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Colorimetric monitoring of humidity by opal photonic hydrogel

Mohammad Bagher Sobhanimatin *
Amirkair University of Technology, Tehran, Iran
***Corresponding Author:** Mohammad Bagher Sobhanimatin Amirkair University of Technology, Tehran, Iran, E-mail: mshakeri@mail.kntu.ac.ir*

ABSTRACT
The present study demonstrated a new fast colorimetric humidity sensor using the opal hydrogel composite (OHC) First, a highly monodisperse polystyrene (PS) latex was synthesized by soap-free emulsion polymerization and deposited on a glass substrate in order to form a three-dimensional opal photonic crystal. Then, the homogenous hydrogel precursor was infiltrated into the interstitial space of opal by capillary forces and underwent chemical polymerization to construct an embedded PS crystalline colloidal array within a poly (acrylamide-co-acrylic acid) hydrogel network. The scanning electron microscopic images confirmed the formation of opal structures. An interesting feature of the presented OHC sensor is that the sensor is transparent in a dry state and an increase in relative humidity (RH) leads to a colorful film. In addition, UV/Vis spectroscopy was performed within an RH range of 25-95%, indicating that reflection peak height gradually develops by RH increasing and the peak position shifts from 413 to 518 nm. Further, the sensor functions extremely rapidly and changes its color by increasing RH within a few seconds (less than 3 s) and becomes transparent again quickly as humidity represents a decrease. Based on the results, repeated humidity changes revealed that the sensor has an excellent reproducibility without any reduction in response time and sensitivity or a color change. Finally, it has good adhesion to the glass substrate which makes it a suitable RH sensor in different applications, along with the rapid response time, high sensitivity, repeatability, and the visual alarm.

Key words: Hydrogel composite, UV/Vis spectroscopy, opal photonic crystal.

INTRODUCTION

We demonstrate a fast response colorimetric humidity sensor using a crosslinked poly(2-hydroxyethyl methacrylate) (PHEMA) in the form of inverse opal photonic gel (IOPG) soaked in 1-butyl-3-methylimidazolium tetrafluoroborate ([BMIM+][BF4−]), a non-volatile hydrophilic room temperature ionic liquid (IL). An evaporative colloidal assembly enabled the fabrication of highly crystalline opal template, and a subsequent photopolymerization of PHEMA followed by solvent-etching and final soaking in IL produced a humidity-responsive IOPG showing highly reflective structural color by Bragg diffraction. Three IOPG sensors with different crosslinking density were fabricated on a single chip, where a lightly crosslinked IOPG exhibited the color change response over entire visible spectrum with respect to the humidity changes from 0 to 80% RH. As the water content increased in IL, thermodynamic interactions between PHEMA and [BMIM+][BF4−] became more favorable, to show a red-shifted structural color owing to a longitudinal swelling of IOPG. Highly porous IO structure enabled fast humidity-sensing kinetics with the response times of ~1 min for both swelling and deswelling. Temperature-dependent swelling of PHEMA in [BMIM+][BF4−] revealed that the current system follows an upper critical solution temperature (UCST) behavior with the diffraction wavelength change as small as 1% at the temperature changes from 10 °C to 30 °C.

The present study demonstrated a new fast colorimetric humidity sensor using the opal hydrogel composite (OHC). First, a highly monodisperse polystyrene (PS) latex was synthesized by soap-free emulsion polymerization and deposited on a glass substrate in order to form a three-dimensional opal photonic crystal. Then, the homogenous hydrogel precursor was infiltrated into the interstitial space of opal by capillary forces and underwent chemical polymerization to construct an embedded PS crystalline colloidal array within a poly (acrylamide-co-acrylic acid) hydrogel network. The scanning electron microscopic images confirmed the formation of opal structures. An interesting feature of the presented OHC sensor is that the sensor is transparent in a dry state and an increase in relative humidity (RH) leads to a colorful film. In addition, UV/Vis spectroscopy was performed within an RH range of 25-95%, indicating that reflection peak height gradually develops by RH increasing and the peak position shifts from 413 to 518 nm. Further, the sensor functions extremely rapidly and changes its color by increasing RH within a few seconds (less than 3 s) and becomes transparent again quickly as humidity represents a decrease. Based on the results, repeated humidity changes revealed that the sensor has an excellent reproducibility without any reduction in response time and sensitivity or a color change. Finally, it has good adhesion to the glass substrate which makes it a suitable RH sensor in different applications, along with the rapid response time, high sensitivity, repeatability, and the visual alarm. In summary, we fabricated a crosslinked IOPG via DEECA followed by photopolymerization of HEMA and crosslinker which was subsequently soaked in [BMIM+][BF4−], a non-volatile hydrophilic IL at room temperature to demonstrate a colorimetric humidity sensor. Under varying humidity from 0% to 80% RH, IOPGs with different crosslinker contents were exposed, to exhibit structural color changes over entire visible ranges especially for a lightly crosslinked IOPG. Fast color change responses with exponential time constants of 0.6~2.8 min were obtained due to highly porous IO structure of the sensor. From a temperature-dependent color change test, temperature increase resulted in a swelling of IOPG, implying that the thermodynamic interaction between PHEMA IOPG and [BMIM+][BF4−] is supposedly UCST behavior. However, the dimensional change was less than 1% at the temperature variations from 10 °C to 30 °C.

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