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Photopatternable Multifunctional Nanobiomaterials

28.1 Introduction

Over the past decades, two-dimensional micropatternable nanobiomaterials with desired bulk and surface properties have attracted considerable attention, which has led to a wide range of applications in miniature biochemical sensors, engineered cellular microenvironments, and medical diagnostic microdevices (Zakhidov et al. 1998; Aizenberg et al. 1999; Shi et al. 1999; Cui et al. 2001; Veinot et al. 2002). A number of techniques have been demonstrated to prepare functional nanobiomaterials with topological micropatterns (De Rosa et al. 2000; Demers and Mirkin 2001; Chou et al. 2002; Loo et al. 2002; Whitesides and Grzybowski 2002), among which photolithography-based and soft lithography-based techniques have been the most popular choices. In comparison with soft lithography, direct photolithography techniques eliminate the extra molding step, resolve compatibility issues, and thereby, provide more efficient rapid-prototyping processes to prepare a microstructured surface of functional nanobiomaterial. In this chapter, we present the recent development of photopatternable nanobiomaterials with particular emphasis on novel multifunctional micropatternable nanocomposites. Nanobiomaterials possessing a unique combination of photopatternability with the desired physical and chemical
properties (such as conductivity, superhydrophobicity, antimicrobial and non-fouling properties, etc.) have demonstrated their extensive usage in the area of biosensors, bionics, and self-assembly.

28.2 Photopatternable Conductive PDMS Nanocomposite Material for Bioelectrical Sensing

28.2.1 Polydimethylsiloxane

Polydimethylsiloxane (PDMS) has been widely used in a variety of academic and industrial applications due to its unique physical and chemical properties. With recent advances in soft lithography and polymer microelectromechanical systems (MEMS), PDMS has been constructed into a large array of micro- and nanoscale devices for biological and medical applications (Jo et al. 2000; Sia and Whitesides 2003; Huh et al. 2005; Liu 2007). Besides its well-known superior elasticity and flexibility in mechanical applications, PDMS has become a popular choice for biological studies because of its nontoxicity to cells and high permeability to gases (De Silva et al. 2004; Haubert et al. 2006; Lounaci et al. 2006; Bhagat et al. 2007). To fabricate PDMS-based micro-nanoscale devices, the molding method is presently the most common approach, which inversely replicates well-defined features from a conventionally micro-machined mold (Sia and Whitesides 2003). Uncross-linked PDMS pregel is mixed at a 10:1 (w/w) ratio with a curing agent, and after thermal curing, it forms a replica at 80°C within an hour’s duration. The molding process, though itself robust and reusable, creates microfabrication compatibility and integration issues, for instance, misalignment and packaging problems to other substrates. Moreover, high electrical impedance and poor adhesion with evaporated metal prevent further applications of PDMS in the area of electrical sensing and flexible circuits (Lee et al. 2005; Niu et al. 2007).

28.2.2 Photopatternable PDMS

An alternative approach to PDMS processing is to make the PDMS pre-polymer photo-cross-link under selective exposure of high-energy wavelength lights (<400 nm), and thus, it can be directly photopatterned. This can be accomplished by adding a photoinitiator of 2,2-dimethoxy-2-phenyl acetophenone (DMAP), which makes PDMS function as a negative photoresist (Lotters et al. 1997; Ward et al. 2001; Almasri et al. 2005; Niu et al. 2007). Exposure to UV light results in PDMS cross-linking and curing. Dow Corning has recently introduced photodefinable silicone products (WL-5000 series), prepared through this technique (Gardner et al. 2004; Harkness et al. 2004; Corning 2005), into the semiconductor packaging market. Micropatterns with 15 µm resolution can be fabricated through a completely photolithography-compatible process, involving spin coating, film baking, UV exposure, and solvent development (Corning 2005). Recently, another PDMS photolithographic process has been reported using benzophenone as photoinitiator (Bhagat et al. 2007). Benzophenone is a photosensitizer often used to initiate the free-radical polymerization of acrylates and monomers with certain functional groups under UV exposure. A group of investigators have reported its use with siloxane polymers (Muller et al. 1991, 1992; Pouliquen and Coqueret 1996; Tsougeni et al. 2007). The photodefinable mixture of PDMS and photoinitiator, eliminating the need of replicate molding and the compatibility issues related to molding, provides a more efficient way to the rapid prototyping of polymer-based MEMS devices.

