description:** Oil-in-water emulsions containing droplets stabilized by three (or more) layers are formed using a multiple-stage process. The emulsifiers and biopolymers used can be food-grade phospholipids, small molecule surfactants, fatty acids, proteins, polysaccharides and biopolymer complexes. In this way food-grade emulsions can be produced containing droplets surrounded by layers of different substances, rather than the conventional one or two layers.
- **Applications:** (a) Encapsulation of oil-soluble food and non-food components inside oil droplets, such as vitamins, antioxidants, colorants, bioactive lipids, preservatives, or minerals. (b) Encapsulation and protection of water-soluble food and non-food components, such as those mentioned above. (c) Controlled release, and release in response to environmental changes, (pH, ionic strength, temperature), of both oil and water soluble ingredients. (d) Creation of low-calorie food products by using a non-digestible interfacial membrane – such as sauces, desserts, soups, beverages, creamers, meat products, pet food.
- **Advantages:** Three-layer interfacial membranes have advantages over conventional emulsions: (a) dramatically improved stability to freeze-thaw cycling; (b) improved stability to pH and salt concentration; (c) improved stability to thermal processing; and (d) can be produced economically using existing production technology. All ingredients can be food-grade, thus, no need for FDA approval

Rapid Production of Structured Materials

UMA 04-10; Watkins (Patent process initiated)

- **Description:** Structured metal oxides can be prepared by the condensation of metal alkoxides or other suitable precursors within patterned organic templates diluted with supercritical fluids. Templates can be rapidly prepared and patterned by appropriate techniques such as hot embossing, nano-imprint lithography, step and flash lithography, or by conventional photolithography. Complex three-dimensional structures can be prepared by two-photon lithography in a process called three-dimensional lithographic micro-fabrication. Supercritical fluid drying of MEMS (micro-electro-mechanical systems) is a common practice to prevent feature collapse and problems with stiction. This process offers a means to compress multiple process steps using equipment already familiar in the industry.
- **Applications:** Useful for a variety of applications. The metal oxide device structures can be dense or can exhibit well-defined mesoporosity. Enables rapid and economic production of structures for MEMS, NEMS (nano-electromechanical systems), microfluidic devices, devices for sensing and detection. Can be extended to a number of structural materials including various metal oxides. Possible extension to calcium carbonate mimics of bone, which would lead to net-shape medical implants.

- **Advantages:** A unique process which is rapid and efficient. Reduced number of process steps to achieve structures not possible through conventional processing (e.g., below 50 nm).

A Masking Method for Nanotemplated Surface

UMA 04-02; Santore (Patent process initiated)

- **Description:** A development of materials, surfaces and method for exclusion-masking technique at the nanometer or micron length scale, and for controlling the selective adhesion of materials, (such as proteins, bacteria, viruses, cells or particles and molecules of non-biological origin).
- **Applications:** Protein separations, biomaterials, tissue scaffolds, materials with controlled wetting and adhesive properties. Biological and non-biological adhesive preparations.
- **Advantages:** This method produces patterned surfaces with different chemical libraries available on the patterned areas. The pattern detail can range from 3 nm up to micron scale, with spacing as large as 1 pattern repeat (of a 3-nanometer-sized feature) per micron is possible, surpassing the range of spacing achievable by the phase separated polymer film method. The variation achievable in size and shape of the masking area is also greatly enhanced. The method could be applied on irregular objects and fibers.

Novel Polymer Capsules Prepared by Interfacial Crosslinking of Amphiphilic Graft Copolymers

UMA 03-25; Emrick (Patent pending)

- **Description:** A chemical crosslinking process is used to prepare capsules from PEGylated polyolefins using either oil-in-water (i.e., oil inside the capsule in a water-based system), or water-in-oil system. The covalent network structure of these capsules makes them more robust than many other systems under investigation in controlled-release. The unique nature of the crosslinking chemistry is such that the crosslinks can be made either hydrolytically stable or unstable. Those with hydrolytically stable crosslinks have longer carrier lifetimes, while those with hydrolytically unstable crosslinks will degrade over a time period that can be controlled by crosslink density and the type of crosslinker used.
- **Applications:** Capsules for controlled release in drug delivery. Release of flavors and scents.
- **Advantages:** A unique feature of this new approach is the ability to construct a "dual release" system in which molecules from both the capsule periphery and from its interior can be separately released in a controlled manner.

