Low Power Liquid Crystal Sensors for Rapid, Sensitive Detection of Toxic Gases

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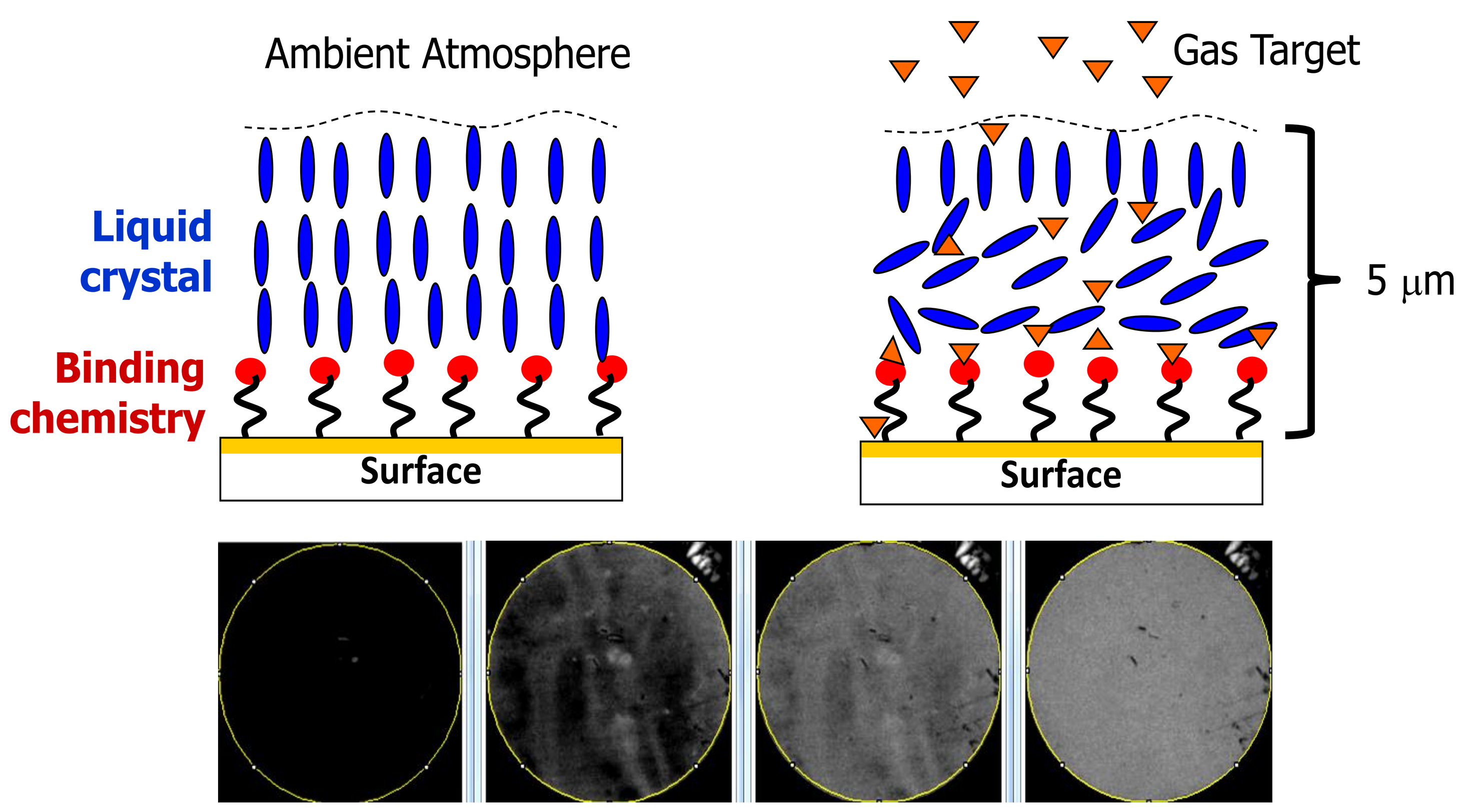
Summary

The same liquid crystals (LCs) used in TV and computer screens can also be used for gas sensing. LC films provide a much simpler means to read out chemical interactions than instrumentation. A gas sensor is made by spreading a thin film of LC over a chemically functionalized surface. The detection chemistry aligns the LC molecules in one orientation before exposure to the target, and after interaction with the target it aligns the LC molecules in a different orientation. The change in LC orientation appears as a change in brightness when viewed through crossed polarizers. No power supply is needed.