28.2.3 Conductive PDMS

To overcome the low electrical conductivity of PDMS, highly conductive fillers (typically inorganic powders) are usually introduced into the polymer matrix, which provide continuous conductive pathways for electron migration (Engel et al. 2006; Liu 2007). This simple concept has been of extensive use in various practices, where both excellent electrical and thermal conductivities have been demonstrated.
28.2.4 Fabrication of Photopatternable Conductive PDMS

Combining the two approaches aforementioned (adding conductivity and photopatterning ability to the PDMS matrix), our group has developed the first conductive photodefinable PDMS composites, providing both high electrical conductivity and photopatternability (Cong and Pan 2008). The photosensitive composite, consisting of a photosensitive reagent, a conductive filler, and a PDMS pre-polymer, can be processed as a regular photoresist. To prepare the composite, the PDMS base and curing agent (Sylgard® 184) are mixed at a 10:1 (w/w) ratio. Benzophenone (3 wt%) and silver powder (17–22 vol%, 2 μm) are added to the PDMS mixture and degassed for 15 min. The prepared PDMS-Ag photoresist mixture is then spin-coated onto a flat substrate (e.g., glass, silicon, polyester, or silicone) for 30 s. The spin-coated wafer is loaded toward the photomask in an approximate mode with 50 μm spacing. Ten minutes UV exposure at 12 mW/cm² is followed by a postexposure bake for 50 s at 120°C. Heavy UV exposure dosage (7200 mJ/cm²) is necessary to induce complete photochemical reactions under significant decay of light transmission by silver particles. During the postexposure bake, the unexposed region gets fully cross-linked while the exposed region remains uncured. The uncured PDMS is then removed in toluene during the development. Finally, the wafer is rinsed in 2-propanol and blow-dried in nitrogen flow (Bhagat et al. 2007).

28.2.5 Properties of Photopatternable Conductive PDMS

Table 28.2 summarizes the key physical properties of the conductive PDMS-Ag composite. By incorporating 17–21 vol% of silver powder and 3 wt% benzophenone into the Sylgard 184 PDMS prepolymer, the resultant multifunctional PDMS composite is incorporated with electrical/thermal conductivities as well as photopatterning ability, which completely removes the need of a master mold for the micropatterned features. Highest conductivity of $\sim 10^4$ S/m and minimal lithographic resolution of 60 μm (Figure 28.1) have been achieved using the conductive PDMS composite on flexible polymeric substrates.
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Electrical conduction mechanism is based on establishing electronic paths through percolation and contact between filler particles in the insulating matrix (Kirkpatrick 1973; Zallen 1983; Biller 1985; Dovzhenko and Zhirkov 1995; Jiguet et al. 2005). Increasing content of the conductive filler reduces the electrical resistivity of the PDMS composite matrix by adding more interconnected clusters of silver particles into the conducting paths. As the conductive filler, silver powder significantly lowers the electrical resistance in the PDMS matrix through interconnecting percolation paths. In addition, the composite formula possesses enhanced mechanical properties. The silver particles in the PDMS matrix participate in physical cross-linking and thus considerably improve the mechanical strength of the composites. Moreover, the nanotopology and interfacial property of the composite lead to interesting surface phenomena.

According to the established wetting models (Cassie and Baxter 1944; Wenzel 1949), adding silver powder substantially changes the physical and chemical heterogenesis of the composite surface, which tends to become more hydrophobic than the pure PDMS with a higher contact angle of water. The increased surface hydrophobicity results from the high surface roughness of the formed PDMS-Ag composites as shown in Figure 28.1. As shown in Table 28.2, the measured contact angles of the PDMS surface containing 0, 17, 19, and 21 vol% silver powder are 109°, 119°, 127°, and 131°, respectively.

In addition, silver is historically known for its superior antibacterial properties, which can be used for biomedical devices to retard bacterial colonization and reduce the incidence of infections (Gabriel et al. 1995; Fung et al. 1996; Dowling et al. 2001; Wang et al. 2007). Silver particles work as catalysts to attack the bacteria from several aspects: poking bacteria membranes, destroying metabolic enzymes, denaturing proteins, disrupting bacteria division and the proliferation process, and lead to excellent antibacterial properties (Horn 2004). To assess the antibacterial properties of the formed PDMS-Ag photoresist membranes, Escherichia coli is used in the bacteria adhesion tests. The bacteria are incubated on the membrane surfaces at 37°C for 48 h prior to SEM inspection. As shown in Figure 28.2, the PDMS-Ag conductive composite with 19 vol% of silver particles shows outstanding antimicrobial properties compared with the pure PDMS control. The silver particles presented in PDMS largely remove the amount of bacteria adherence and thus improve the antibacterial property of the membrane. The excellent antimicrobial property of PDMS-Ag offers a desired safety feature to the multifunctional biomaterial.