Process For Synthesis Of Oriented Molecular Sieve Membranes With Improved Separation Performance

UMA 03-11; Tsapatsis (Patent pending)

- **Description:** A modified seeded growth method was developed that allows the fabrication of zeolite MFI films that have straight 5.5Angstrom channels perpendicular to the membrane surface. The membranes show improved separation performance. For example, they have the highest permeance and selectivity reported up to now for xylene isomer separation.
- **Applications:** Separation of hydrocarbon mixtures, membrane reactors.
- **Advantages:** The membranes show highest flux and selectivity compared to those reported before. The membranes are potentially more resistant to cracking compared to those reported before.

Design of Polymer Surfaces With High Affinities Toward Biological Cells

UMA 03-04; Nuesslein (Patent pending)

- **Description:** This is a new method to sense microbial cell types at high levels of selectivity. The development of a bacteria-friendly surface is achieved through polymer imprinting, a process wherein monomers are polymerized around a target cell to retain a replica imprint. If this "mold" of the target cell is coupled to the surface of a vibrating detection device, bacterial cells can be detected selectively in less than a minute by the significant reduction in the vibration frequency of the detection device. The novel aspect of this invention is the ability to now sense microbial cells directly (on-line) in environmental samples, very quickly, selectively, and in real time through the cell-friendly man-made surfaces. Furthermore, one can fabricate bio-material surfaces for drug testing, or create attachment sites to support specific recognition and growth by human cells in medical prostheses.
- **Applications:** This invention may have great impact on health and welfare by supporting pharmaceutical and medical diagnostics, minimizing rejection of medical prostheses, as well as industrial process control, food and water processing. In addition, it could be useful in first-line-of-defense detection applications where quickness and selectivity are paramount, such as military situations, bioterrorist attacks, environmental contamination, and disease control.
- **Advantages:** This system senses different kinds of microorganisms selectively, quickly, directly, and at low concentrations. Currently the fastest sensing devices are indirect and need at least 15 minutes of sample processing time.

Novel Ligands and Functionalized Nanoparticle Compositions Compatible in Either Organic or Aqueous Solutions

UMA 02-31; Skaff & Emrick (Patent pending)

- **Description:** This invention provides a variety of nanoparticle-polymer composite materials, each such composite having a nanoparticle component, a polymeric component and a coupling component, each of which is dictated by the solvent system (either water or an organic solvent) in which the nanoparticle is to be dispersed, such that the nanoparticle-polymer composition retains the stability, photoluminescence and quantum yield properties of the nanoparticle. An example of this invention is a new class of ligands, specifically polyethylene glycols (PEGs) terminated with covalently bound pyridine groups, synthesized and used to prepare water and oil soluble CdSe nanoparticles. This scheme represents a novel route to water soluble nanoparticles, and the methodology allows one to prepare water soluble nanoparticles more quickly than previously. Water solubility does not depend on pH, due to the charge neutral PEG chains. A unique aspect of these nanoparticle materials is their amphiphilic nature, as the isolated PEG-covered nanoparticles are soluble in both water and organic solvents, and exhibit absorption, photoluminescence, and quantum yield properties.
- **Applications:** Nanoparticle bio-tags; medical uses such as biological detection agents.
- **Advantages:** The products are new materials, and the preparation method provides an easy, rapid synthesis of water-soluble nanoparticles, which is amenable to scale-up and mass production.

