Polymer top covered Bragg reflectors as optical humidity sensors

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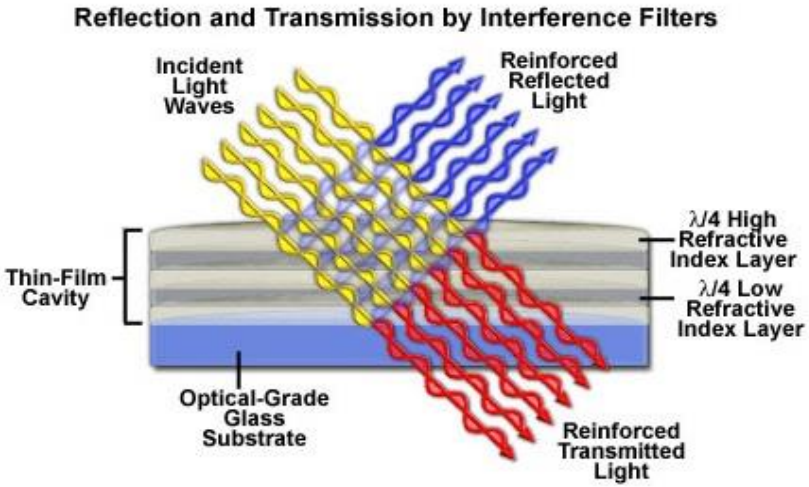
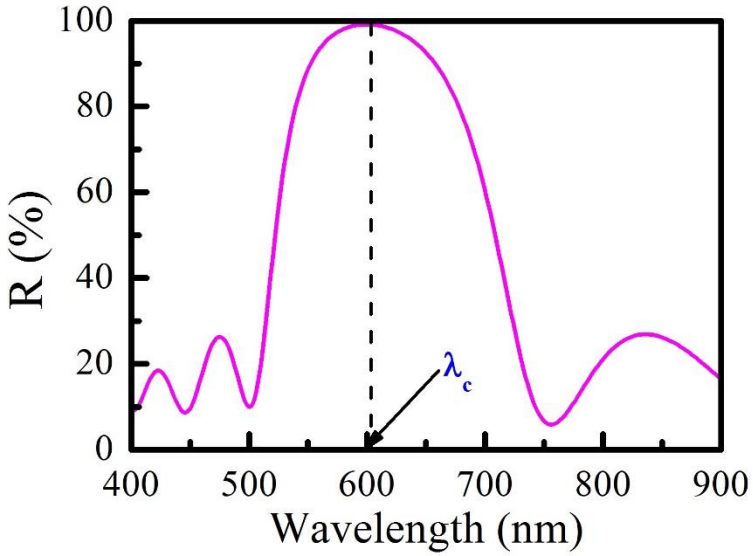
What are Bragg reflectors?



Bragg reflectors are multilayered systems comprising layers with alternating low and high refractive index and quarter-wavelength optical thickness.

- If Bragg reflector is design in a way the operating wavelength to be in the visible part of the spectra, then a distinctive color called structural color is observed.
- The position of λc and reflector's color depend strongly on refractive index and thickness of the layers and change when one or both of these parameters change.



The concept:

Implementing top covered Bragg reflectors as optical sensors for humidity

Humidity sensitive media:

Thin films of poly(N,N-dimethyl acrylamide)-poly(ethylene oxide) block copolymer with branched macromolecular architecture

How it works?

- Thin films of the block copolymer are deposited by spin-coating on top of two types of Bragg reflectors, having different optical contrast and operating wavelengths.
- The humidity sensing ability are demonstrated through transmittance measurements at relative humidity of 5 % and 95 %.
- Color of the sensor change at different humidity levels .

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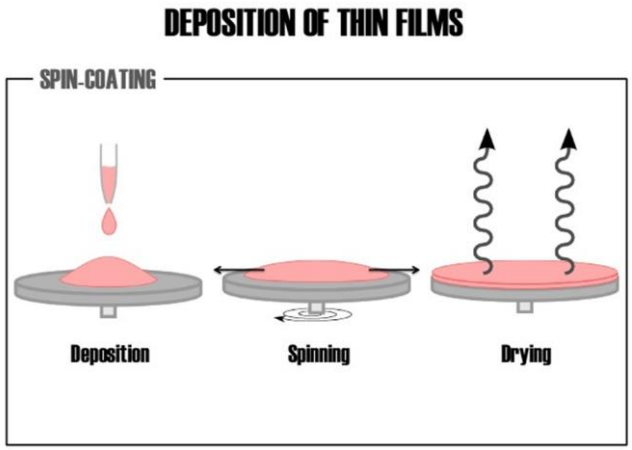
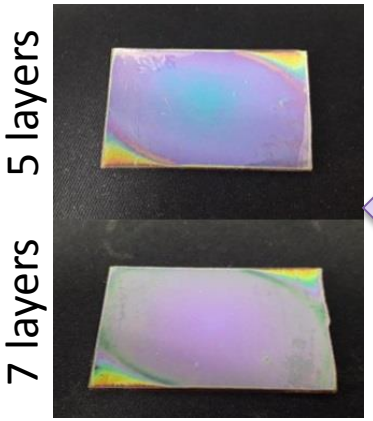
Materials and Methods