28.2.6 Application in Bioelectrical Sensing

Figure 28.3 demonstrates a prototype of a capacitive pressure sensing array constructed by the PDMS-Ag conductive photoresist. The conductive composite is first patterned as both the sensing component and the connecting circuitry onto a pure PDMS flexible substrate. Subsequently, two layers of sensing circuits are folded over in a crossover configuration. Following the alignment step with the aid of surrounding
alignment marks, covalent bonding between the two-folded layers is conducted through oxygen plasma treatment. Subsequent to thermal compression molding in an aluminum mold in contact with a 300°C hotplate, the PDMS sensing device is molded into a contact lens shape, as shown in Figure 28.3 (Cong and Pan 2009). The bioelectrical sensing array built on a flexible substrate enables easy, direct, adaptive assessment of biomechanical measures in a range of medical applications (Stieglitz 2001; Subbaroyan et al. 2005; Fagaly 2006).

28.3 Photopatternable PEG Hydrogel Material for Nanoassembly

28.3.1 Polyethylene Glycol

As one of the best known nonfouling biomaterials with extremely low energy and nonadhesive surfaces, (Wang et al. 2001; Bremmel et al. 2005; Gudipati et al. 2005), polyethylene glycol (PEG) hydrogel, also known as polyethylene oxide (PEO) hydrogel, has been micromachined using both photolithography and soft lithography methods (Rezvani et al. 2001, 2003; Kim et al. 2005). These patterned PEG surfaces are widely used in cell culture, drug delivery, and biomedical devices (Albrecht et al. 2005; Kim et al. 2006; Duan et al. 2007). The nonadhesive property of PEG hydrogel comes from its high surface
resistance to the nonspecific adsorption of macromolecules in aqueous environment (Peppas et al. 2000; Underhill et al. 2007). Over the past decades, nanoscale components, including nanocolloids, biomolecules, and nanoparticles, are considered as the basic functional building blocks for future biochips (Jacobs and Whitesides 2001; Kumacheva et al. 2002; Zheng et al. 2002; Allard et al. 2004; Winkleman et al. 2005). Therefore, a highly programmed assembly of these objects onto the two-dimensional ordered biomaterial surface becomes an active area of research with particular focus on low-cost, large-area, and efficient manufacturing approaches.

### 28.3.2 Fabrication of PEG Hydrogel Nanopatterns

Polyethylene glycol diacrylate (PEG-DA) is one of the commonly used photosensitive prepolymerms in the production of PEG hydrogel micropatterns. In this case, the PEG hydrogel patterns are fabricated from the precursor solution of PEG-DA (MW 575) with 1% (w/v) photoinitiator and 2-hydroxy-2-methyl-propiophenone. Using a spin coater, the solution is spun at 800 rpm for 8 s onto a 3-acryloxypropyltrichlorosilane-treated glass surface containing terminal acrylate groups. The thin layer of the PEG-DA precursor solution on glass is then exposed through a chrome/soda-lime photomask to an UV light source of the photointensity of 15 mJ/cm² at 365 nm. The exposure time is 0.7 s. The regions of PEG-DA exposed to UV light undergo free-radical polymerization and become crosslinked, while the unexposed regions are dissolved in DI water after 5 min development. Coating silane coupling agents onto the glass substrate is critical to the adhesion of PEG hydrogel micro/nanostructures (Plueddemann 1982; Vandenberg et al. 1985; Lesho and Sheppard 1996).

Figure 28.4 shows AFM images of the fabricated PEG nanopatterns. As can be seen, the feature size of 500 × 500 nm² with 1500 nm spacing as well as that of 1 × 1 µm² with 1 µm spacing lead to an ultrahigh feature density of 250,000 wells/mm² on glass substrates. The depth of the microwell features is about 300 nm as measured by AFM. To achieve high-resolution PEG photolithography, the contact mode between the PEG substrate and the photomask is employed, given the fact that the minimal feature size is proportional to the square root of the separation distance (Ghandhi 1994). The additional cleaning procedure of the photomask with acetone is necessary to remove excess uncross-linked PEG pre-polymer in the postexposure treatment. The 500 × 500 nm² nanowells define the highest resolution of PEG hydrogel patterns achieved by the photolithography method, compared with the minimal resolution of 20 µm in the previous study using conventional proximity exposure (Rezvin et al. 2001, 2003).