A Method of the Synthesis of a Novel Layered Silicate with Three-Dimensionally Microporous Layers

UMA 02-26; Tsapatsis (Patent pending)

- **Description:** The material is a three-dimensionally microporous layered silicate, and is obtained in a highly crystalline form, which remains crystalline up to 723 K with little lattice contraction. There are channels in the silicate layers, including pores perpendicular to the layers, the layers being bonded by cations. The structure may be altered by substituting alternative ions. Layers may be delaminated to produce single porous silicate layers. In another aspect, the material can include a polymer to produce a composite material.
- **Applications:** Layered silicates may be used in applications such as catalysis, adsorption, ion-exchange and separation; in nanocomposites with polymers as active filters like conventional layered silicates or clays. The 3-D porosity enables its use for membrane applications, such as gas separation applications: oxygen generation/enrichment from air streams, natural gas purification, and carbon dioxide recovery.
- **Advantages:** This layered silicate is the first with three-dimensional channels. It has a unique topology, it possesses thermal stability up to 500 degrees C, which is important for high temperature catalysis applications.

A Rapid Interfacial Route to Produce Water Dispersible Nanoparticles

UMA 02-12; Emrick (Patent pending)

- **Description:** This invention describes a simple direct route by which water-dispersed nano-particles can be prepared. Water-oil dispersions with nanoparticles, the elemental composition of which allows the attachment of oil-soluble ligands, are shown to undergo a process at the oil-water interface that imparts a water solubility to the particles. The nanoparticles are photoluminescent in both the oil-soluble and water soluble states.
- **Applications:** Nanoparticle-based materials, especially those with active electronic and luminescent properties, are attracting interest as components in biotechnology for use as fluorescent tags in diagnostics and detection of disease. Nanoparticles of different sizes differ in emission wavelength, opening opportunities to perform complex biological studies based on this precise detection mechanism.
- **Advantages:** Production of water-soluble nanoparticles by an interfacial process, which overcomes previous limitations that require multiple preparative steps to achieve water solubility.

Mesoporous Materials and Methods

UMA 01-30; Watkins (Patent pending)

- **Description:** A novel process by which well ordered mesoporous films can be created by the three-dimension replication of pre-organized block copolymer templates using supercritical fluids. Mesoporous silicate, carbon and titanium dioxide films have been prepared by the infusion and selective condensation of precursors within one phase domain of highly ordered, preformed block copolymer templates using supercritical carbon dioxide as the reaction medium. The template is then removed to produce the mesoporous oxide. To date we have replicated ordered spherical and cylindrical morphologies to yield titania, silica, organosilicate and mixed silica/organosilicate mesostructures in films over 1 micron thick while maintaining all the structural details of the sacrificial copolymer template.
- **Applications:** Principal applications involve the preparation of device quality thin films for microelectronics, separations, sensors and energy conversion. Extensive development of ultra-low k dielectric thin films (ULKs) has taken place. For ULKs, the first-generation of templates yielded films dielectric constants as low as 1.8. A film with $k = 2.2$ was selected for further evaluation and found to survive CMP in a planar test stack. The process

can be scaled for full wafer production on a Si platform using existing production scale (200 mm and 300 mm wafer) tools for SCF processing.

- **Advantages:** In combination with, Structured Materials and Methods U.S. 2005/0186515, advantages of this approach include rapid and high degrees of network condensation, low film stress, rapid cycle times, stable templates and precursors and opportunities for pore alignment direct patterning strategies. Phase-segregated block copolymer films with cylindrical domains oriented normal to the substrate can be replicated to yield the corresponding silicate mesostructures containing arrays of continuous, perpendicular channels with tunable pore sizes. Direct patterning of mesoporous films using optical lithography for selective area exposure of templates containing photoacid generators prior to precursor infusion has been demonstrated..

