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Wettability of conducting polymers: From superhydrophilicity to superoleophobicity

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ABSTRACT

The review reports most of the works realized in the field of the surface wettability based on conducting polymers. The surface wettability is highly depending on the intrinsic hydrophobicity of materials and the roughness geometry. Conducting polymers have unique properties allowing to tune the surface wettability, for example, by reversibly incorporating various hydrophobic/hydrophilic doping ions, by changing the nature of the polymerizable core or by functionalization with various hydrophobic/hydrophilic substituents. Conducting polymers are obtained by monomer oxidation using various strategies such as the chemical oxidative polymerization in solution, the electrochemical polymerization on conductive substrates or the vapor-phase polymerization, leading to have an easy control of the surface morphology at micro- or a nanoscale with a surface wettability going from superhydrophilicity to superoleophobicity.

Contents

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Nomenclature

α	sliding angle
γ_{LV}	liquid-vapor surface tension
γ_{SL}	solid-liquid surface tension
γ_{SV}	solid-vapor surface tension
θ	apparent contact angle
CNT	carbon nanotubes
DoMIm	1-dodecyl-3-methylimidazolium
EDOP	3,4-ethylenedioxypyrrole
EDOT	3,4-ethylenedioxythiophene
EOTT	3,4-ethyleneoxythiathiophene
FD-POSS	fluorinated decyl polyhedral oligomeric silsesquioxane
H	hysteresis
HDTMAm	hexadecyltrimethylammonium
HTAB	hexadecyltrimethylammonium bromide
ITO	indium tin oxide
PANI	polyaniline
PDMS	polydimethylsiloxane
PEDOP	poly(3,4-ethylenedioxypyrrole)
PEDOSe	poly(3,4-ethylenedioxyselenophene)
PEDOT	poly(3,4-ethylenedioxythiophene)
PEDTP	poly(3,4-ethylenedithiopyrrole)
PEG	poly(ethylene glycol)
PEO	poly(ethylene oxide)
PEOTT	poly(3,4-ethyleneoxythiathiophene)
PET	poly(ethyleneterephtalate)
PFDMIm	1*H*,1*H*,2*H*,2*H*-perfluoro-1-decyl-3-methylimidazolium
PFl	polyfluorene
PFOSA	perfluorooctanesulfonic acid
PFSEA	perfluorosebacic acid
PMMA	poly(methyl methacrylate)
PProDOP	poly(3,4-propylenedioxypyrrole)
PProDOT	poly(3,4-propylenedioxythiophene)
PPy	polypyrrole
ProDOP	3,4-propylenedioxypyrrole
ProDOT	3,4-propylenedioxythiophene
PS	polystyrene
PSS	poly(styrenesulfonate)
PTFE	poly(tetrafluoroethylene)
PTh	polythiophene
PVA	poly(vinyl acetate)
PVP	poly(vinylpyrrolidone)
Py	pyrrole
SDS	sodium dodecyl sulfate

1. Introduction

The control of the surface wettability is crucial from a theoretical viewpoint and also for various applications including cookware coatings [1], self-cleaning windows for the industry of automotive and aeronautics [2], waterproof textiles [3], anti-fingerprint [4] or anti-reflective [5] properties for optical instruments and mobile phones, liquid transportation [6], separation membrane [7], cell [8] and antibacterial adhesion [9]. Biomimetic and bioinspired approaches were necessary to well understand and reproduce adhesion phenomena and also improve surface properties. Indeed, nature has produced since millennia several plants, insects and animals with surface properties going from superhydrophilicity to superoleophobicity [10–12].

Superhydrophilicity is characterized by the full spreading of water on a surface. *Ruellia devosiana* (Fig. 1a) shows a remarkably rapid spreading of water on its leaves [13]. The superhydrophilicity of their leaves was found to be a combination of conical cells, hydrophilic glands, multicellular hairs, hair-papilla and channel-like structures. In nature, superhydrophilicity is an advantage for plants for the uptake of water ($\gamma_{LV} \leq 72.8$ mN/m) and nutrients from the environment, especially in dry periods [10]. For example, mosses, which have no roots for water uptake and no vascular system for water transport, use porous structures and trichomes in order to absorb high quantity of water [14]. Carnivorous plants of genus *Nepenthes* (Fig. 1b) are able to capture prey with their peristome, a fully wettable microstructured anisotropic surface causing prey to slip by aquaplaning on a thin water film [15–18]. The slipperiness of these surfaces is due to the combination of hydrophilic surface chemistry and downward pointing epidermal cells to trap the prey. To capture water, desert beetles and plants possess hydrophobic and hydrophilic regions in order to guide water into their mouth [19], while spiders use webs with periodic spindle-knots made of random nanofibrils (Fig. 1c) [20,21].

Superhydrophobicity is characterized by the non-adhesion of water on a surface. The advantages to possess superhydrophobic surfaces are extremely various and allow to resist to various kinds of environments and weathers using different strategies. The self-cleaning properties of plants and flying insects allow to remove all kind of particles and dusts [22–24]. These properties are often due to the combination of hydrophobic compounds and the presence of micro and/or nanostructures (Fig. 1e). Other insects can walk on water [25,26], on sticky webs [27] or climb on vertical surfaces thanks to tiny hairs present on their foot (Fig. 1d) [28,29]. We can also cite the structural color of butterfly wings to push away predators [30], the antireflective and anti-fogging properties of moth and mosquito eyes [31] and the bactericidal properties of cicada wings [32].

However, for various applications such as in anti-soil textiles [33], antifingerprint optical devices [4], printing technologies [34], oil transportation [35], digital microfluidics [36], it is necessary to repel liquids other than water. Superoleophobic properties allow the repellency of low surface tension liquids such as oils (typically $\gamma_{LV} \leq 35$ mN/m, including alkanes, sunflower oil, motor oil, etc.) while the term of superhygrophobic introduced by Marmur allow the repellency of all kind of liquids [37,38]. Due to their low surface tension, in comparison to water, it is much more difficult to impede the wetting of oils. As a consequence, almost all superoleophobic materials reported in the literature are also superhydrophobic even if there are extremely rare examples of materials with both superoleophobic/oleophobic and superhydrophilic/oleophilic properties [39,40].