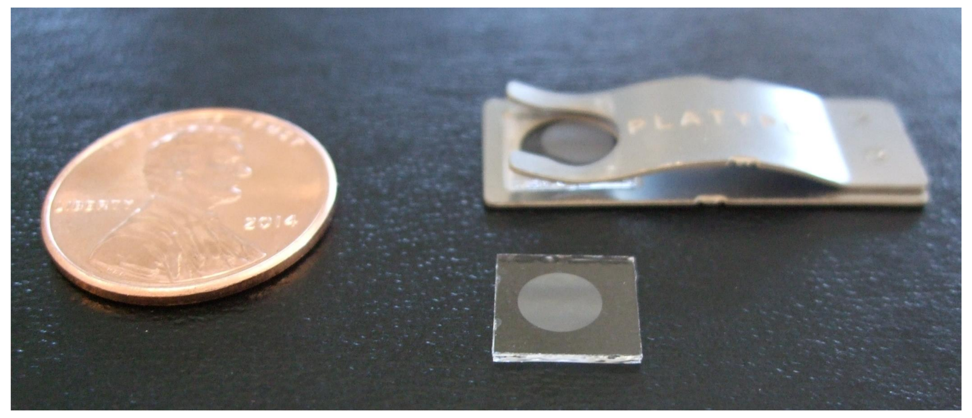
This technology has been used to make dosimeters that measure ppb levels of H_2S over a period of hours. We now report an increase in sensitivity of two orders of magnitude, enabling detection of 100 ppb in less than 60 seconds of three target gases - H_2S, NO_2, and NH_3. These advances were made by optimizing the surface density of the chemistry that interacts with the target gas. This paves the way for highly sensitive, small, lightweight, low power gas sensors for environmental monitoring and safety applications.

Liquid Crystal Sensing

The defining property of nematic liquid crystals is that the molecules have no positional order (like liquids) but have long-range directional order (like crystals). This allows changes in alignment at the surface to be to be communicated to the bulk of the liquid crystal; actions of a few molecules at the surface are amplified to a passive visual readout.



Micro-pillared glass substrates are functionalized with reactive chemistries (red) that align the LCs (blue) in a homeotropic alignment (perpendicular to the substrate). When viewed through crossed polarizers, the LC sensor appears dark before exposure (left image). When the sensor is exposed to the target gas, the gas reacts with the surface chemistry, which no longer aligns the LC molecules. As a result, the LC molecules assume a planar orientation (parallel to the surface) and the sensor becomes bright (right image).

