Applications of Polymer Network Liquid Crystals (PNLC) as Smart Coating Layers

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Abstract ID: 10491
: ThinFilms2024
Symposium: 12. The 2nd Int'l Symposium on Smart Coating Techniques (SMT)
Keywords: PNLC, liquid crystals, sensors

Recently, mixtures of low-molecular-weight liquid crystal (LMWLC) and reactive mesogen (RM) are blended and polymerized to form polymer network liquid crystal (PNLC). Herein, we report a PNLC which exhibits a full color spectrum for temperature and chemical vapor sensing applications. Due to the high flexibility of PNLC, it can be applied as smart coating layers on solid surfaces to report spatial distribution of temperature and chemical vapor. Next, we report a new mechanism of forming PNLC through a secondary polymerization step after UV irradiation. With insufficient UV irradiation time, some free radicals remain in the PNLC for several hours. During this time, a secondary polymerization can be induced by phase transition upon heating, which causes free movement of remaining free radicals in the PNLC and formation of a secondary polymer network. Unlike the primary polymer network which is uniform, the secondary polymer network is disordered. As a result, the LC trapped inside the polymer network is able to scatter light strongly and appear cloudy. Because oxygen can deactivate free radicals when it diffuses through the PNLC, this principle can be used to detect oxygen or monitor the irradiation time to oxygen.

Finally, we use a sphere-like polymer network to stabilize the phase transition process of LMWLC. Appearance of the film undergoes a cycle of transparent, cloudy and then transparent again with increasing temperature. During the temperature range of 35 °C to 46 °C, where PNLC undergoes a phase transition from a liquid-crystal state to an isotropic state, LC is stabilized as droplets by the sphere-like polymer network and the film shows a cloudy appearance with a transmittance of 2.7%. This work enables new functions and flexibility for current smart windows.

Design and growth of infrared transparent conductive films and coupling mechanism between optical and electrical properties

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Abstract ID: 10308
: ThinFilms2024
Symposium: 12. The 2nd Int'l Symposium on Smart Coating Techniques (SMT)
Keywords: Infrared transparent conductive films, atomic layer deposition, coupling mechanism

This article addresses the urgent need for infrared transparent conductive film technology for infrared windows, as well as the fundamental theoretical issue of difficulty in coordinating photoelectric properties of infrared transparent conductive films. It initiates a series of related research work on the prediction, growth, and modification of infrared transparent conductive films. Based on the multi-dimensional characteristics of material chemical bonds, crystal structures, and film systems, a coupling mechanism for infrared transparent conductive films is proposed. The coupling mechanism of infrared transparent conductivity based on high-frequency permittivity regulation is revealed; a method for synergistic control of infrared transparent conductivity using materials with small n and large μ is established; and a technical means for achieving infrared transparency and conductivity synergy by constructing a "sandwich" composite structure is developed. A series of infrared transparent conductive materials have been obtained, and infrared transparent conductivity spectra have been obtained. Technical bottlenecks such as atomic layer deposition (ALD) spatial low-temperature differential heating technology and gas source uniformity diffusion methods for coating on special-shaped curved surfaces have been broken through. An ALD system suitable for the growth of large-size photoelectric window films has been developed and constructed, establishing a complete system of principles, materials, processes, and equipment for infrared transparent conductive films.

Effect of Plasma State on Microstructures and Properties of Vanadium Dioxide Films During Deposition

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Abstract ID: 10080
: ThinFilms2024
Symposium: 12. The 2nd Int'l Symposium on Smart Coating Techniques (SMT)
Keywords: Plasma analysis, Smart film, Vanadium dioxide, magnetron sputtering

Vanadium dioxide (VO_2) is well known because it can undergo a reversible metal-insulator transition (MIT) accompanied by a significant change in electrical resistivity and optical transmission around 68℃. This passive property change has widely used as smart coating especially in infrared region. During the magnetron sputtering deposition, energy has a great influence on the properties of the film. In this paper, we deposited the films VO_2 with different substrate bias and temperature and focus on the relationship between the state of plasma and film properties. Langmuir probe, ion energy analyzer, optical spectrometer, and mass spectrometer were used to analyze plasma parameters, such as density, ion energy. SEM, Raman, four-probe, and infrared spectrum were used to measure the microstructures and properties. Our results revealed that the different ion energy cause the different grow modes during the deposition and then affect the properties of VO2 films. This research enables a better understanding of the film growth mechanism of VO2 film deposited by magnetron sputtering to obtain better performance.

