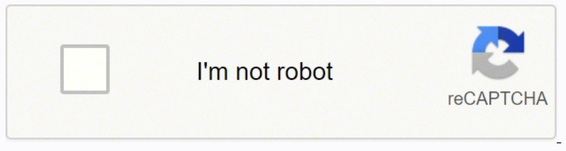

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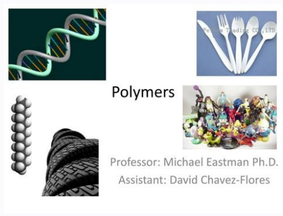

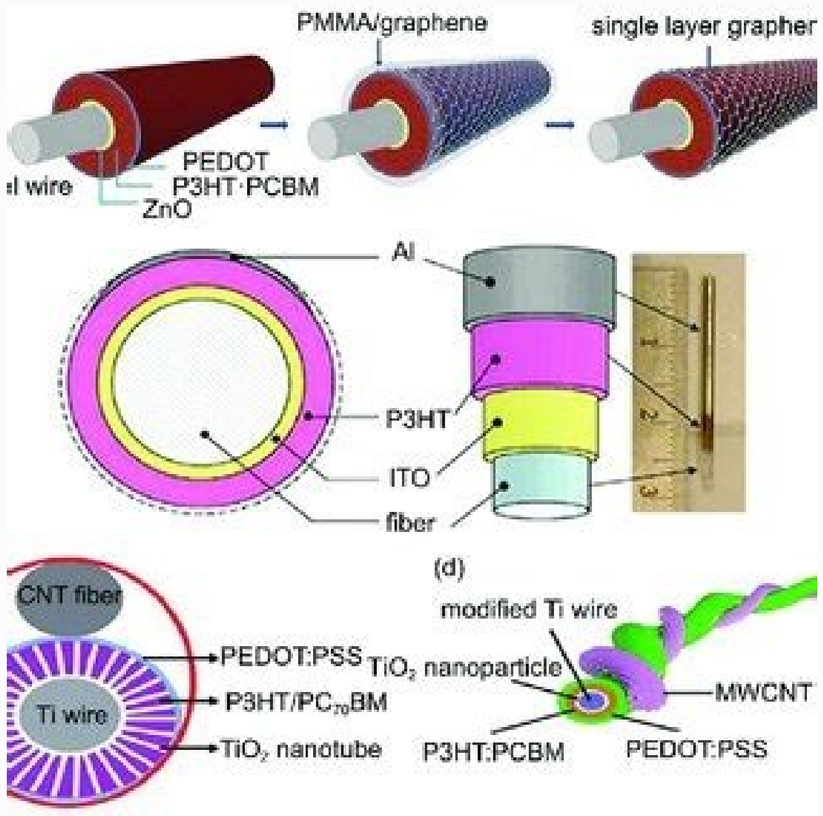

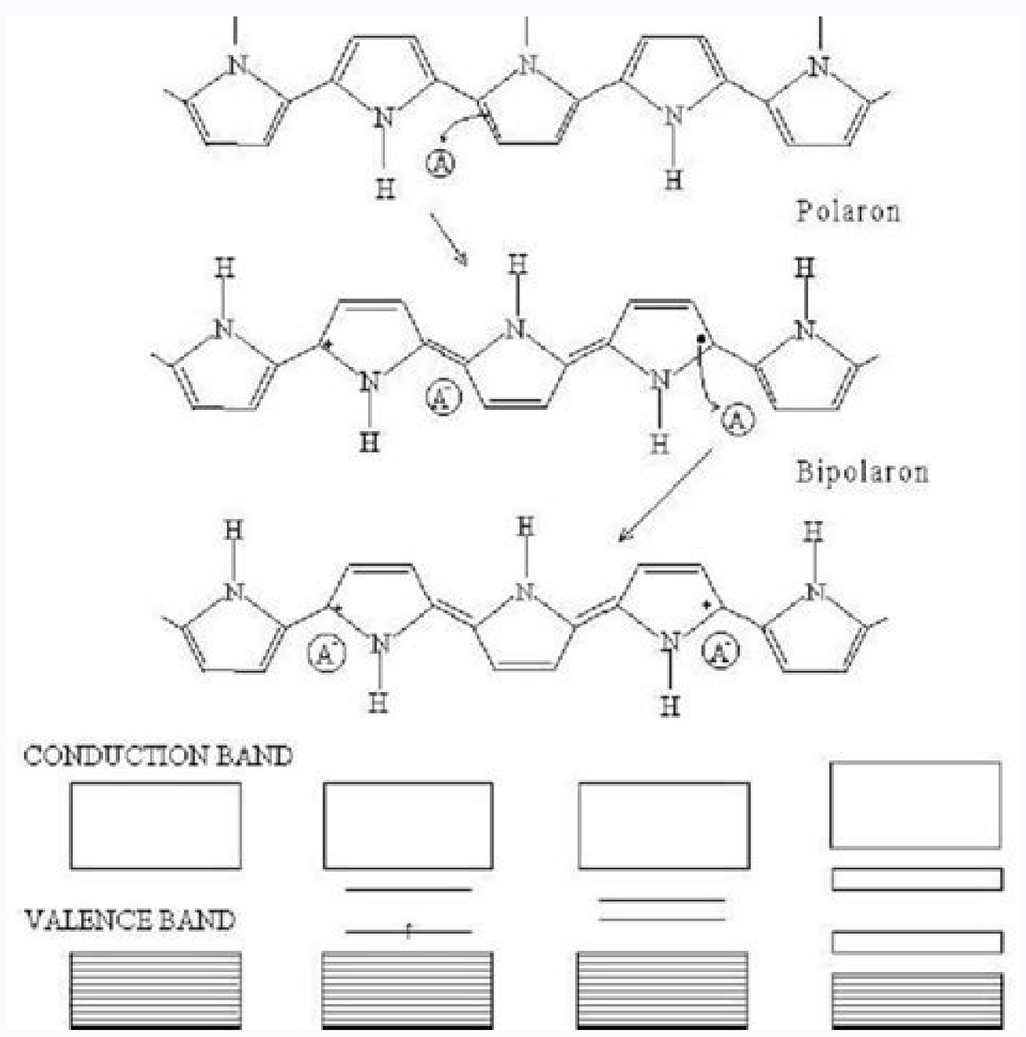

Current passage tubes in conductive polymer composite for fluid heating

Conductive polymers.

(B) Drain current versus drain voltage characteristics of PPY electrolyte-gated transistor based on EHL fabricated pillars shown in a top-view optical image (inset B,i) and gate voltage performance (inset B,ii) of the PPy-FET described in (A).Furthermore, structured conductive polymer based substrates exhibit an increased electrochemically accessible surface area along with the high electrical conductivity. Mass-flow controllers (MKS Instruments Model 1179A with a PR4000F readout) regulated the flux of the carrier gas, N2 through two lines. We show the feasibility of the polypyrrole-based structures for field-effect transistor devices. A reduction in the topographically induced feature size and an increased electrical potential (75 V) results in PPy lines as small as 100 nm height and 120 nm width (Figure 2A). Thus, sub-100 nm patterns with structure-to-structure spacing on the order of 100 nm can be achieved with a leaky dielectric by both exploiting conducting polymer as a film material and gap materials that combine a low interfacial tension with the film with a high electric strength.Vertical FETs hold the potential to combine good performance with high device density. 10.1002/elan.200403071. The cross-sectional AFM image in Figure 2B reveals a line height of 2.0 μm and a width of 2.5 μm. 10.1002/adma.201104159. Electroanalytical and Bioelectroanalytical Systems Based on Metal and Semiconductor Nanoparticles. [CrossRef] [Google Scholar]Drury C. Because EHL lithography requires homogeneous films for the patterning process, an optimized synthesis of PPy19 has been carried out in this study to prepare electroconductive PPy, which is soluble in organic solvents and can be spin-coated into uniform thin films. All tubes and connectors were made from solvent-resistant materials (glass and Teflon). Chem. To ensure the integrity of the formed structures, patterned electrodes were rendered hydrophobic by the deposition of a 1,1,1,2H-perfluorodecyltrichlorosilane self-assembled monolayer to reduce the adhesion between the mask and the polymer. After quenching the samples to room temperature, the electric field was disconnected and the upper electrode was removed.The sample topography was analyzed by optical microscopy and atomic force microscopy. Electrically Induced Structure Formation and Pattern Transfer. 10.1002/adfm.200500388. Y.; Kang H. 10.1002/elan.200302930. F.; Wudl F. Thin Solid Films 2005, 477, 169–173. Patterning of Conducting Polymers Based on a Random Copolymer Strategy: Toward the Facile Fabrication of Nanosensors Exclusively Based on Polymers. EHL can be used to fabricate patterns in a wide variety of polymers and composites using both featureless and topographically structured masks.18 Patterning of thin films using electrohydrodynamic instabilities possesses many desired characteristics and has convincingly been used as a simple method to structure and replicate patterns of nonconducting, dielectric polymers (e.g., polystyrene (PS), poly(methyl methacrylate), polycaprolactone, nanocomposite carbon nanotubes integrated in PS18) on submicrometer length scales targeting various applications. Funct. †School of Chemical Engineering, University of Birmingham, Birmingham B15 2TT, United Kingdom‡Department of Physics, Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, United KingdomFind articles by Jonathan James Stanley Rickard‡Department of Physics, Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, United KingdomFind articles by Ian Farrer†School of Chemical Engineering, University of Birmingham, Birmingham B15 2TT, United KingdomFind articles by Pola Goldberg OppenheimerReceived 2016 Feb 18; Accepted 2016 Feb 23.Copyright © 2016 American Chemical SocietyThis is an open access article published under a Creative Commons Attribution (CC-BY) License, which permits unrestricted use, distribution and reproduction in any medium, provided the author and source are