Nanofabrication

UMA 01-26; Tuominen & Russell (Patent pending)

- **Description:** Multilevel 3D nanofabrication process using laterally-patterned block copolymer templates and nano wires to yield functionalized nanoscopic structures on various surfaces. Very cost effective method for manufacturing of nano scale structures.
- **Applications:** Electronic field emission arrays for flat panel displays and spin polarized electron emitters. High density magnetic data storage devices in the 1000 Gbct/in² density range. Solid state thermoelectric cooling devices. Biomolecular diagnostic-sensor arrays. Magnetic electronic devices for magnetic sensing applications and for "spintronics" applications.
- **Advantages:** Cost effective, rapid fabrication of 3D multi-level nanostructures. Field emission arrays which have higher resolution, are less expensive to manufacture and can be thinner, more flexible, and possibly brighter than those currently available. A simple process which allows for the patterning of the ordered arrays of cylinders which can then be filled with electro deposition of many types of metals or substances to accomplish active physical and chemical nano devices. Flexible, thin nanoscopic thermoelectric cooling devices can now be made which may be very energy efficient and cost effective to manufacture. Simple, cost effective process for creating high density magnetic storage, smart media, microelectrodes and molecular electronics.

Classification, Separation, and Capture of Ultra- Fine Particles by Impact Separation

UMA 01-14A; Blake & Jakus (Patent pending)

- **Description:** A system for handling, collection and classification of ultra-fine and nano-scale particles is based on impact separation technology through control of the operating environment. The fractional efficiency for particle capture and the cut-diameter are affected by the geometry of the device, flow rate, and operating pressure, together with the particle characteristics.
- **Applications:** Classification of particles and removal of agglomerates. Separation of particles from carrier gas. Collection of powders.
- **Advantages:** Based on commercial embodiment with simple design. Ease of scale-up. Continuous operation. Readily integrated with synthesis processes or other collection devices.

Ultra-High-Density Magnetic Arrays

UMA 00-12; Tuominen & Russell (Patent pending)

- **Description:** A technology for manufacturing extremely dense magnetic arrays for next-generation data storage applications. Produced by a novel imaging technique and conventional manufacturing processes, this technology has the potential for storing very large volumes of data on the order of 200 gigabits per sq inch or more. Other applications include giant magnetoresistive (GMR) materials for disk drive read/write heads.
- **Applications:** Next-generation ultra-high-density magnetic data storage media. Patterned data storage media for smart cards or other microchip applications. High density GMR read heads and encoders.
- **Advantages:** Combines a novel imaging system with conventional manufacturing processes. Simple, fast, reproducible process. Scaleable and adaptable to a wide range of media geometries. Ultra-high-densities of 1.2 trillion+ magnetic images per sq. inch. High thermal stability for long-term data integrity. Imaging technique allows for ultra-fine patterning. Low power consumption.

Functionalization of Surfaces by Surface-Initiated Graft Polymerization

UMA 00-08; Bianconi, Ingall. ShROUT & Long (Patent pending)

- **Description:** This invention comprises a novel method for attaching polymer and copolymer films of desired thickness (nanometers to microns) to a variety of substrates. The invention provides strong surface attachment to silicon, glass, oxide ceramics, and all structural metals. The method makes possible this strong surface attachment of any desired polymer or copolymer layer; both polar and nonpolar monomers can be used. Surface interfaces can be specifically tailored for optimum chemical modification, chromatographic properties, lubricant and wetting properties, anti-fouling properties, and biocompatibility and biostealth properties. Photolithographically-patterned polymer features, useful for metallization, etch barriers, fabrication of nano-scale

devices such as capacitors, and other functions in microelectronics, can be generated on any of the above-mentioned surfaces.

- **Applications:** Optimization of any coating for innovative biomaterials, microelectronics, and all structural materials. Novel properties that can be attained include: **Biomaterials:** Tethering of ligands, biomolecules, reporter groups to surfaces; Biological and chemical sensors; Reduction of nonspecific adsorption of proteins and cells (biostealth materials); Artificial membranes; **Microelectronics:** Metallization or other functionalization of nanoscale patterned polymer features; Chemically modified electrodes; Alternative method for production of nanoscale photolithographic features for semiconductor devices; **Structural materials:** Polymer to ceramics adhesion; Polymer to polymer adhesion; Anti-fouling coatings; Optimization of lubrication and wetting properties of ceramics and metals.
- **Advantages:** Specific tailoring of any surface for optimized chemical or physical properties. Substrates not limited to gold. Wide range of polymers, copolymers, and combinations. Polymerization site at the distal end of the polymer chain, allowing for unlimited polymer growth and selected functionalizations of the polymer film surfaces. Chemical attachment to surfaces by strong covalent bonds, instead of less robust physical adhesion. Readily adaptable process. Controllable for highly uniform, dense polymer coverage.