![AFM images of PEG hydrogel wells on silane-modified glasses: (a) 500 × 500 nm² nanowells and (b) 1 × 1 µm² microwells. (From Cong, H.L. et al., Nanotechnology, 20(7), 75307, 2009. Reproduced with permission from IOP Publishing Ltd.)](image)
28.3.3 PEG Pattern-Assisted Nanoassembly

Figure 28.5 illustrates the pattern-assisted nanoassembly method used to fabricate nanocolloidal arrays onto PEG wells. Experimental procedures are described as follows. First, a suspension of poly(styrene-methyl methacrylate-acrylic acid) (PSMA, 190 nm) colloidal particles is diluted to a defined concentration using deionized water (Cong and Cao 2005a,b; Cong et al. 2008, 2009a,b). Then, the glass slide fabricated with PEG hydrogel wells is immersed vertically into the dispersion and lifted up at a constant speed varied from 0.1 μm/s to 1 mm/s precisely controlled by a step motor.

Figure 28.6 shows that the PSMA nanocolloids are self-assembled and display a highly organized single-bead nanocolloidal array embedded into PEG nanowells (operation condition: 0.1 μm/s pulling speed and a 1.5 mg/mL nanocolloidal concentration). As illustrated in the inset of Figure 28.5, under the

![Figure 28.5](image_url)

**FIGURE 28.5** Illustration of the pattern-assisted nanoassembly method for the fabrication of nanocolloidal arrays. (From Cong, H.L. et al, Nanotechnology, 20(7), 75307, 2009. Reproduced with permission from IOP Publishing Ltd.)

![Figure 28.6](image_url)

**FIGURE 28.6** SEM images of nanocolloidal arrays formed in the 500 × 500 nm² PEG nanowells. (From Cong, H.L. et al., Nanotechnology, 20(7), 75307, 2009. The arrow indicates the pulling direction, reproduced with permission from IOP Publishing Ltd.)
influence of gravitation, the colloids inside the trapped suspension tend to move downward in the well during the evaporation. Once the self-assembly process is accomplished, all the beads are uniformly aligned along the bottom edge of the wells.

Different nanocolloidal arrays can be obtained by changing the pulling speed, the inclined angle of the substrate, the shape and size of the PEG nanopatterns, as well as the concentration of colloids in the nano-assembly process. Figure 28.7 shows that varying the concentration of PSMA colloidal particles in the aqueous suspension can lead to different morphologies of nanocolloid arrays in the PEG microwells, such as linear bead arrays (4a, 4b, 4c) and multiline arrays (4d), which are of potential use in biosensing and biofabrication.

### 28.3.4 Influence of Surface Property of PEG

The PEG hydrogel, one of the best known antifouling biomaterials with an extremely low surface energy, plays an important role in preventing the PSMA nanocolloids from adhering to the surface during the nano-assembly process. To verify this unusual antifouling mechanism, oxygen plasma has been carried out to modify the PEG surface property. After 20 s at 200 W of plasma treatment, about 100 nm PEG hydrogel on the surface is removed under oxygen plasma, and the contact angle of the PEG hydrogel surface reduces from 22° to 9°. The antifouling property of the PEG hydrogel surface drastically deteriorates where both hydroxyl and carboxyl groups are introduced during the modification. The oxygen plasma modified PEG microwells are then used to fabricate nanocolloidal arrays under the same conditions as the unmodified ones, and the comparison is illustrated in Figure 28.8. As expected, Figure 28.8b shows that after the oxygen plasma surface modification, nanocolloidal arrays are packed into the microwells, but also adhere onto the modified PEG surfaces unlike the highly selective assembly that resulted in Figure 28.8a.