cited.An increasing number of technologies require the fabrication of conductive structures on a broad range of scales and over large areas. NSG 20 cantilevers with a resonance frequency of 260 kHz and a stiffness of 28 N m–1 were used. P.; Steiner U. These structures have potential for applications in the development of microelectronics, displays, and biotechnological assemblies, such as flexible display devices or bio and chemical sensors. J.; Hart C. Photolithographic Patterning of Electroactive Polymer Films and Electrochemically Modulated Optical Diffraction Gratings. Individually Addressable Conducting Polymer Nanowires Array. Dewetting of Conducting Polymer Inkjet Droplets on Patterned Surfaces. Despite the shorter destabilization time and faster growing modes of fully conducting material compared to a prefect dielectric (minutes vs hours15,22), smaller accessible scale-sizes (in the range of 100 nm (Figure 2A and D) vs the typical micrometer arrays15,22,23) and greater aspect ratios (e.g., 0.83 in Figure 2), the pattern formation process of Figure 1 is reminiscent of the well-studied case of generic polymers,20,21,24 thus confirming the same underlying physical mechanism. Such a lateral field variation is typically achieved by using a topographically structured mask as one of the electrodes, thus enabling the generation of a broad variety of structures on different length scales. [CrossRef] [Google Scholar]Goldberg-Oppenheimer P.; Mahajan S.; Steiner U. 1996, 8, 531–534. Mater. H.; Guirado G. The final height of the polymer structures is dictated by d and h0. PPy soluble in organic solvents has been synthesized (with slight modifications) following the procedure described in ref (19): 0.14 g of dried pyrrole monomer was added to a solution comprised of 0.0745 mol of dodecylbenzenesulfonic acid (DBSA) dissolved in 300 mL of deionized water (DW) and dynamically stirred for 30 min. Patent WO 02/10251, 2002.Harkema S.; Steiner U. 10.1063/1.1529686. Theoretical studies addressing pattern generation have predicted electrohydrodynamic pattern formation in conducting liquids;12−14 yet, these have not been demonstrated to date. 2012, 24, OP175–OP180. The molecular weight of PPy was 157 kg/mol and the glass transition temperature was 98 °C.Highly polished p-doped silicon (Si) wafers, with (100) crystal orientation (Wafernet Gmbh, Eching, Germany) covered by 100 or 300 nm thick oxide layer were used as substrates. Both requirements are fulfilled by imposing a laterally heterogeneous electric field with variations smaller than the intrinsic wavelength. F.; Russel W. 10.1155/2009/436375. The chamber and a regulated water bath containing the solvent bottle and the mixing chamber were held at the same temperature. Image processing and analysis was carried out with the instrument software version V612r2 and V530r2. Inset ii of Figure 3B, presents the transfer characteristics (source-drain current versus gate voltage, IDS–VG) at a constant drain-source voltage (a representative value of VDS = 4 V). E.; Schäffer E.; Lin Z.; Russell T. 2004, 3, 171–176. 2004, 4, 1237–1239. Electroanalysis 2004, 16, 19–44. Chloroform (Fischer Inc.) was used as a main solvent.Thin films were generated by spin-coating onto a silicon wafer substrate (dimensions of 1 × 1 cm2) from chloroform solution with typical concentrations of 2–3% polymer by weight. The following discussion is based on the formalism proposed by Pease and Russell13,14 for charge-driven electrohydrodynamic patterning of leaky dielectric films.The pattern selection of EHL instabilities is given in terms of a linear stability analysis for an incompressible Newtonian fluid assuming the nonslip boundary condition at the substrate (Figure 1A). When a laterally varying electric field is applied to the capacitor device, the instability is focused in the direction of the highest electric field and because the electrostatic pressure is inversely proportional to a square of the capacitor gap, it is considerably stronger for smaller interelectrode distances.EHL replication of line and columnar patterns. K. This method provides a single-step and cost-effective approach for direct patterning of conjugated polymers on solid substrates, generating a variety of feature sizes ranging from tens of micrometers to hundreds of nanometers.15−17 The EHL concept exploits an instability induced by an applied electric field across the liquefied polymer–air bilayer sandwiched between two-electrodes in a capacitor-like device. 2005, 17, 1523–1527. 2004, 16, 1905–1908. In a homogeneous electric field, this typically results in pillar structures that span the two