Enhancement of open circuit voltage of diamond voltaic battery by titanium oxide film surface passivation

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Abstract ID: 10595
: ThinFilms2024
Symposium: 12. The 2nd Int'l Symposium on Smart Coating Techniques (SMT)
Keywords: Diamond, Schottky diode, Surface passivation, TiO2, Voltaic battery

Nuclear batteries based on voltaic effect using Schottky diode or PN junction energy converter are usually named alpha-/beta-voltaic batteries. They present particularly unique properties making them highly interesting in many key technological applications. Diamond exhibits a great potential in designing such high performance alpha-/beta-voltaic battery and self-powered UV detectors. In this study, we present a novel strategy to create highly efficient diamond Schottky diodes. Our approach consists in incorporating a thin TiO_2 layer in the vertical diamond Schottky diode using reactive magnetron sputtering to enhance the barrier height and improve the voltaic performance. Compared to the original device without TiO_2, it shows big battery performance improvement. The V_{oc} and J_{oc} increased from 0.8 V and 4.23 nA/cm^2 to 1.7 V and 8.12 nA/cm^2 between the two cases. The conversion efficiency of the TiO_2 passivated device is 2.7%, 3.9 times higher than the original device. The V_{oc} of 1.7 V obtained in this work is the highest reported value for documented alpha-/beta-voltaic based on single junction diamond energy converter under realistic isotope irradiation, which is close to 1.85 V of diamond membrane beta-voltaic battery measured by EBIC. Also, the photovoltaic performance of the device under UV light illumination was characterized. The Voc of 1.8 V and FF as high as 80% reconfirmed the good performance of TiO_2 passivated device. The SNR of the diode at 0 V bias was calculated to be 1.5×10^6, showing a great potential in self-powered UV detector.

Functional Color-Changing Cholesteric Liquid Crystal Elastomers

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Abstract ID: 10261
: ThinFilms2024
Symposium: 12. The 2nd Int'l Symposium on Smart Coating Techniques (SMT)
Keywords: Cholesteric liquid crystal elastomers, Dynamic covalent bonds, Ionic conductive, Mechanochromic, Self-healing

Cholesteric liquid crystal elastomer (CLCE), a class of chiral soft photonic crystals, is uniquely suited for the development of biomimetic smart color-changing materials. We developed a functional color-changing CLCE by introducing dynamic covalent B-O bonds into main-chain CLCE by an anisotropic deswelling method, which endows them with shape/color programming and room-temperature self-repairing properties. We also combined CLCE with ionogels by using silane coupling agents, to prepare CLCE with both mechanochromism and ionic conductivity and applied them in human-machine interactions. Based on the color-changing property of CLCE, this study develops their self-healing and ionic conductive functions and promotes their practical applications in the fields of bio-inspired camouflage, soft actuators and flexible electronics.

HiPIMS deposition of hard yet transmissive protective films for infrared window at low temperature

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Abstract ID: 10516
: ThinFilms2024
Symposium: 12. The 2nd Int'l Symposium on Smart Coating Techniques (SMT)
Keywords: HiPIMS, hard fiim, transmissive

At lower temperatures, using HiPIMS technology and reactive magnetron sputtering method, a high hardness amorphous aluminum oxide coating suitable for visible light and near-infrared windows was prepared, significantly improving the sand corrosion resistance of the substrate, enhancing its service performance, and solving the problem of fast failure of existing infrared window protective coatings.

In response to the problem of rapid failure of existing infrared windows in sand erosion environments, a material optimization design method was used to select and prepare high hardness Al_2O_3 coatings as reinforcement coating materials. In response to the low melting point of the substrate relative to aluminum oxide, HiPIMS coating technology was selected to study the effects of reaction state, substrate temperature, auxiliary bias voltage, and pulse frequency on the thin film. The surface state, crystal structure, and mechanical properties of the thin film were analyzed and characterized. Finally, a high hardness coating with a hardness of 27 GPa was prepared under bias conditions of 600 ℃ and -250V

Multi-responsive smart films electrospun from polymer network liquid crystal core-sheath fibers

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Abstract ID: 10505
: ThinFilms2024
Symposium: 12. The 2nd Int'l Symposium on Smart Coating Techniques (SMT)
Keywords: electro-spun fibers, liquid crystals, optical response, phase transition, polymer networks, smart films