1. PDMA/PEO copolymer of branched macromolecular architecture was synthesized.

2. Thin polymer films with thickness in the range 140 – 550 nm were deposited by spin-coating method both on silicon substrate and Bragg reflectors using polymer solutions with different concentrations.





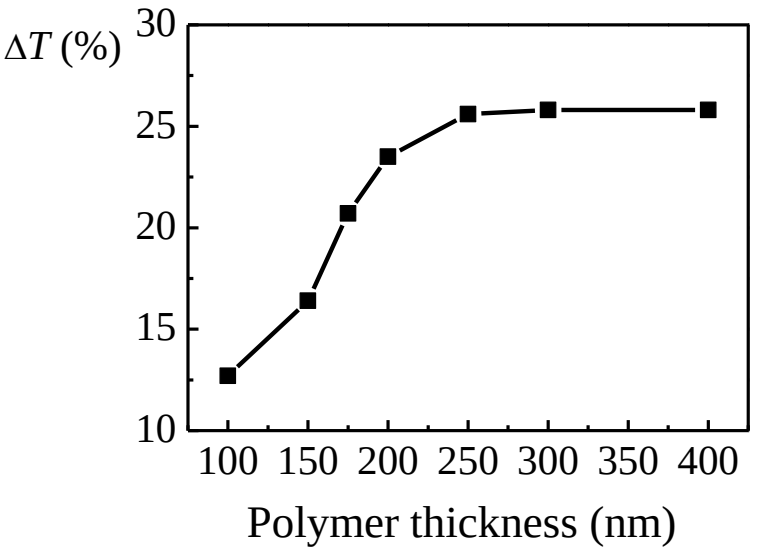
3. 5- and 7-layers Bragg reflectors are prepared on glass substrates by alternating deposition of:
   - sol-gel Nb_2O_5 and SiO_2 films
   - dense and porous Nb_2O_5 films

4. Refractive index *n*, extinction coefficient *k* and thickness *d* of the films were calculated using two-stages nonlinear curve fitting of measured reflectance spectra.

5. The sensing behavior was tested by measuring transmittance spectra at low and high levels of relative humidity.

Theoretical modelling

In order to achieve the highest sensitivity toward humidity we optimize the thickness of polymer film through theoretical modelling.



ΔT increases with thickness of the polymer film reaching steady state for thickness higher than 250 nm.

We use polymer film with thickness of 290 nm and deposit it on our different Bragg stacks.

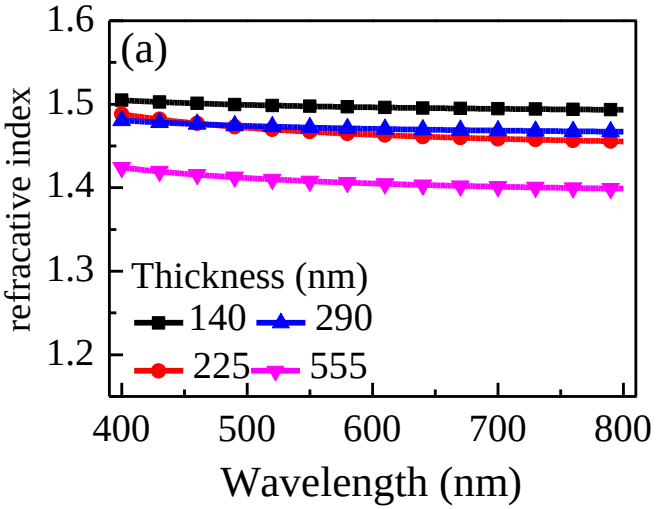
Why?