Chemical Fluid Deposition Method for the Formation of Metal and Metal Alloy Films on Patterned and Unpatterned Substrates

UMA 00-06; Watkins (U.S. Patents 6,992,018, and 6,689,700)

- **Description:** A novel process by which high-purity metals or metal oxides are deposited from supercritical carbon dioxide solution by the chemical reduction or oxidation of soluble organometallic compounds. The process is demonstrated by deposition of ultra-high purity copper, platinum, ruthenium, palladium, gold, and their alloys as well as hafnium oxide, titania and other materials onto substrates including silicon wafers. The same method could be used to deposit a wide variety of metal and semiconductor thin films.
- **Applications:** Principal application is the deposition of high purity metal or metal oxide films suitable for microelectronic devices. The invention overcomes two significant deficiencies of the current state of the art, chemical vapor deposition. The invention can also be used for the metallization of porous inorganic solids for use as supported catalysts where conventional approaches such as metal ion exchange are ineffective. Water purification and hydrocarbon processing could be two target markets.
- **Advantages:** The principle benefits of this invention are four-fold. First, in combination with US 5,789,027, it enables the conformal deposition of pure films in very high aspect ratio features. Conformal deposition is possible because of high precursor concentrations that yield surface reaction rate-limited depositions. Second, because transport occurs in supercritical solution, precursor volatility constraints are eliminated. Third, alloys of defined composition can be deposited in a single step using this technique. Finally, deposition temperatures are lower than traditional CVD processes.

Formation of Submicron Patterns on Films

UMA 00-05; Russell, Thurn-Albrecht, Schaffer, Mlynek & Steiner (U.S. Patent 6,391,217)

- **Description:** This invention offers a novel but easily adapted approach to well defined and well organized hollow structures in polymers. Extremely dense submicron lithographic patterns in films have numerous applications in Microelectronics and data storage, medical and research biotechnologies, high-tech materials for insulators and adhesives. More generally, this invention is suitable for applications requiring well-defined submicron features.
- **Applications:** Ultra-high density lithographies on films for Computing (next generation data storage and microelectronics); Biotechnology (drug delivery systems and biomaterials); Applications also include insulating materials, ultra-thin laminations, filters, adhesives, and other uses requiring well-defined submicron features.
- **Advantages:** Novel and easily scaled patterning system makes use of conventional manufacturing processes. Simple, fast, reproducible process is inexpensive and adaptable to a wide range of polymers and geometries. Exceptionally high patterned densities. Environmentally sound.

Benign Process for Creating Micro-Porous Polymer

UMA 99-36; Winter & Gappert (U.S. Patent 6,558,607)

- **Description:** A novel and environmentally benign process for creating open-pore structures in a variety of polymers. The zero-emission process is applied to create tailored pore size distributions during or after processing (extrusion, injection molding, blow molding) for a wide variety of geometries (film, fibers, molded parts) while preserving the overall shape of the polymer. The process is easily scaled-up.
- **Applications:** Textile applications for "breathable" laminates of fibers. Bio-tech/Medical use of ultra-clean porous materials. Filter applications for purification of liquids. Membrane separations involving separation of gasses and liquids. Battery separators. Super absorbency fibers and membranes.
- **Advantages:** Works with a variety of polymers including polyethylene and polypropylene. Processing allows control of pore size and distribution. Employs conventional equipment and techniques which are easily scaled-up. Sample geometry controlled by conventional shaping methods (extrusion, injection molding, blow molding,

etc.). Microporosity induced either during or after shaping and composite fabrication. Environmental benefits – processing fluids are benign, recoverable, and reusable. Resultant porous polymers are exceptionally clean, and retain shape and structural integrity.