electrodes. P.; Lee C.; Myung N.; Penner R.; Yun M. One of the main limiting factors has been its nonsolubility in any solvent due to the strong intermolecular interactions of the heterocyclic planar structure of PPy. Although electropolymerization yields predominantly rough films, which inhibits PPy electronic functions, whereas chemical polymerization results in insoluble powder. In order to exploit this natural structure formation process, it is important, first, to control the resulting pattern and, second, to decrease the length scale to technologically interesting feature sizes. Though the pattern selection during the early stage of the process is a sinusoidal surface undulation, for all samples, the filling ratio establishes the late stage of pattern formation. Copyright 2013, Springer International Publishing, Switzerland.Katz H. [PubMed] [CrossRef] [Google Scholar]Harkema S.Capillary Instabilities in Thin Polymer Films. [CrossRef] [Google Scholar]Lowe J.; Holdcroft S. Linear Stability Analysis of Thin Leaky Dielectric Films Subjected to Electric Fields. The application of vertical transistors in memory devices is especially sought after due to its potential in shrinking individual devices and capability of multilevel memory structures three-dimensionally. P.G.O. is a Royal Academy of Engineering Research (RAEng) Fellowship holder.The authors declare no competing financial interest.Portions of this Letter are adopted from part of the series Springer Theses, pp 107–115, with permission from Springer. With properly chosen experimental parameters, combined with a suitable master electrode, it should be possible to generate patterns with sub-100 nm widths over very large areas. Moreover, generation of high-fidelity submicrometer architectures with a good adhesion to the substrate in a controlled manner is essential to realize the full potential of CPs patterning for their future integration into applied devices.5 Conducting polymer micro- and nanostructures can, for instance, be used for red, green, or blue (RGB) pixels in multicolour OLED displays and interconnects in all-polymer integrated circuits.6Routes for patterning CPs have been explored extensively, and the most prominent techniques are soft-lithography,7 electron beam lithography,8 photochemical patterning by photolithography,9,10 and nanoimprinting.11 Hitherto, however, most of the existing approaches to pattern CPs exhibit limitations in certain aspects including resolution, position control, versatility, and reproducibility. The flow volumes per time were individually regulated to values between 1 and 20 cm3 min–1. An additional pattern of ordered columns has been generated using EHL patterning after the application of 55 V between the electrodes. The films were allowed to swell in the controlled solvent vapor atmosphere until they reached their equilibrium thickness after around 30 min. H.; Li H. 2000, 12, 269–273. The final morphology of the replicated pattern is determined by the partial coalescence of the initial pattern.The shape of the generated pattern depends on the ratio of the intrinsic film undulation wavelength and the lateral periodicity of the master electrode. Optical micrographs reveal large areas comprised of conductive PPy patterns exhibiting a range of feature sizes (Figure 2A–C). 