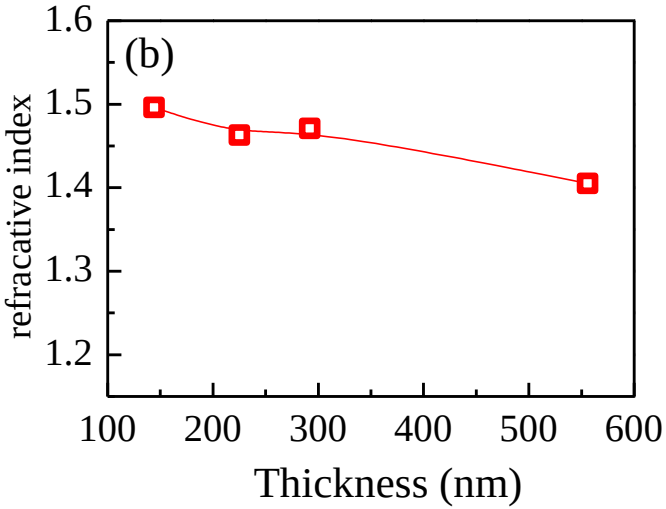
1) Films thicker than 300 nm are not suitable because the time response of the sensor will increase due to the longer diffusion path length in thicker polymer films.
2) There is no enhancement of the sensitivity when films thicker than 250 nm are used.

Optical characterization of thin films

How the thickness of branched polymer film influences its refractive index?

To answer that polymer films with different thicknesses in the range 140 – 550 nm are deposited on silicon substrate using polymer solutions with different concentrations.





Calculated values of *k* are smaller than 0.003 thus confirming the good quality and transparency of the studied polymer films.

All studied samples obey normal dispersion

Refractive index *n* is almost the same for films with thickness values up to 300 nm and decreases for thicker films.

Humidity sensing

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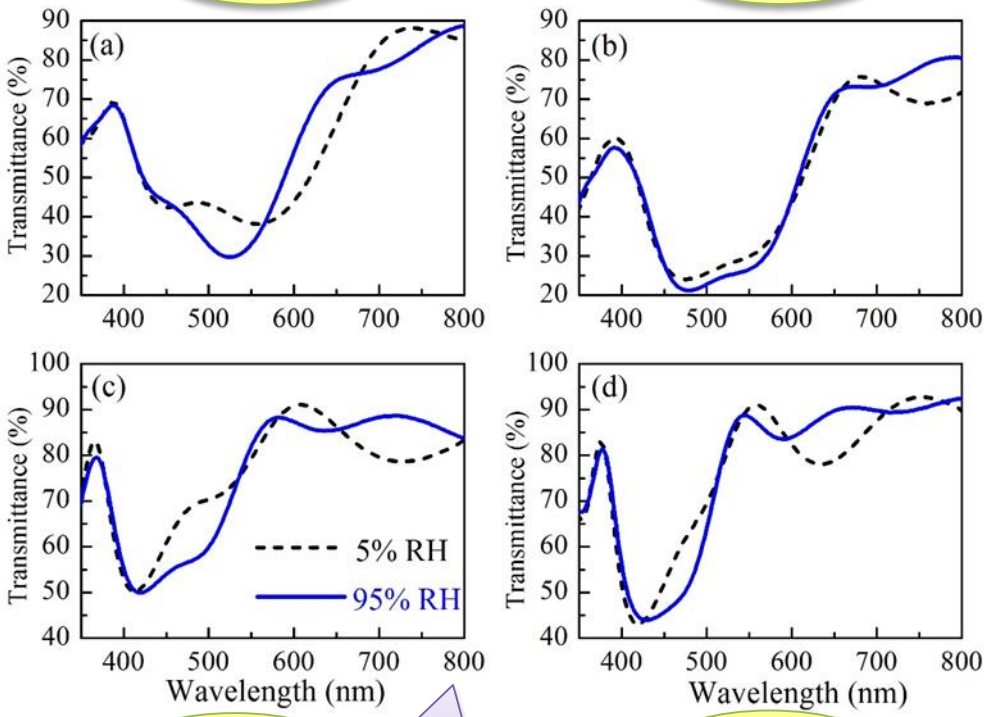
Nb_2O_5 and SiO_2

3 layers

5 layers



3 layers

5 layers

dense and mesoporous Nb_2O_5

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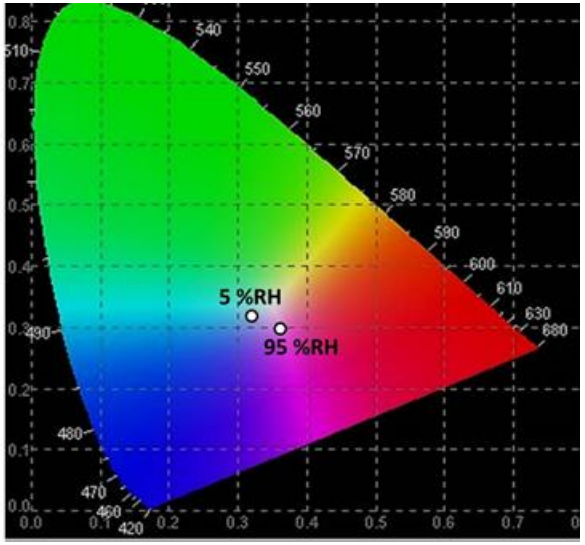
Transmittance spectra of Bragg stacks with deposited branched polymer film with thickness of 290 nm

