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MOFs for the Sensitive Detection of Ammonia: Deployment of fcu-MOF Thin-Films as Effective Chemical Capacitive Sensors.

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ABSTRACT: This work reports on the fabrication and deployment of a select metal-organic framework (MOF) thin film as an advanced chemical capacitive sensor for the sensing/detection of ammonia (NH₃) at room temperature. Namely, the MOF thin film sensing layer consists of a rare-earth (RE) MOF (RE-**fcu**-MOF) deposited on a capacitive interdigitated electrode (IDE). Purposefully, the chemically stable naphthalene-based RE-**fcu**-MOF (NDC-Y-**fcu**-MOF) was elected and prepared/arranged as a thin film on a pre-functionalized capacitive IDE via the solvothermal growth method. Unlike earlier realizations, the fabricated MOF-based sensor showed a notable detection sensitivity for NH₃ at concentrations down to 1 ppm, with a detection limit appraised to be around 100 ppb (at room temperature) even in the presence of humidity and/or CO₂. Distinctly, the NDC-Y-**fcu**-MOF based sensor exhibited the required stability to NH₃, in contrast to other reported MOFs, and a remarkable detection selectivity towards NH₃ vs. CH₄, NO₂, H₂ and C₇H₈. The NDC-Y-**fcu**-MOF based sensor exhibited excellent performance for sensing ammonia for simulated breathing system in the presence of the mixture of carbon dioxide and/or humidity (water vapor), with no major alteration in the detection signal.

Keywords: MOFs, Sensing, Ammonia, Capacitive sensors, thin films.

Our ecosystem comprises various gases/vapors in a relatively definite concentrations, generated as result of unceasing volcanic eruptions that overcame our planet, including greenhouse gases (e.g. water vapor, methane, carbon dioxide) and various other harmful gases such as carbon monoxide and ammonia.¹ Nonetheless, today the concentration of ammonia (NH₃) in the atmosphere is increasing as a result of direct or indirect human activities. Manifestly, the global emission of NH₃ has almost doubled in the last 40 years, from 25 million tons in the 1970's to approximately 50 million tons in recent years.²⁻⁵ Perceptibly, the non-controlled release/increase of NH₃ in our atmosphere represents a serious threat to the suitability of our ecosystem, e.g. promoting unwarranted particulate formation, climate change with multiple associate health side effects.³

Recognizably, three major sources contribute to the release of NH₃ in the atmosphere. The first is atmospheric deposition, which

mainly entails the direct deposition of ammonium and nitrate salts via their addition to the soil in the form of dissolved dust or particulates in rain water.⁶ The second source is nitrification by bacterial nitrogen fixation, which is the result of certain bacteria activity through which they bind nitrogen and then release the excess ammonia into the atmosphere.⁷ The third source is associated to the combustion of fossil fuels in both chemical industries and transport sectors.¹

The ever increasing production of ammonia necessitates: i) in the long term, the development of sustainable technologies limiting the over production/release ammonia, ii) immediate deployment of the necessary means to remediate excess ammonia and critically derive tools to prevent over-exposure to ammonia and in a timely-manner prevent its potential harm by early sensing. Decisively, the effective detection/sensing of NH₃ is essential in a variety of technologies/areas, including automotive and environmental sectors, chemical industries, and medical diagnostics.^{1,8} It is to be noted that the human nose fails to detect the unforeseen exposure to low-concentration of ammonia, but unbearably senses effectively the presence of ammonia in a relatively high concentrations due to its very penetrating associated smell. Certainly, the detection of ammonia at low concentrations is critical and in some instances with very high sensitivity/quantified at ultra-low concentrations below parts per billion (ppb) in the air, as required in many fields of applications like for example, in automotive industry (measure NH₃ emission from vehicles, passenger cabinet air control and detection of NH₃ slip) and in chemical industries as leakage alarm.^{8,9}

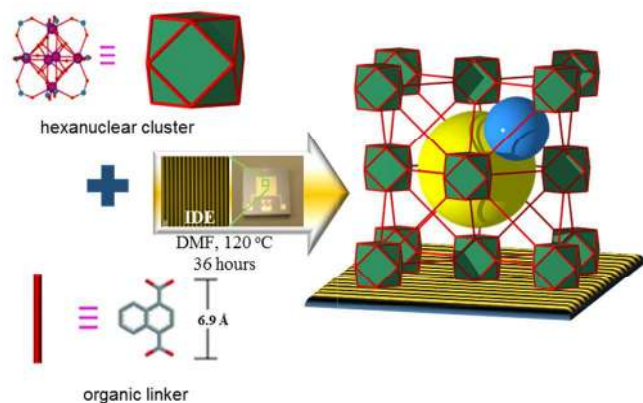
Nowadays, various approaches were deployed to detect/sense different levels of ammonia in various contexts, as described in the open literature.^{1,8} Namely, a variety of sensors are used in the automobile exhaust pipes for measuring the resultant ammonia, at ultra-low concentration levels, and monitoring its subsequent release to the ambient environment. It is to be noted that the most frequently used techniques in commercial ammonia detectors are metal-oxide gas sensors,¹⁰⁻¹⁴ catalytic ammonia detectors,^{15,16} conducting polymer ammonia analyzers and optical ammonia detection methods.¹⁷⁻²⁰ For example, Nayak *et al.* reported a detection of 400 ppm of ammonia at 300°C using mixed metal oxide WO₃-SnO₂ hierarchical nanostructured materials.²¹ Polyaniline nanoparticles were used to detect ammonia down to 1 ppm at 80°C.²² Aubrecht *et al.* developed an optical method for the detection of ammonia, based on the absorption of evanescent waves by