**FIGURE 28.7** SEM images of nanocolloid arrays formed in the 1 × 1 μm² PEG microwells using different PSMA colloidal particle concentrations. (From Cong, H.L. et al., *Nanotechnology*, 20(7), 75307, 2009. Reproduced with permission from IOP Publishing Ltd.)
28.3.5 Application in Biosensing

After emulsion polymerization, the PSMA nanocolloid has carboxy functional groups on surface, which can easily be labeled as antigens/antibodies, biomolecules, and fluorescent agents. For example, IgG-FITC can be coupled onto its surface by using the carbodiimide method described elsewhere (Ortegavinuesa et al. 1995). The IgG-FITC labeled PSMA colloidal particles (∼5.0 mg/mL) are used to fabricate nanocolloidal arrays, and the results are shown in Figure 28.9. The IgG-FITC labeled colloid arrays emit green light (520 nm) via an excitation wavelength of 490 nm under a fluorescence microscope, which can have potential implications for microchip-based drug identification, analyte detection, cell sorting, and biological sensing (Zhong et al. 2000; Gu et al. 2002; Pregibon et al. 2006).

28.4 Photopatternable Superhydrophobic PTFE Nanocomposite Material for Bionics

28.4.1 Polytetrafluoroethylene

Polytetrafluoroethylene (PTFE), well known as Teflon™, is a synthetic fluoropolymer of tetrafluoroethylene. PTFE is chemically nonreactive due to the strong carbon–fluorine bonds in the molecular structure. It is almost insoluble in any solvent and has a high chemical resistance. Moreover, PTFE has been...
widely employed as nonsticky coatings and lubricants as it possesses an extremely low surface energy (18.6 mJ/m$^2$) (Ellis et al. 2001; Zhao et al. 2002; Zhang et al. 2004). Due to the remarkable nonfouling property, flexibility and biocompatibility, PTFE has been used in a variety of biomedical devices and implants such as man-made blood vessels and artificial filtration devices. However, due to its chemical inertness and high melting temperature, the PTFE surface is difficult to process through conventional microfabrication.

### 28.4.2 Superhydrophobic PTFE

Since the discovery of the self-cleaning mechanism of the lotus leaf surface, surface superhydrophobicity has experienced extensive explorations in a wide range of fundamental researches as well as translational investigations (Barthlott and Ehler 1977; Callies and Quere 2005; Nosonovsky 2007). Further explorations have revealed the wide presence of remarkable superhydrophobic surfaces in nature for various reasons, including self-cleaning lotus leaves and duck feathers, the nonwetting legs of water striders, the adhesive nanofibrous setae on gecko feet, and water condensation micropatterns on desert beetles (Barthlott and Neinhuis 1997; Neinhuis and Barthlott 1997; Parker and Lawrence 2001; Gao and Jiang 2004). In theory, surface superhydrophobicity is primarily contributed by two underlying mechanisms: the chemical inertness of the solid material and the physical roughness of the surface (Han et al. 2007). The PTFE material typically has an extremely low surface energy of 18.6 mJ/m$^2$ due to its chemical structure, and exhibit the highest degree of hydrophobicity as a flat surface with a contact angle of 120° (Zhang et al. 2004). To further improve the hydrophobicity, nanoscopic roughness is a natural choice to be incorporated, as the theory predicts (Cassie and Baxter 1945; Bormashenko et al. 2007). PTFE nanoparticles are commercially manufactured by emulsion polymerization, in this case, embedding the nanomorphology and ultra low (Lopez et al. 1993; Drellich et al. 1994; Tadanaga et al. 2000; Gu et al. 2002; Sun et al. 2003; Kim et al. 2004a,b; Mornet et al. 2004; Seemann et al. 2005; Ma and Hill 2006; Garrod et al. 2007; Yang et al. 2007; Zhang et al. 2007a,b; Piret et al. 2008; Voronov et al. 2008; Bhushan 2009; Song et al. 2009) interfacial energy of PTFE nanoparticles into the polymeric matrix will be established with nanoscopic surface roughness and an ultrahigh contact angle of water (>150°), which is considered as the superhydrophobic effect.