Electro-spun polymer-liquid crystal (PLC) fibers have potential applications such as wearable sensors and adaptive textiles because of their rapid response and high flexibility. However, existing PLC fibers only have a narrow responsive range and poor resistance to heat and chemicals. Herein, a new type of PLC fiber is prepared by using a coaxial electro-spinning process. The core solution is 4'-pentyl-4-biphenylcarbonitrile (5CB), and the sheath solution is a mixture containing 13 wt. % PVP and 10 wt. % reactive mesogen (RM). After UV exposure of the fibers, 5CB in the core and RM diffusing from the core are cross-linked into an LC polymer. The fibers have a highly uniform morphology with an average diameter of 3.2 ± 0.5 μm, and mesogens inside the fibers align unidirectionally with the long axis of the fibers. The films spun from these fibers show a broad phase-transition temperature range between 13.5 °C and 155.5 °C and have a response time of less than 10 s. The temperature range can also be controlled by adjusting components in the electro-spun fibers and UV exposure time. The core-sheath fibers and their electrospun films prepared in such a manner exhibit excellent heat and chemical resistance with reversible optical responses. Moreover, when the films are exposed to volatile organic compounds (VOCs) such as toluene, the films show a rapid optical response to toluene vapor within 25 s. This study demonstrates that the films are potentially useful for preparing flexible temperature and chemical sensors.

Nanophotonics Enabled Mid-Infrared Artificial Intelligence (AI) Sensing Systems

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Abstract ID: 10588
: ThinFilms2024
Symposium: 12. The 2nd Int'l Symposium on Smart Coating Techniques (SMT)
Keywords: AI, Mid IR, Nanophotonics, Sensor, Waveguide

Nanophotonics, manipulating light-matter interactions at the nanoscale, is an appealing technology for diversified biochemical and physical sensing applications. In terms of nanophotonics technology for the mid-Infrared (MIR) sensing which can identify molecules by the IR fingerprint absorption due to the surface state changes, there are plasmonic nanoantennas (PNAs) and waveguides for free-space and guided-wave light-matter interactions, respectively. Leveraging the multi-dimensional features captured by the nanophotonics, we develop machine learning (ML) methods to extract complementary physical and chemical information from molecules. Furthermore, refractive index (RI) is another intrinsic property of molecules associated with electronic polarizability, but with limited contribution to molecular identification in mixed environments currently. Here, we investigate the coupling mode of localized surface plasmon and surface phonon polaritons for vibrational de-overlapping. The coupling mode is sensitive to the molecular refractive index, attributed to the RI-induced vibrational variations of surface phonon polaritons (SPhP) within the Reststrahlen band, where such RI-dependent SPhP vibrations are linked to molecular RI features. On the other hand, Mid-infrared hyperspectral imaging (MIR-HSI) uniquely offers visualized location information and conformational fingerprint features for molecular screening. Advancements in nanophotonics have realized real-time dynamic hyperspectral imaging achieved by encoding and reconstructing multi-dimensional light properties (amplitude, phase, and wavelength) utilizing nanoantennas. Machine learning-augmented nanophotonics is also reviewed in the advances in hyperspectral imaging towards intelligent clinical diagnosis. Lastly, on-chip nanophotonic waveguide sensor is another promising solution for miniaturization and label-free detection of gas mixtures and chemicals in water mixtures utilizing the absorption fingerprints in the mid-infrared (MIR) region. As a result, the aforementioned works prove the potential for broader sensing and analytical capabilities of the MIR nanophotonics sensing platform for multiple organic gas components toward MIR on-chip spectroscopy.

Optical and mechanical properties of MgAlON infrared films

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Abstract ID: 10514
: ThinFilms2024
Symposium: 12. The 2nd Int'l Symposium on Smart Coating Techniques (SMT)
Keywords: Infrared transmission, Mechanical strength, MgAlON

Spinel transparent ceramics have excellent mechanical properties, good thermal properties and chemical stability, and their cubic crystal structure makes them show high optical transmittance from ultraviolet to mid-infrared wavelength range. Therefore, such materials are receiving increasing attention in the fields of infrared Windows and lenses. As a spinel-type quaternary disordered solid solution, the transmission of MgAlON samples by magnetron sputtering at 3-5μm wavelength is higher than 80%. The results show that decreasing Mg content and increasing N content in MgAlON can improve the hardness and bulk modulus of transparent ceramics, and reduce the coefficient of thermal expansion. Reducing N content is helpful to reduce the refractive index and improve the theoretical transmittance of transparent ceramics. It is of great significance to prepare MgAlON transparent ceramics with desired properties through element content adjustment, and it also provides guidance for the design and functionalization of new spinel materials with various uses.