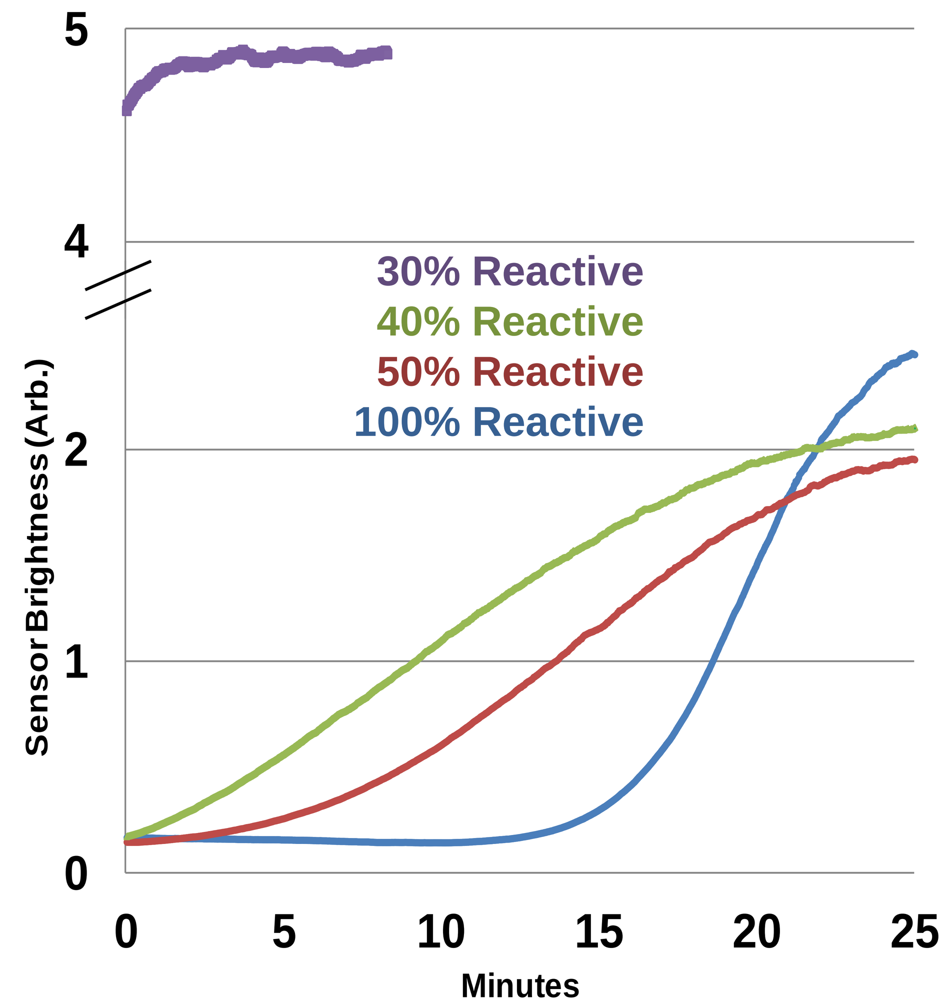


Sensors are fabricated as 5mm LC discs on glass chips.

Surface Optimization for Increased Sensitivity

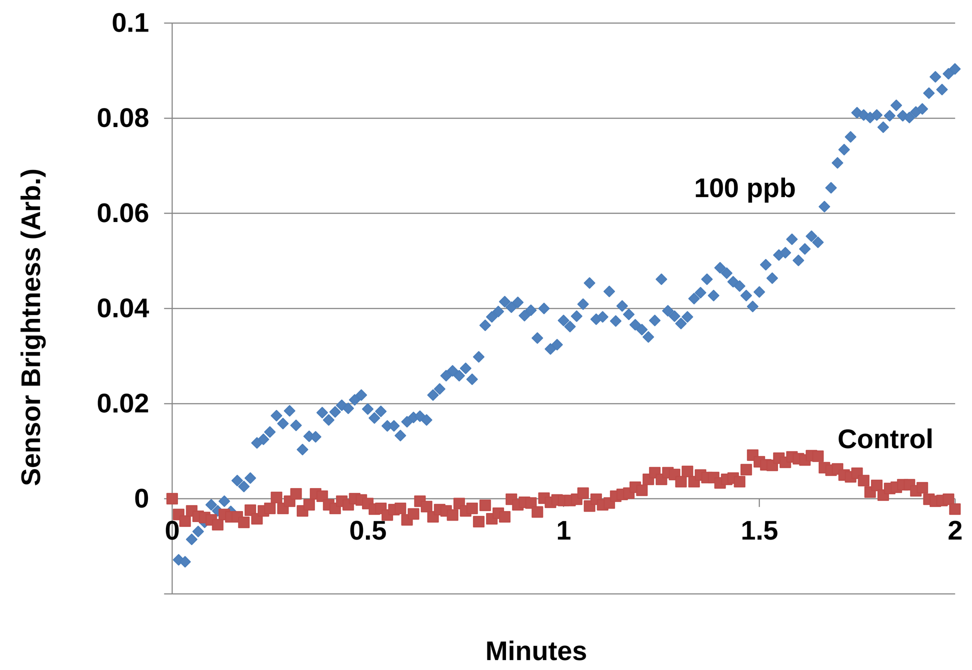
To achieve high sensitivity, the surface density of the detection chemistry must be optimized. We have demonstrated that using the minimum amount of reactive chemistry needed to attain initial alignment of the LC allows the target gas to have a rapid effect on disrupting alignment, providing increased sensitivity.