organometallic reagents, permitting detection at lower ammonia levels of approximately 30 ppm.²³ Yavari *et al.* reported a detection of ammonia at 20 ppm by employing continuous nano-sheets of graphene foam.²⁴ Attractively, Duy *et al.* reported a 5 ppm ammonia detection at room temperature using reduced graphene oxide (RGO) films.²⁵

Nonetheless, these different types of sensors, which have shown good performance, suffer from some drawbacks associated to their composition (e.g., the metal-oxide sensors lack the desired selectivity to a specific gas) and to their concomitant high operation temperature (e.g., in relation to WO₃, which has the lowest ammonia detection down to 1 ppm at an elevated temperature of over 400°C).¹ In the case of catalytic detectors, the lower detection limit is normally in the low-ppm range and their accuracy is restricted.¹⁵ For conducting polymer sensors, the irreversible reaction with NH₃ results in an increase in the mass of the polymer film, causing the sensitivity of the sensor to decay with continuous exposure to NH₃.¹⁷

Sensors based on interdigitated electrodes (IDEs) have been gaining more attention in recent years, due to the interesting advantages that they offer over other types of sensors.²⁶⁻²⁹ Capacitive chemical sensors constructed using IDEs offer the prospective to increase the IDE-contact area between the sensing material and the sensor circuitry.²⁶ In this case, the chemical sensing layer acts as the dielectric between two parallel IDE. As a result, a capacitive sensors reaction to stimuli is measured by a change in the sensors capacitance. In addition, the ability to miniaturize and lower the cost of IDE sensors offers potential to operate with a low volume of samples and promotes their plausible integration with electronics reasonably simpler. Particularly, IDEs offer a prospect for accessing the requisite low-power sensing platforms, such as lab-on- open chip applications.²⁷⁻³²

Metal-organic frameworks (MOFs), organic-inorganic hybrid crystalline porous materials, are composed of single metal ions or metal clusters linked by polytopic organic ligands. MOFs offer unique structural diversity in contrast to other porous materials, allowing the successful control of framework topology, porosity and functionality.³³⁻³⁵ MOFs have shown great potential for various applications pertaining to energy and environmental sustainability.³³⁻³⁶ Recently, MOFs have been applied as sensitive layers for various gas detection systems.³⁸⁻⁴⁰ It is to state that the use of a given MOF with adequate pore size/shape is not the sole requisite for efficient detection of hazardous gases/vapors. Additionally MOF should encompass suitable adsorption sites promoting specific interactions between the harmful adsorbates and the MOF host and subsequently present the desired sensing performance.³⁷



Scheme 1. Schematic representation of the optimized solvothermal preparation approach of naphthalene-based fcu-MOF (NDC-Y- fcu-MOF) thin film on IDE substrate.

For example, the presence of metal sites (i.e. coordinative unsaturated metal centers) or certain functionalization on the pore surface may enhance the sensing performance of MOFs for certain toxic compounds via coordination bonds, acid-base/electrostatic interactions. An efficient strategy for the synthesis of materials that preferentially sense a particular gas/vapor is thus to target a particular surface chemistry instead of optimizing the porosity alone.