Phase transition and property analysis of VO2 thermochromic / photochromic films in mid-infrared optical modulation

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Abstract ID: 10475
: ThinFilms2024
Symposium: 12. The 2nd Int'l Symposium on Smart Coating Techniques (SMT)
Keywords: vanadium dioxide (VO2); structural and electronic phase transition; mid-infrared optical modulation; photo-thermal excitation; intelligent optical regulation

Understanding ultrafast phase transition characteristics of vanadium dioxide (VO2) films is extremely important, as such a phenomenon has broad application prospects in energy, electronics, and optics fields. In this work, relative contributions of lattice transitions and electronic interaction to the changes in mid-infrared optical modulation are found from temperature-dependent experiments and ultrafast photoexcitation experiments. The results show significant detailed differences between the two-phase transitions. Furthermore, the temperature accumulation and non-thermal contribution of VO2 film irradiated by femtosecond pulsed laser under different powers was simulated by COMSOL Multiphysics to further distinguish the thermal and photo-induced phase transition. A clear and detailed analysis of the phase transition process promotes the exploration and development of VO2 in the field of mid-infrared irradiation.

Photoelectric and sensing properties of Tin oxide infrared transparent conducting films

by Liangge Xu | Sam Zhang | Jiaqi Zhu | Harbin Institute of Technology | Harbin Institute of Technology | Harbin Institute of Technology

Abstract ID: 10510
: ThinFilms2024
Symposium: 12. The 2nd Int'l Symposium on Smart Coating Techniques (SMT)
Keywords: Photoelectric, infrared transparent, thin films

Tin oxide (SnO2) has been widely explored for various applications due to its excellent n-type semiconductor properties, low resistance, and high optical transparency in the visible range. However, few studies on the preparation of SnO2 films using high power pulsed magnetron sputtering have been reported. Oxygen content is a critical parameter in the practice of SnO2 thin films by high-power pulsed magnetron sputtering. the average free range of Sn atoms is usually much smaller than O atoms. SnO2 films deposited in a pure Ar atmosphere are likely to be oxygen-deficient and form O vacancies. and such oxygen vacancies will cause lattice distortion, which will affect the mobility and concentration of charge carriers in the SnO2 film.According to Drude's model, the carrier concentration is closely related to the resonance of infrared photons.

In this paper, the crystal structure and infrared transparent conductive properties of SnO2 films prepared at 600°C were investigated at different oxygen partial pressures. Then, it is described that integrating SnO2 transparent conductive film into a multi-resonant surface enhanced infrared absorption (SEIRA) platform can overcome the shortcomings of poor selectivity and opacity of multi-gas sensing, and can simultaneously sense ultra-low concentrations of greenhouse gases on-chip. And realize the application in the transparent window scene. This strategy takes advantage of the near-field intensity enhancement of the multi-resonance SEIRA technology and the infrared light reflectivity that can be modulated by the SnO2 infrared transparent conductive film. Experiments have proved that the platform realizes synchronous on-chip sensing of VOCs, with fast response time, high accuracy, high visible light transparency, and excellent linearity in a wide concentration range. In addition, the excellent scalability to detect more gases was explored.

Research on Ion Beam Regulation of Novel Solid Lubrication Composite Friction Technology

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Abstract ID: 10163
: ThinFilms2024
Symposium: 12. The 2nd Int'l Symposium on Smart Coating Techniques (SMT)
Keywords: solid lubrication ion beam films

By preparing composite solid lubrication molybdenum disulfide coatings on the surface of bearing steel and ion implantation into the mating surfaces, the study systematically investigates the properties of the coatings and surfaces after ion implantation, such as friction reduction and wear resistance. By examining the effect of the surface film transfer on the friction coefficient, the research reveals the friction system of the novel solid lubrication films prepared by ion beam, further enhancing the tribological and wear performance of solid lubrication.

Smart Liquid Crystal Elastomer from Fabrication to Application

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Abstract ID: 10100
: ThinFilms2024
Symposium: 12. The 2nd Int'l Symposium on Smart Coating Techniques (SMT)
Keywords: Artificial muscles; Soft robots, Liquid crystal elastomer; Fibers; Actuators

Liquid crystal elastomer (LCE) is cross-linked network formed by coupling liquid crystal mesogens and polymeric chains. Due to the phase transition of liquid crystals under external stimuli such as heat, light, electricity, magnetic field and chemicals, LCE exhibits anisotropic optical and mechanical properties. Due to its large, reversible deformation and inherent soft elasticity, it has become an excellent material for constructing actuators, artificial muscles and soft robots.