10.1002/(SICI)1521-4095(200002)12:43.0.CO;2-5. They are thus driven toward the downward protruding structures of the top mask. Z.; Zheng Z. (B) Heterogeneous force field directs the instability toward the protruding line structures and generates columnar-bridges between the two electrodes, followed by a coarsening of the pillars yielding in a positive replica of the master pattern in (C). [CrossRef] [Google Scholar]Im Y.; Vasquez C. The conductivity of the leaky dielectric suppresses the electric field in the film and the field in the gap drives the EHL pattern formation. S.; Bergstedt T. [Google Scholar]Goldberg-Oppenheimer P.; Eder D.; Steiner U. This current modulation due to the modulation of carrier density in the PPy structures along with the onset of the saturation of drain-source voltage at approximately 9 V is consistent with the measurements previously performed on other PPy-based transistors27,28 The maximum value of ISD of the transistor was 20 mA in the 0.01 M KCl solution at VG = 20 V.FET performance of EHL-PPy architectures. S.; Joo J.; Epstein A. [CrossRef] [Google Scholar]Alam M. In one line, the N2 was bubbled through a solvent-filled bottle resulting in a solvent-saturated gas stream. Fabrication of One-Dimensional Organic Nanostructures Using Anodic Aluminum Oxide Templates. Nature 2000, 403, 874–877. Hierarchical Electrohydrodynamic Structures for Surface-Enhanced Raman Scattering. Synthesis and Photolithography of Polymers and Copolymers Based on Poly(3-(2-(methacryloyloxy)ethyl)thiophene). Phys.: Conf. T. 10.1021/jz4018688. [CrossRef] [Google Scholar]Ramanathan K.; Bangar M. 2002, 102, 233–250. This yields the dimensionless conductivity, Σ representing the ratio of a time scale for free charge conduction to the process time scale2where, γ is a surface tension, σ is a conductivity, and η is the viscosity of the polymer. The conductivity of the films was measured to be 1.7 ± 0.5 S/m (spin-cast from chloroform). P.; Tseng H.-R. Liquid-ion gate FET geometry was constructed using a potassium chloride (KCl) solution and tungsten needle as contacting electrode (Figure 3A). This method provides a promising route for a straightforward and cost-effective large area patterning of CPs, opening up many opportunities for high resolution and high throughput structures with applications in nano- and biotechnology related fields and devices.All the chemicals were purchased from Sigma-Aldrich and used without further purification. 1998, 73, 108–110. This is potentially useful for the development of rapid-response biochemical sensors, which are selective for targeted chemical and biological molecules. In order to evaluate the electrolyte-gated vertical FET performance, EHL-generated structure arrays were fabricated with gate length of 700 nm and a pitch of 500 nm as schematically shown in Figure 3A, top and 3B,i (top view optical microscopy image). [CrossRef] [Google Scholar]Lee M. In the case of dielectric polymers, the electric field causes the energetically unfavorable buildup of displacement charges at the dielectric interface, leading to the alignment of the dielectric interface parallel to the electric field lines, which lowers the electrostatic energy. M. Addition of methanol stopped the reaction and the final solution was filtered to obtain black PPy powder. In unstructured regions, the film remains stable on a much longer time scale.The EHL patterning process of various structures is illustrated in Figure 1A–C. Herein, a versatile organic semiconductor, polypyrrole (PPy) film is patterned via the EHL technique enabling highly ordered structures which can be easily assembled into functional devices. The EHL approach can be further extended to lateral complex or hierarchical structures consisting of bilayers or larger numbers of different materials with set mismatched conductivities.This is the first time that a conductive polymer has been patterned using EHL technique. [PubMed] [CrossRef] [Google Scholar]Pease L. The reflection of white light from the sample enabled us to resolve submicrometer features. 10.1038/nmat789. The solvent vapor pressure was adjusted using a homemade apparatus. F. The acquired data in our experiments is complemented by the in situ monitoring of EHL pattern formation and replication in thin films, using a digital camera and imaging software (Carl Zeiss VisioCam). W.; Huck W. [PubMed] [CrossRef] [Google Scholar]Al-Kaysi R. Olympus Optical Microscope GX61 was employed in our experiments. Because the total potential difference generated by the dipole layers at the interface is suppressed across the conductive liquid layer, the driving force of the pattern formation in the case of a leaky dielectric polymer subjected to the EHL patterning lies in the electric field in the