Successful deployment of MOFs as reliable sensors for NH₃ has been hindered/delayed due to the scarcity of stable MOFs upon exposure to ammonia.³³ Distinctively, Dinca *et al.* recently reported two types of MOFs with sensing capabilities to NH₃ at 100°C based on changes in their associated luminescence, but with no noticeable NH₃ sensing selectivity at room temperature.⁴¹⁻⁴² Prominently, a rare earth (RE)-based MOF platform with **fcu** topology (RE-**fcu**-MOF), an isostructural MOF platform to the zirconium-based UiO-66, has been recently disclosed by Eddaoudi *et al.*³⁵⁻³⁷ The **fcu**-MOF platform was constructed using the molecular building block (MBB) approach,³⁶ where the 12-coordinated RE hexanuclear MBBs were connected by ditopic ligands, either hetero- or homofunctional and fluorinated or non-fluorinated linkers, in the presence a modulator/structural directing agent (SDA). Importantly, The application of reticular chemistry enabled the fine tuning of the triangular window, the sole entrance to the pore system, aperture size and functionality, by employing shorter and/or bulkier bridging organic ligands, and the subsequent attainment isoreticular RE-**fcu**-MOFs with fine-tuned adsorption/kinetic properties.³⁵⁻³⁷ In light of the unique adsorption properties of these RE-**fcu**-MOFs associated with a remarkable thermal and chemical stability,³⁵⁻³⁷ we deposited/grown them as thin films on capacitive IDE substrates and proven their usage as ultra-sensitive sensors for H₂S.³⁸ Rationally, we aimed to extend the prospective sensing capabilities of this unique RE-**fcu**-MOF platform to include other critical toxic gases such as NH₃.³⁵⁻³⁸ Markedly, the naphthalene (NDC) based RE-**fcu**-MOF (NDC-Y-**fcu**-MOF) showed exceptional sensing ability for ammonia.

EXPERIMENTAL SECTION

X-ray diffraction (XRD) measurements, were carried out at room temperature on a PANalyticalX'Pert PRO diffractometer 45kV, 40mA for CuK α ($\lambda = 1.5418 \text{ \AA}$), with a scan rate of 1.0° min⁻¹ and a step size of 0.01° in 2 θ . Scanning electron microscope (SEM) characterization was performed using an FEI Quanta 600 field emission SEM (accelerating voltage: 30kV)

Interdigitated electrodes (IDEs) were fabricated on a silicon wafer. Specifically, a 2 μm oxide layer was thermally grown for electrical isolation. A layer of 10 nm Ti and 300 nm Au was first deposited via physical vapor deposition (PVD) in an ESC reactive and metal sputter system. Photolithography was then utilized to pattern the electrodes. The metal layer was patterned by dry etching using the Oxford Instruments PlasmaLab System and the exposed oxide thickness was further verified using a Nanospec 6100 Reflectometer to ensure that the metal layer was properly etched. The IDEs were designed with 4 μm fingers and 5 μm spaces. Two Au wires and contact pads were patterned to perform the electrical measurements.

Thin films of the NDC-Y-**fcu**-MOFs were prepared solvothermally by heating a solution that containing 1, 4-naphthalene dicarboxylic acid (18.8 mg, 0.087 mmol), Y(NO₃)₃·6H₂O (33.4 mg, 0.087 mmol), 2-fluorobenzoic acid (97.5 mg, 0.70 mmol) DMF (3.0 mL), deionized H₂O (0.5 mL) and Nitric acid (0.4 ml of 4M solution in DMF), all combined in a 20 mL scintillation vial. A pre-functionalized IDE chip with the 11-mercaptoundecanol (MUD) self-assembled monolayer (SAM) was placed inside the vial, which was sealed and heated to 115°C for 48 h and then

cooled to room temperature. The IDE chip was collected and washed with approximately 10 mL of anhydrous DMF and immersed in 10 mL of ethanol for three days, during which the ethanol solution was refreshed three times daily.

Gas-sensing tests were performed using a fully automated measurement system with the LabVIEW.^{39,40} The coated sensor was placed inside the detection chamber and connected to the LCR meter to detect the capacitive change. The samples were first activated under vacuum for one hour; then the chamber was purged with pure nitrogen. Nitrogen gas was used as a carrier gas to dilute the NH₃ to desired concentrations; ranging from 1 to 100 ppm.

RESULTS AND DISCUSSION

A series of three isorecticular Y-**fcu**-MOFs, based on three ditopic ligands namely 2-fluoro-4-(1H-tetrazol-5-yl)benzoic acid (H₂FTZB), 1,4-naphth-alenedicarboxylate (1,4-NDC) and fumarate (fum),³⁵⁻³⁷ were tested by exposing the resultant powder material to NH₃ vapor at room temperature for various extent of time. The material stability was evaluated/checked using XRD and gas adsorption measurements after exposure to ammonia. The NDC-Y-**fcu**-MOF was observed to express a prominent stability as confirmed by the XRD studies, where no change in the pattern or decrease in the intensity of the peaks was observed (Figure 1a). Additionally, the N₂ adsorption isotherms confirmed the exceptional stability, as no noticeable changes were observed in the shape of the isotherms nor on the uptake amounts after NH₃ vapor exposure (Figures 1b).

