Supplementary

CQDs@NiO: An Efficient Tool for CH_4 Sensing

1. General Description

From an electronics point of view, the gas concentration sensor records changes in electrical resistance of an appropriately chosen material. Additional important aspects are (1) control of the temperature of the sensing material and (2) recording of the relative humidity and temperature of the environment.

A schematic of the used device is presented in Figure S1. It is a custom-made single-purpose data logger built from low-cost commercially available components, i.e., an Arduino micro-controller complemented with customized expansion shields. The aim was to develop an economic and user-friendly device with a performance that can, within its specified scope, compete with the performance of more costly professional solutions. The system was designed to support up to three gas-sensing shields and temperature control shields, each operated in parallel. It can also measure the ambient temperature and relative humidity in the gas chamber.

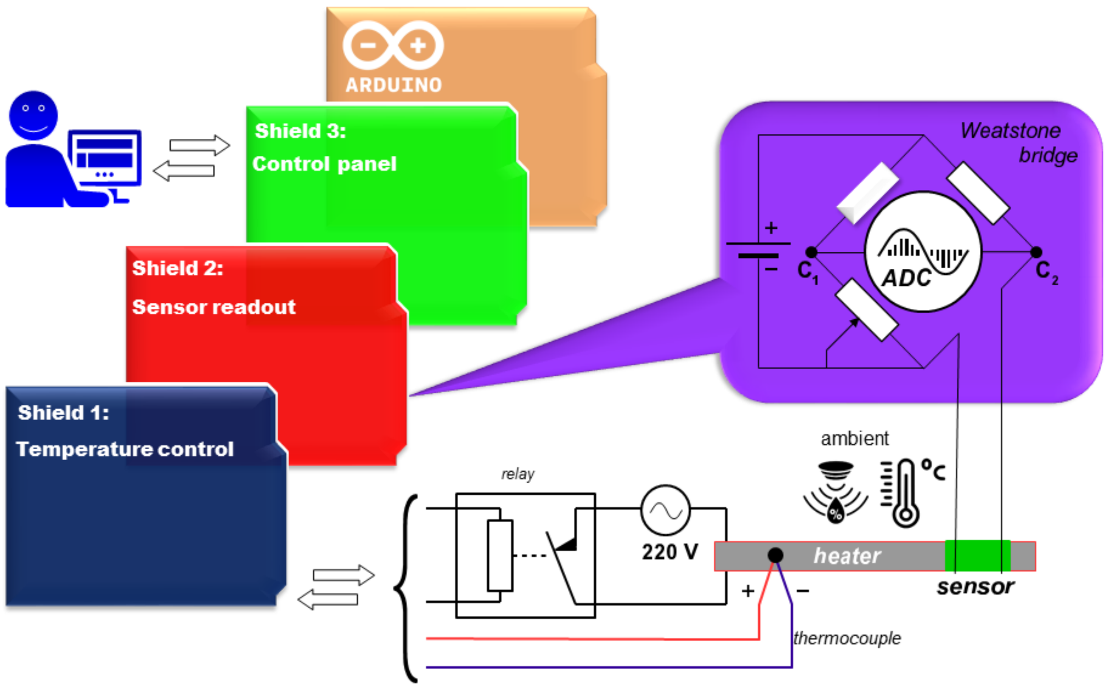

Figure S1. Schematic layout of the gas sensor measuring module. See text for details.

2. Components

2.1. Sensor Support

The gas-sensitive material is deposited near the tip of a 3.8 mm diameter, 60 mm long ceramic rod, which can be heated up to a temperature of 480 °C. It is made from the ceramic heating element (CXG A1324) of a temperature-controlled soldering iron (CXG-936D).

To record the temperature of the rod, the signal of the built-in thermocouple is digitized with a MAX31855 [1] breakout board operated at 5 V. It communicates with the Arduino microcontroller through the serial peripheral interface (SPI). The board can record a temperature in the range from −200 to +1350 °C with 0.25 °C increments. However, the thermocouple has a specified accuracy of ±2 to ±6 °C. Typically, we operate with steps of 10 °C.

The heater is directly powered by the mains (220 V) and controlled by the microcontroller through a solid-state relay [2]. Software on the microcontroller permits control over the hysteresis and heating power. The latter was implemented as a 2.5 Hz pulse-width modulation of the input power with a 20% to 100% duty cycle.

2.2. Gas Concentration and Resistance Measurement

The resistance measurement is performed with a 16-bit differential analog-to-digital converter (ADC), an ADS1115 [3], which was configured to work in a range of ±5 V. It features a programmable 1–8× input gain amplifier and an output sample rate between 8 and 860 Hz. It uses an I^2C interface for communication with the microcontroller, which is also used as source for the 5 V reference voltage.