air gap, E1.14 A subambient pressure within the film balances the electrostatic force due to the field in the air gap on the polymer–air interface, placing the film in tension, and therefore, generating the origin of the EHL instability. O.; Ghaddar T. S.; Sirringhaus H. PPy can be synthesized by electrochemical or chemical polymerization methods. In light of the complexity involved in obtaining high resolution registration from soft-lithography, together with an increasing need to develop low-cost and high-throughput methods for patterning conductive polymer films, interest in alternative patterning processes has grown.In the present work, we introduce an elegant, straightforward EHL technique for direct patterning of conductive polymers. 10.1002/adma.200500938. S.; Kang H. Typical values for the vapor pressures were p = psat = 0:5/0:7. III; Russel W. This has resulted in a columnar structure with a typical height of 700 nm, a diameter of 1.2 μm and a periodicity of 2 μm (Figure 2C). The characteristic time constant for the instability is given by4Schematic representation of electrically driven patterning setup. The intrinsic length scale of instabilities in thin films is on the order of microns. The electrostatic force is balanced by surface tension, γ yielding the characteristic spacing, λ of the instability with viscosity η. 10.1063/1.121783. 10.1088/1742-6596/38/1/016. Thereafter, substrates as well as electrodes covering the films were subjected to snow-jet cleaning immediately before film deposition and device assembply. B.; Shen C. [PubMed] [CrossRef] [Google Scholar]Mahajan S.; Hutter T.; Steiner U.; Goldberg Oppenheimer P. Though patterning of PPy is a proof-of-concept, the versatile EHL patterning method can be applied to a variety of CPs. The feasibility of a PPy-EHL-based device as a FET is successfully demonstrated. The destabilizing electrostatic pressure, p scales with the square of an applied voltage, U1with the capacitor electrode spacing, d, the dielectric permittivity of free space, ε0, and the dielectric constant of the gap fluid, εg (which is an air gap in our case, i.e., εg = ε1). Low-Cost All-Polymer Integrated Circuits. Electrolyte-Gated Transistors Based on Conducting Polymer Nanowire Junction Arrays. Chemically Sensitive Field-Effect Transistors and Chemiresistors: New Materials and Device Structures. Here, we introduce advanced yet simple electrohydrodynamic lithography (EHL) for patterning conductive polymers directly on a substrate with high fidelity. To note, EHL patterning has successfully taken place when using a heterogeneous electric field that is formed by using a structured rather than planar top electrode. The vapor pressure in the mixing chamber can be estimated by the ratio of the saturated (psat) to dry gas (p) flow as determined by the flow-meter readout. S. 10.1002/adma.200401967. B. However, the applicability of this technique to a new range of materials, that is, conductive polymers, has not been demonstrated yet. Electroanalysis 2004, 16, 1837–1842. 10.1002/smll.201000060. [CrossRef] [Google Scholar]Schanze K. Microcontact Printing as a Versatile Tool for Patterning Organic Field-Effect Transistors. This process (described in the Methods Section) yielded 7% of pure PPy soluble in DMF, THF, m-cresol, and chloroform. AFM measurements were performed using a Nanoscope IV Dimension 3100 (Veeco Instruments Inc.) microscope operated in the tapping mode. The synthesized PPy was readily spin-cast into homogeneous films both on Si wafer substrates and on indium tin-oxide (ITO) glass, which serve as bottom electrodes during the patterning process. [CrossRef] [Google Scholar]Pease L. Phys. Lett. V. [PubMed] [CrossRef] [Google Scholar] For example, high density electrically conducting microstructures can be directly used as miniaturized sensors. [Google Scholar]Yonngin S.Method for Making Polypyrrole. [CrossRef] [Google Scholar]Wang J. Carbon Nanotube Alignment via Electrohydrodynamic Patterning of Nanocomposites. Moreover, the imposed modulation periodicity of the structured electrode, for which the amplitude can be adapted, not only plays an important role in obtaining a faithful replication but also opens up a route toward decreasing the patterns