Bragg reflectors transmittance spectra are changing with humidity (5%RH to 95%RH)

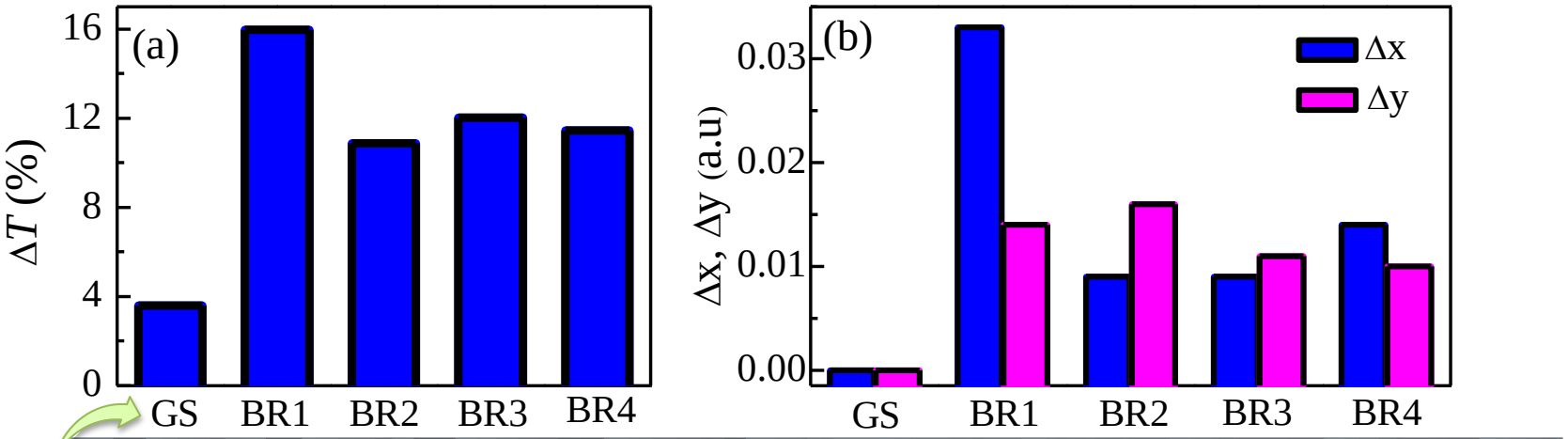


It is seen that the color changes from blueish to magenta. The separation of colors in the color scheme is substantial for visual color detecting of humidity to take place.

Humidity sensing

Humidity induced changes in transmittance

Humidity induced changes in CIE color coordinates *x* and *y*



single polymer film with thickness of 290 nm deposited on bare glass substrate (GS) and on Bragg reflectors (BR) (BR1-5 layers, BR2-7 layers - Nb_2O_5 and SiO_2; BR3-5 layers, BR4-7 layers – dense and mesoporous Nb_2O_5).

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The advantage of using Bragg reflectors over bare glass is obvious: a fourfold increase in ΔT is obtained when Bragg reflectors are used.

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Summary

- ✓ The concept of using Bragg reflectors top covered with polymer film for optical sensing of humidity is verified and confirmed.
- ✓ Thin films of branched poly(N,N-dimethylacrylamide)-based copolymer with optimized thickness are used as humidity sensitive media while 5- and 7-layers Bragg reflectors comprising SiO_2, dense and porous Nb_2O_5 films are used for transducing elements.
- ✓ The detection of humidity is performed both by measuring transmittance spectra and monitoring the change of sensor's color in transmission mode.
- ✓ It is demonstrated that the implementation of Bragg reflector as a sensor's transducer element enhances more than 4 time the sensitivity compared to this when glass substrate is in operation.
- ✓ The obtained sensitivity of 0.18 % / % RH is comparable with those of single film on silicon substrate (0.16 % / % RH) while the accuracy of humidity detection (1.1 % RH) is higher as compared to the case of reflectance measurement due to the smaller experimental error of transmittance measurement.

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