### 28.4.3 Photopatterning PTFE

Well-defined micropatterns with desired superhydrophobicity offer great extension to rapid-evolving micro-nanoengineering applications (Lopez et al. 1993; Drellich et al. 1994; Tadanaga et al. 2000; Gu et al. 2002; Sun et al. 2003; Kim et al. 2004a,b; Mornet et al. 2004; Seemann et al. 2005; Ma and Hill 2006; Garrod et al. 2007; Yang et al. 2007; Zhang et al. 2007a,b; Piret et al. 2008; Voronov et al. 2008; Bhushan 2009; Song et al. 2009). Therefore, a simple microfabrication method to establish superhydrophobic micropatterns on universal surfaces would enable novel functionalities and applications of the extraordinary superhydrophobic phenomena. Due to the nonreactive nature of PTFE presents a technical hurdle for micromachining, polymer-based nanocomposite materials offer such a powerful hybrid solution to the challenge, where a photosensitive polymer matrix is introduced with the necessary photochemistry for direct micropatterningability (Cong et al. 2007; Lee et al. 2007; Ahn et al. 2009). Incorporating the PTFE nanoparticles, known as photosensitive nanocomposite materials, into a photosensitive polymer matrix could result in unique combinational properties from both the polymer matrix and the nanofiller (for instance, photopatternability and optical transparency of the polymer matrix, and physical roughness and chemical inertness of the nanofillers). The nanocomposite consists of commercially available PTFE nanoparticles to provide nanomorphology and chemical inertness,
and SU-8 photoresist as the photosensitive matrix. In superhydrophobic nanocomposite, the PTFE nanoparticles are directly mixed into the SU-8 photoresist matrix to form a uniform nanocomposite.

### 28.4.4 Fabrication of Photopatternable Superhydrophobic PTFE

The nanocomposite formula comprises 20 wt% of PTFE nanoparticles (250 nm in diameter) added into SU-8 2050 photoresist and mixed through agitation until a uniform mixture is formed. The mixture is then spin-coated onto a transparent substrate (e.g., glass or polymers) followed by a soft bake at 95°C for 7 min. Subsequently, backside UV exposure through a photomask is processed, followed by a postexposure bake at 95°C for 7 min. After development in a regular SU-8 developer, the unexposed nanocomposite surface is dissolved, leading to cross-linked PTFE-SU-8 nanocomposite patterns.

### 28.4.5 Properties of Photopatternable Superhydrophobic PTFE

Figure 28.10a illustrates the SEM image of the PTFE-SU-8 nanocomposite. As can be seen, the nanocomposite surface exhibits nanoscopic roughness with severe aggregations of PTFE nanoparticles in the SU-8 matrix. As shown in Figure 28.10b, the nanoroughness and chemical inertness of the PTFE-SU-8 nanocomposite lead to the contact angle of water at 150°.

The SU-8 polymeric matrix offers the direct photopatternability of the superhydrophobic nanocomposite. During the development, the unexposed PTFE-SU-8 composite coating is dissolved, which leads to the desired superhydrophobic micropatterns on the substrate. Figure 28.11 shows the SEM images of

![FIGURE 28.10](a) SEM morphology and (b) contact angle of the PTFE-SU-8 nanocomposite surface. (Scale bar in (a): 50 μm, in inset: 4 μm.)

![FIGURE 28.11](a) Photolithography resolution of the PTFE-SU-8 nanocomposite: (a) 100 μm and (b) 50 μm features. (Scale bars: 100 μm.)
28-4.6 Application in Bionics

The novel PTFE-SU-8 nanocomposite surface provides a unique combination of superhydrophobicity and photopatternability along with excellent adaptability and simple processability. Recent discovery reveals an intriguing nature-engineered design in the back-shell structure of the Namib Desert beetle, which comprises hydrophilic patches (~0.5 mm in diameter) surrounded by a superhydrophobic waxy shell surface. Amazingly, this design exhibits highly efficient water-capture ability and minimal evaporative exposure in humid ocean winds, of particular importance for survival under the harsh dry desert weather (Zhai et al. 2006). To mimic this remarkable moisture-capture design, the superhydrophobic nanocomposite is photopatterned onto an oxygen plasma-treated hydrophilic polyethylene terephthalate (PET) substrate, followed by a thermal compression molding at 230°C to create the curved hunchback in a metallic mold. As displayed in Figure 28.12, an artificial desert beetle with a superhydrophobic nanocomposite-patterned hunchback is engineered successfully, which possesses the moisture-capture ability under a humid air flow.

28.5 Future Perspectives

This chapter describes several exciting nanoengineered implementations of multifunctional nanobiomaterials, which sketches the rapid development in such an active area of research. As a major advantage, the photopatternability is incorporated into the multifunctional nanobiomaterials matrix, which offers high-resolution micropatterning in single-step lithographic processing. A novel multifunctional performance of nanobiomaterials has been demonstrated, including high electrical/thermal conductivities, antibacterial properties, superhydrophobicity, and nonfouling property, all leading to exciting possibilities in emerging biomedical and chemical applications.
## References