length scale to the sub-100 nm range. A.; Yun M.; Chen W.; Mulchandani A.; Myung N. (A) Schematic representation (top) and an overview image (bottom) of the configuration of a liquid-ion gate vertical FET using the EHL-generated structures on top of Si-SiO2 substrate. Initial instabilities are coupled to the lateral field variation and further focused in the direction of the highest electrostatic force. This condition was determined by experiments using a sample chamber lid with a window, providing optical access to the chamber. Hierarchical Pattern Formation in Thin Polymer Films Using an Electric Field and Vapor Sorption. Ser. E. 10.1038/35002540. The electrical measurements of electrolyte gated transistors based on PPy structures in buffered aqueous media of KCl at room temperature under ambient condition were conducted by using a Keithley 2400 semiconductor source-meter and a Wonatech WBCS 3000 potentiostat.We acknowledge funding from the EPSRC (EP/K503873/1) and the Wellcome Trust (174ISSFPP) grants. 10.1002/adfm.201002692. 2006, 125, 184716. 2006, 38, 61–64. Cooling sample to RT, or removal of the solvent by passing dry nitrogen through the sample chamber, solidified the polymer before the voltage was removed, terminating the patterning process. Flexible All-Polymer Field Effect Transistors with Optical Transparency Using Electrically Conducting Polymers. 10.1016/j.tsf.2004.08.128. Single Metal and Conducting Polymer Nanowire Sensors for Chemical and DNA Detections. Red, Green, and Blue Colors in Polymeric Electrochromics. 10.1016/S0377-0257(01)00180-X. 2005, 17, 2736–2741. 10.1021/ma00117a035. 2003, 118, 3790–3803. 10.1021/nl049477p. Tunable Microstructured Surface-Enhanced Raman Scattering Substrates via Electrohydrodynamic Lithography. J. In the presence of the laterally varying confinement, the liquid morphologies are organized according to the ratio of the plate spacing and the initial amount of polymer in the capacitor gap. Nat. [CrossRef] [Google Scholar]Granlund T.; Nyberg T.; Roman L. [CrossRef] [Google Scholar]Parashkov R.; Becker E.; Riedl T.; Johannes H.-H.; Kowalsky W. 2009, 2009, 1–14. Nanomater. Contact potentials at each interface give rise to the electric field, Ef that drives the flow. B 2005, 109, 12777–12784. Submicrometer structured conducting polymers possess improved properties and performance compared with bulk material devices. Along with promising electrical transistor characteristics, the use of low-cost lithographic technology and simple gate definition process steps could make such devices suitable candidates for next generation technology nodes.In conclusion, a conducting polymer EHL patterning process is directly performed on silicon substrates yielding high fidelity structures with a range of feature scale sizes. Ph.D. Thesis, University of Groningen, 2006. The PPy was washed several times with methanol and excess of DW followed by filtering, eventually yiding pure PPY. A probe tip comprised of a tungsten needle was employed under a 1000× magnification of an optical microscope to establish a good connection between the source and the drain. Patterning of Polymer Light-Emitting Diodes with Soft Lithography. We illustrate the generality of this robust, low-cost method by structuring thin polypyrrole films via electric-field-induced instabilities, yielding well-defined conductive structures with feature sizes ranging from tens of micrometers to hundreds of nanometers. 2013, 4, 4153–4159. Facing it, a topographically structured electrode was mounted at a specific distance using silicon oxide colloids as spacers, leaving a thin air gap, d (between the mask and the film, Figure 1A).The spin-cast films were liquefied either by annealing above the softening temperature of the polymer or by exposing them to controlled chloroform vapor atmosphere to induce chain mobility and facilitate equilibration. A topographically structured electrode induces an inhomogeneous electric field in the capacitor gap. Small 2010, 6, 1248–1254. They may be used to generate well-defined electrical contacts and may provide a route for incorporating chemical functions by functionalization along their longtinudal axis. 2005, 15, 2016–2020. [CrossRef] [Google Scholar]Sonmez