For practical reasons, the resistance of the gas sensor was put inside a Weatstone bridge fed by the power source of the microcontroller. Here, we note that the resistance of the sensor is generally high (kΩ to MΩ range) and such a set-up is not strictly necessary. However, it does provide a flexible option to optimize the working voltage range of the experimental set-up for wide gas-sensor resistances and, thus, to optimize the resolution of the ADC with the aid of the programmable gain controller.

The ADS1115 features a four-channel input. In the default mode, the board is configured to perform a differential measurement between channels 1 and 2 (see Figure S1). The remaining channels can be activated by software to either sample the signal of an LM35DZ [4] temperature sensor and/or sample the output of commercially available gas sensors of the MQ type [5]. Since the input channels of the ADC are multiplexed, this reduces the maximum sampling rate of the device. However, it is possible to put up to three ADS1115 shields in parallel.

3. Ambient Sensor

The module features an input for a DHT22 [6] to measure the relative humidity and temperature close to the gas sensor. It permits measurements of the relative humidity in a range from 0–100% with a typical accuracy of 2%. The temperature can be recorded in a range between −40 and +80 °C. Measurements can be recorded with a rate up to 0.5 Hz.
For reference, the user interface is also equipped with an HTU21D [7] relative humidity and temperature sensor. Unlike the DHT22 sensor, this device is mounted close to the microcontroller, which makes it more difficult to position inside the gas chamber.

4. Microcontroller and User Interface

The microcontroller is an Arduino Uno R3 [8], configured as a data logger. Long-term persistent memory is provided with a DS3231 precision clock and memory module. It features remote control through an HC-06 Bluetooth module. Measurement data can be stored on a local micro SD card.

Measurements can be controlled through the USB interface of the Arduino microcontroller or using a Bluetooth-enabled android device. These channels can also be used to obtain real-time measured data. Additionally, there is a user interface such that it can be operated standalone. It permits basic functions such control of the sensor temperature, calibration of the Wheatstone bridge and the data-recording frequency (≤10 Hz), and triggering of measuring sequences that are stored in separate files on the SD card.

5. Sensor Performance

The reproducibility of the 1%CQDs@NiO-based sensor measurements was probed, and is the results are reported in Figure S2.

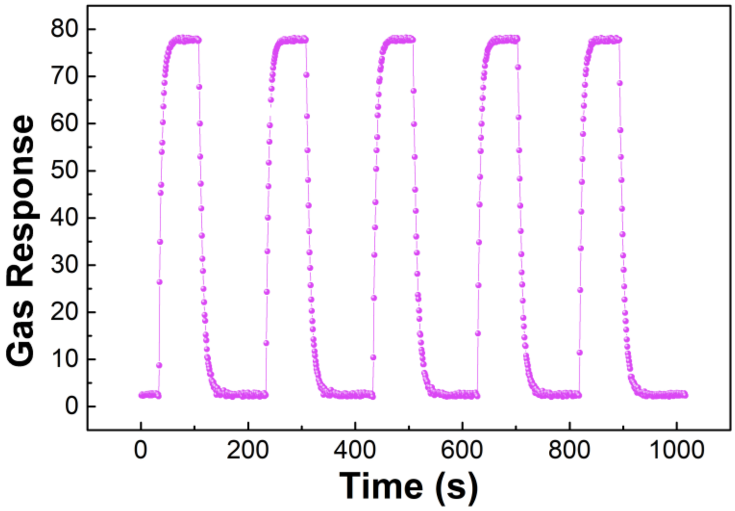

Figure 2. Reproducibility of CH_4 detection using the1%CQDs@NiO sensor at 30 ppm.

References

1. MAX31855 datasheet: https://datasheets.maximintegrated.com/en/ds/MAX31855.pdf
2. G3MB datasheet: https://www.openhacks.com/uploadsproductos/g3mb-ssr-datasheet.pdf
3. ADS1115 datasheet: http://www.ti.com/lit/ds/symlink/ads1115.pdf
4. LM35 datasheet: http://www.ti.com/lit/ds/symlink/lm35.pdf
5. MQ Gas sensors: https://playground.arduino.cc/Main/MQGasSensors
6. DHT22 digitial relative humidity and temperature sensor datasheet: https://cdn-shop.adafruit.com/datasheets/Digital+humidity+and+temperature+sensor+AM2302.pdf
7. HTU21D relative humidity and temperature sensor: https://e2e.ti.com/cfs-file/__key/communityserver-discussions-components-files/171/1899_5F00_HTU21D_5F00_chip_5F00_datasheet.pdf&usg=AOvVaw2IqvW08nNMswPL7Z7foEb3
8. Arduino Uno R3 datasheet: https://www.farnell.com/datasheets/1682209.pdf