Nitrogen Dioxide



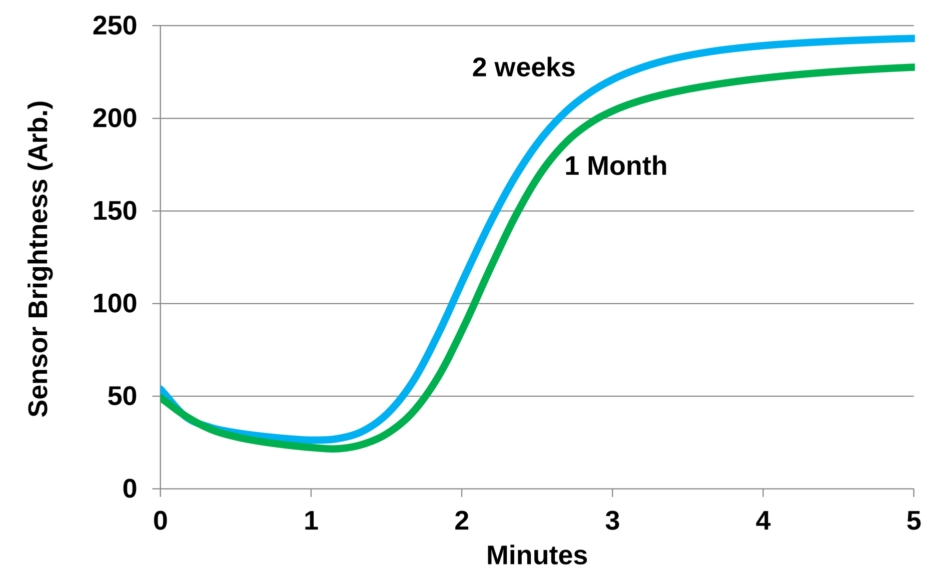
Effects of Surface Density

The density of surface binding sites impacts sensor responses to 1 ppm NO_2 at 45%RH. As the reactive chemistry is reduced, less influence is present to align the LC molecules, so the target gas more readily disrupts the alignment, generating a more sensitive response. Below a threshold level of reactive chemistry, in this case <30%, the LC molecules never align with the surface.



100 ppb NO_2 < 1 min

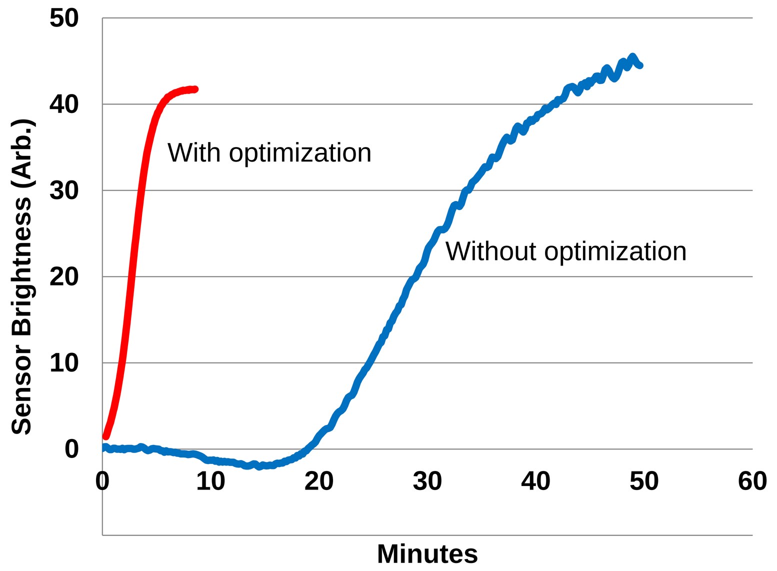
An NO_2 sensor with an optimized surface density of detection chemistry is capable of providing a measureable response to 100ppb NO_2 at 45%RH in less than 1 minute versus a 0 ppb NO_2 45%RH control.

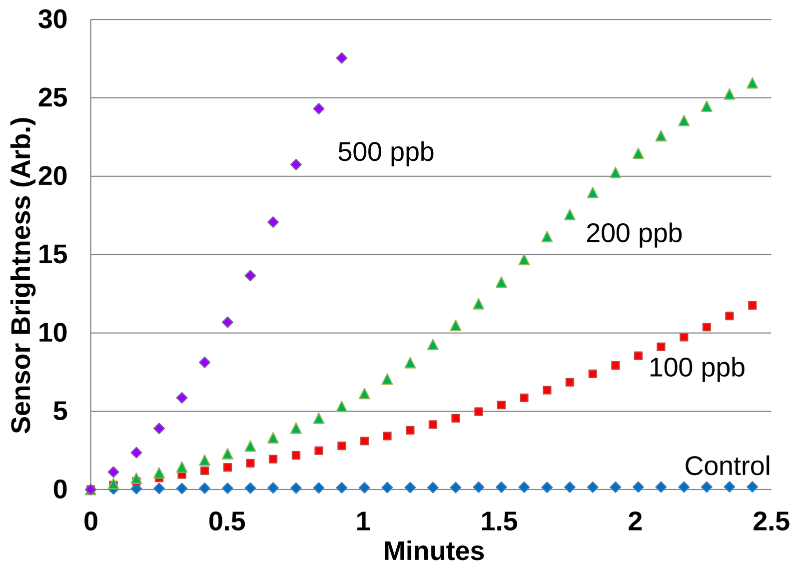


Stability

Before the surface density was optimized the stability of the detection chemistry was tested. Sensors were stored in sealed bags at room temperature for increasing amounts of time and then exposed to 30 ppm NO_2 60%RH. The response times are comparable demonstrating that the sensors are stable.