G.; Sonmez H. Both streams were mixed and passed through the sample chamber. S.; Hauser B. The pattern formation rate, the height and the lateral dimensions (i.e., structures width and spacing, and therefore, the aspect ratio) of the EHL generated patterns can be controlled via adjustment of the applied voltage (increasing U causes higher driving forces), the initial film thickness, the interelectrode gap, and the surface tension. Electrostatically Induced Submicron Patterning of Thin Perfect and Leaky Dielectric Films: A Generalized Linear Stability Analysis. Hierarchical Structure Formation and Pattern Replication Induced by an Electric Field. Adv. Straightforward processing, tunable optoelectronic properties via molecular design, high surface area, and the possibility of modifying conductivity by doping, are only a few of the advantages attributed to CPs. Considerable research has been directed toward studying CPs aiming for their potential implementation into a variety of functional devices, including field effect transistors (FETs),1,2 organic light emitting diodes (OLEDs), integrated circuits, chemical and biological sensors,3 and electrochromic devices.4In order to take full advantage of the functions of π-conjugated macromolecules and, in particular, for generation of flexible organic electronics, patterning of CPs into structures ranging from 100 μm to sub-100 nm is required. Herein, EHL is shown to provide a low-cost, high-resolution patterning of functional π-conjugated polymers without compromising their properties and, therefore, enables a tunable method to fabricate and control the position and dimensions of the generated morphologies (by varying a number of experimental parameters, such as the initial film thickness, interelectrode spacing, applied voltage, surface tension, and lateral periodicity of the master electrode) at a low-cost, but this high-throughput technique also opens up a new avenue for patterning CPs targeting various applications including FETs, LEDs, solar-cells, advanced sensors and microelectronics.Owing to its high electroconductivity, good stability in ambient conditions, and facile processability, the intrinsically conducting PPy polymer has been a topic of extensive research concurrently focusing on practical applications and on synthesis. Optical microscopy images with height AFM images (inset) and three-dimensional AFM micrographs with cross section analysis showing fabricated PPy structures: (A) and (D) 120 nm wide nanolines with a height of 100 nm; (C) and (F) submicrometer pillars with 700 nm in height, 1.2 μm in diameter and with a pitch of 0.5 and 2.5 μm wide and 2.0 μm height microlines (B) and (E).Figure 2 shows optical microscopy (top) and atomic force microscopy (AFM) (inset, height; bottom, three-dimensional) images of line and column patterns obtained after the application of a voltage to the capacitor device. Additional optimization, currently underway, of the EHL generated electroconductive submicron structures will enable devices that can be used directly as arrays of electrodes to fabricate all plastic FETs and biochemical sensors. Rapid Electrohydrodynamic Lithography Using Low-Viscosity Polymers. Y.; Chi L. (A) Thin liquefied confined film develops characteristic undulations at z = h0 while a constant voltage, U is applied to between the electrodes (or across the capacitor gap). F.; Fuchs H. The length scale of the EHL formed patterns is dependent on the feature size of the structured electrode. Patterned silicon wafers were obtained from X-lith eXtreme Lithography, Ulm, Germany). D.; Voicu N. The positive gate voltages decrease the current and the values of IDS increase upon raising the positive VG at a negative VDS indicating that the devices exhibit p-type FET behavior with the holes being the major charge carriers. This results in a pattern of pillars spanning the capacitor gap at the locations of the smallest interelectrode distances (Figure 1B), which by coalescence eventually generates a replicated pattern of the upper electrode (Figure 1C). Although for homogeneous Ef, patterning of CP was somewhat limited, by using topographically structured top electrode, it was possible to successfully modulate the electric field, decrease the characteristic wavelength and increase the aspect ratio of the structures without causing the electrical breakdown of the capacitor patterning device due to high external voltages. [PubMed] [CrossRef] [Google Scholar]Katz E.; Willner I.; Wang J. M.; Wang J.; Guo Y.; Lee S. 10.1002/adma.200400546. Then, 0.35 M of aqueous ammonium persulfate solution was added to this mixture and left to react for 18 h under continuous stirring. 