A Method for Surface Functionalization of Titanium and Other Metals

UMA 99-23; McCarthy (Three patents issued; licensing available in all but one application)

- **Description:** An innovative process for altering titanium and a wide range of other metal surfaces to adapt a variety of functional characteristics. The process results in a thin, high strength coating on the metal surface. Functional characteristics achieved include improved adsorption, wetting and catalytic properties, improved adhesion, and selective adhesion to metal in silica-metal composites.
- **Applications:** Pigments for inkjets, paints, and plastics; Coatings for titanium, stainless steel, nickel and other metals; Reinforced structural and sheet polymers containing Ti fillers; Stronger polymer coatings; Functionalized titania surfaces for adsorbents, catalysts, and membranes; Chemically modified titania electrodes and sensors; Well-characterized, high density surface monolayers
- **Advantages:** Pigments: Functionalized Ti particles resist coagulation to stay evenly dispersed for smoother color quality; Enable Ti polymer or silica filler to act as reinforcement; Highest density surface coverage achievable with organosilanes; Selective modification of composite surfaces – e.g. modify titania exclusively in a silica-titania composite; Lower boiling points allow for vapor phase modification; Eco-Friendly: Method involves less toxic reagents and produces no corrosive byproducts; Stronger, corrosive resistant stronger more durable coatings.

Reversible Hydrogels

UMA 97-22; Petka & Tirrell (U.S. Patent 6,090,911)

- **Description:** The invention is based on the discovery that a block copolymer that includes α -helical blocks, e.g. terminal blocks, which form intermolecular coiled-coil structures, and one or more random-coiled blocks, which link the α -helical blocks, can form suspensions that can reversibly gel to form monodisperse hydrogels. The transition between the gel and liquid phases depends on pH, temperature, concentration, and chemical structure. The copolymers can be synthesized biologically through genetic engineering.
- **Applications:** Bases for cosmetics. Wound dressings, using copolymers to produce a protective, medicated gel surrounding the wound and promoting healing. To encapsulate drug molecules for sustained delivery applications. Because the properties of the gels can be highly sensitive to physical conditions, the gels can find application in gel-based actuators, valves, sensors, motors, switches, artificial muscles, memory devices, optical shutters, filters, toys, paints, coatings, absorbants, bioreactors, micro-machines, display devices, and robotics.
- **Advantages:** Produces monodisperse gels with a uniform pore size. Precision control of structure, pore size, hydrophilicity or hydrophobicity. Gels can have a recognition or peptidic target sequence inserted into the integral block copolymers and can thus be used in affinity chromatography.

Low Temperature Deposition of Materials from Supercritical Fluid Solution

UMA 97-12; Watkins & McCarthy (U.S. Patent 5,789,027)

- **Description:** A novel process by which high-purity metals or metal oxides are deposited from supercritical carbon dioxide solution by the chemical reduction or oxidation of soluble organometallic compounds. The process is demonstrated by deposition of ultra-high purity copper, platinum, ruthenium, palladium, gold, hafnium oxide, titania and other materials onto substrates including silicon wafers. The same method could be used to deposit a wide variety of metal and semiconductor thin films.
- **Applications:** Principle application is the deposition of high purity metal or metal oxide films suitable for microelectronic devices. The invention overcomes two significant deficiencies of the current state of the art, chemical vapor deposition. The invention can also be used for the metallization of porous inorganic solids for use as supported catalysts where conventional approaches such as metal ion exchange are ineffective. Water purification and hydrocarbon processing could be two target markets.
- **Advantages:** The principal benefits of this invention are three-fold. First, in combination with 6,992,018 and 6,689,700, it enables the conformal deposition of pure films in very high aspect ratio features. Conformal deposition is possible because of high precursor concentrations that yield surface reaction rate-limited depositions. Second, because transport occurs in supercritical solution, precursor volatility constraints are eliminated.