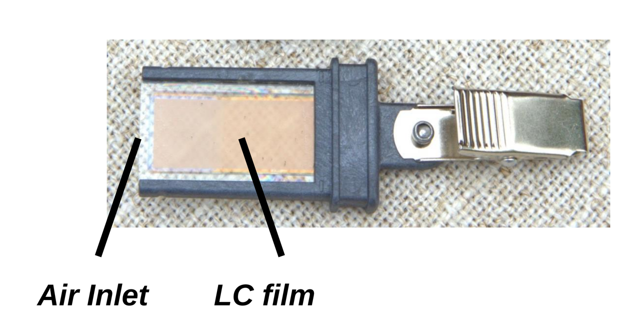
Hydrogen Sulfide

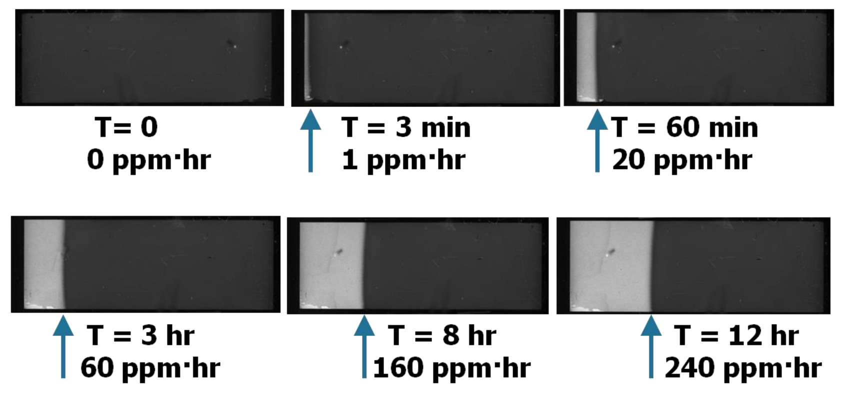




H_2S Sensors With Optimization

Left, an H_2S sensor with full surface density of detection chemistry takes significantly longer (>20 minutes) to respond to 100 ppb H_2S 45%RH than does an H_2S sensor with an optimized surface density of detection chemistry (<1 minute). Right, H_2S sensors with optimized surface density of detection chemistry provide measureable responses to 100 ppb H_2S 45%RH in less than 1 minute. Increasing concentrations give even faster responses. Response rates are a function of concentration, providing a means to quantify target gas concentration.

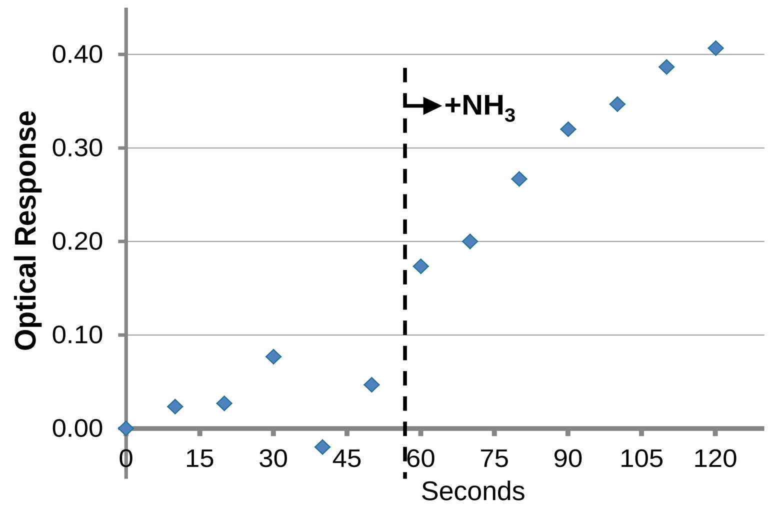




H_2S Dosimeter

This methodology can also be reformatted into a dosimeter for measuring H_2S concentrations over long periods of time.

Ammonia



100 ppb NH_3 < 1 min

NH_3 sensors with optimized surface density of detection chemistry provide measureable response to 100 ppb NH_3 45%RH within 1 minute after the gas is introduced.

Conclusions

Liquid crystal based sensors with optimized surface densities of detection chemistry are highly sensitive, lightweight and require little to no power for readout. These inexpensive sensors are also stable and require no calibration or maintenance.

Acknowledgements

We thank Nicholas Abbott, Jacob Hunter and Marco Bedolla (University of Wisconsin); and Ross Bemowski, Dan Pirsch, Matthew Gajeski and Anthony Moore (Platypus Technologies) for advice and assistance. This work was supported by US Army contract W911SR-11-C-0025, ARO contract W911NF-13-P-0030, and NIOSH Research Grant 1R21OH010116-01A1.

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