10.1038/nmat1073. Macromolecules 1995, 28, 4608–4616. [CrossRef] [Google Scholar]Schaffer E.; Thurn-Albrecht T.; Russell T. Non-Newtonian Fluid Mech. The dielectric constants of the film, ε and the gap εg mediate the electrical forces from the applied voltage. [CrossRef] [Google Scholar]Morariu M. 2011, 21, 1895–1901. Controlled EHL pattering of conductive polymer structures at the micro and nano scale demonstrated in this study combined with the possibility of effectively tuning the dimensions of the tailor-made architectures might herald a route toward various submicron device applications in supercapacitors, photovoltaics, sensors, and electronic displays.Keywords: conductive polymers, electrohydrodynamic lithography, leaky dielectrics, field-effect transistorsConductive polymers (CPs) combine properties of polymers with the electrical, chemical, and optical properties of metals. Using a light microscope in reflection mode the change in film thickness as a function of time was qualitatively monitored. Appl. Although some conventional lithographic techniques approach their physical limits, others are incompatible with CPs due to the poor adhesion between the polymers and the substrate. A voltage of 45–80 V was then applied between the two electrodes. [CrossRef] [Google Scholar]Dong B.; Zhong D. J.; Mutsaers C. M.; Matters M.; de Leeuw D. S.; Svensson M.; Inganäs O. [PubMed] [CrossRef] [Google Scholar]Goldberg Oppenheimer P.Electrohydrodynamic Patterning of Functional Materials; Springer: New York, 2013. Nano Lett. Exploitation of a conductive polymer induces free charge suppression of the field in the polymer film, paving the way for accessing scale sizes in the low submicron range. Prior to spin-coating, the substrates were cleaned in a Piranha solution consisting of 3:1 H_2SO_4 (98%):H_2O_2 (30%), followed by thorough rinsing with deionized water and drying under nitrogen. The electrical drain current (IDS)–drain voltage (VDS) characteristics of the device as a function of different gate voltages (VG) are shown in Figure 3B. 2003, 2, 48–52. Apart from isolated defects, the patterns of the master electrodes were reproduced with high fidelity over the entire electrode area (typically 200 × 200 μm2).Dimensions of a semiconducting channel are known to have a direct impact on the device performance.25,26 The final pattern morphology and its dimensions can be tuned by the specific set of sample parameters. AFM measurements yielded experimental parameters including the initial film thickness, the lateral distances between the generated structures, and the structures' heights and diameters.The conductivity of the patterned film was measured by a micromanipulator (Micromanipulator Co., Serial No. 820243) with a 1 mm delicate probe and 487 PicoAmmeter/voltage source (Keithley). 10.1021/jp050903k. J.; Lee J. With the limit of $\Sigma \gg 1$, (in our study Ef is on the order of 108) the most dominant (characteristic) wavelength3is given by a force balance between the destabilizing electrostatic pressure due to the field in the gap acting on the polymer–air interface with respect to the interfacial height, h0 and the γ acting to minimize the surface area, thus suppressing the height variations. 10.1002/adma.19960080618. [CrossRef] [Google Scholar]Goldberg-Oppenheimer P.; Steiner U. These conductive polymer films were then subjected to the EHL patterning process.The physical mechanism of the EHL pattern formation process in the case of a perfect dielectric is well understood.20,21 For EHL patterning of conductive polymers, however, free charges in the film (which substantially modify the electric field distribution in the film–air double layer) have to be taken into consideration. Charge Driven Electrohydrodynamic Patterning of Thin Films. 10.1063/1.2364497.