This talk will first introduce the fabrication of LCE, in particular, LCE fibers which are excellent building blocks for construction of functional materials. It will explicate how to obtain solid and hollow fibers, control their size, structure and liquid crystal orientation with dry/melt spinning, template method and rotational 3D printing, developed by the research group. Applications based on LCE fibers are demonstrated. For example, (i) LCE fibers can simulate pumping function of heart muscles and ball shooting of human triceps muscles. (ii) LCE fibers with programmed alignment enriched responsive modes of LCE actuators and have achieved not only common shrinkage and bending deformations, but also developed complex deformations such as elongation, torsion and rotation. (iii) Incorporating liquid metal into LCE fibers can integrate sensing and actuating in a single fiber with a simple design, function as Delta Robot. (iv) Additive manufacturing of LCE actuators based on knitting technology can bring about advanced geometry, integrated multi-functions and efficient recyclability. The porous structure and soft elasticity of LCE knitted actuators will facilitate the development of ergonomic and comfortable wearable devices. Knitted LCE actuators incorporated with other functional fibers and smart textiles can act as a deformable, multifunctional platform.

It can be envisioned that LCE fibers can be potentially applied in fields such as wearable devices, including motion assistance and human computer interactions.

Thermal-Responsive Liquid Crystal Elastomer Foam-based Compressible and Omnidirectional Gripper

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Abstract ID: 10216
: ThinFilms2024
Symposium: 12. The 2nd Int'l Symposium on Smart Coating Techniques (SMT)
Keywords: compressible, foam, gripper, liquid crystal elastomer, omnidirectional

Liquid crystal elastomers (LCEs) are considered to be a promising material for the fabrication of soft grippers because of their large and reversible deformations, an LCE gripper with suitable compressibility and omnidirectionality has not yet been developed. To overcome these obstacles, this study utilizes salt template method to fabricate a rod-like LCE foam as gripper. The thickness of the compressible foam can be reduced by up to 77%, temporarily maintaining the deformation and enabling the gripper to pass through slits. The foam was aligned along the long axis and the length of the foam exhibits reversible thermal responsiveness and contract up to 57% along its alignment. Additionally, when the foam approaches a heat source, the generated temperature gradient results in a contraction gradient owing to the low thermal conductivity of the LCE foam. This in turn causes the foam to reversibly bend with a bending angle up to 93° and follow the movement of a heat source omnidirectionally. The developed gripper successfully grasps, moves, and releases hot objects in a cold and safe place, demonstrating its potential for emergency disposal. Thus, LCE foams can be considered suitable materials for novel gripper design and construction.

Using Liquid Crystal Films to Develop Smart Cloud Sensors for Real-Time Environmental Monitoring

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Abstract ID: 10566
: ThinFilms2024
Symposium: 12. The 2nd Int'l Symposium on Smart Coating Techniques (SMT)
Keywords: Liquid crystals, chemical sensors, liquid crystal-based sensors, multiplex detection

The sensors using liquid crystals (LCs) films as the optical signal reporter, i.e., the LC-based sensors, have been considered as new sensing technology suitable for fast-screening and point-of-care applications due to their simplicity and visualized signals. We propose a new integrated sensing technology that combines "organic light-emitting diodes (OLEDs)", "LC-based sensors" and "mobile communication system" into "multifunctional LC smart cloud sensors". The features of this technology are: (1) using microarray chip to accommodate LC, the production cost is low; (2) visualized optical signals are recorded without using expensive and complicated instruments; (3) multiplex detection can be achieved by cross-analysis of the array-based signals; (4) the optical signal can be analyzed by image processing software, and the mobile phone can be used to capture the signal and upload it to the cloud; (5) the database collected in the cloud can be used for quick intelligent analysis and comparison to reduce detection errors. Currently, this sensing technology can be used for the rapid screening of environmental water quality. This sensor device is lightweight, low-cost, simple to operate, and the target-of-interest can be custom-made according to user needs. In this work, the molecular design strategy of the LC molecules will be highlighted.

Visible Light Stealth and Infrared Encryption Emitter Based on ENZ Materials

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Abstract ID: 10515
: ThinFilms2024
Symposium: 12. The 2nd Int'l Symposium on Smart Coating Techniques (SMT)
Keywords: Optical encryption; ENZ material; Directional control; Infrared detector

Optical encryption is significant for infrared detectors in both the infrared band and visible light. There has been many research on infrared encryption. However, achieving both of them currently difficult, We introduce a thermal emitter consisting of a dielectric layer gradient epsilon-near-zero (ENZ) films, The thermal emitter enable directional control of thermal emission in the 8-12μm band and stealth in visible light, The emitter exhibits high emissivity (>0.9) in p-polarization at specific directions and has a small Angle width(<20°),which make the thermal emitter intensive sufficiently at perspective Angle. Additionally, only in p-polarization in the oblique direction, the infrared encryption information on the emitter can be observed. Besides the emitter has a not bad hardness which makes it less likely to lose efficacy