Certainly, the IDE sensors were fabricated using clean room technologies, following the protocol reported previously.³⁹ Prior to the growth of the MOF thin film, the IDEs were firstly functionalized with an OH-terminated MUD SAM.⁴⁴⁻⁵⁰ By applying the optimized reaction conditions from the solvothermal growth method for the fabrication of the NDC-Y-**fcu**-MOF, we were successful in growing a homogenous NDC-Y-**fcu**-MOF thin film on the IDE support. The fabricated thin film crystallinity was confirmed using X-ray diffraction (XRD) measurements, as shown in Figure 2, which revealed a preferential orientation growth along the [111] direction.^{32, 44-48} The thin film morphology was characterized using SEM (see Figure 3), corroborating the formation of a thin film composed of a densely packed NDC-Y-**fcu**-MOF crystals. This approach resulted in the fabrication of the NDC-Y-**fcu**-MOF thin film with the desired preferential growth orientation, affording the readily exposure of the triangular windows of the NDC-Y-**fcu**-MOF for the prospective adsorption/inclusion of various guest molecules, such as ammonia the subject of this study.^{31, 34}

The successful growth of the NDC-Y-**fcu**-MOF crystals on the IDE substrate affords the ability to monitor and measure the changes in sensing film permittivity upon gas/vapor adsorption.^{38,39} Appropriately, we investigated the sensing properties of NDC-Y-**fcu**-MOF thin film on capacitive IDEs for NH₃ and various other gases/vapors, including methane (CH₄), propane (C₃H₈), nitrogen dioxide (NO₂), hydrogen (H₂) and toluene (C₇H₈). The gas sensing tests were performed using a fully automated measurement system with the LabVIEW.³⁹ The coated sensor was placed inside the detection chamber and connected to the LCR meter (E4980A) to detect the capacitive change. The samples were first activated under vacuum for one hour; the chamber was later purged with pure nitrogen. Nitrogen gas was used as a carrier gas to dilute the NH₃ to the desired concentration.

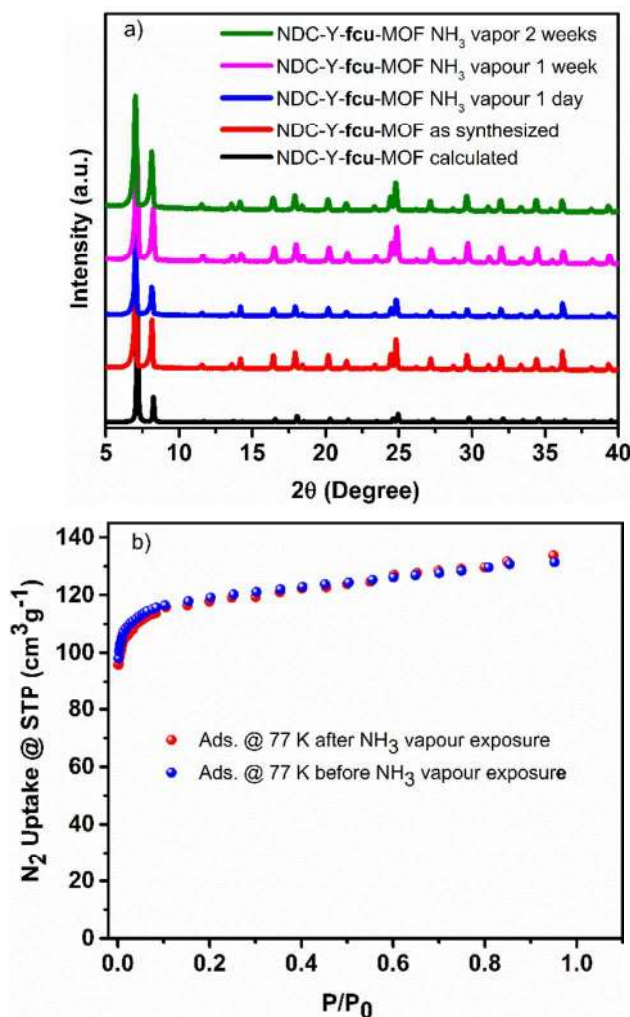


Figure 1. (a) X-ray diffraction (XRD) patterns of NDC-Y-**fcu**-MOF before (black) and after different times of exposure to NH₃ vapor. (b) N₂ sorption isotherms for NDC-Y-**fcu**-MOF before (blue) and after (red) exposure to NH₃ vapor for 14 days. Encouraged by the evident chemical stability of the NDC-Y-**fcu**-MOF and its presumed maintained structure integrity in the presence of NH₃, we aspired the fabrication/deposition of the NDC-Y-**fcu**-MOF as a thin film to act as the sensing layer on capacitive IDEs (Scheme 1).³⁵⁻³⁹

As depicted in Figure 4, the NDC-Y-**fcu**-MOF sensor was able to detect NH₃ at range from 1 to 100 ppm with a linear response (see Figure 4 inset), with a detection limit of 92 ppb, which was calculated based on the root-mean-square deviation method.⁵¹ The response time of our sensor, which is limited by the gas chamber size, is estimated to be around 250 seconds and be regarded good when compared to other sensors.^{24,43}

The stability of the NDC-Y-**fcu**-MOF capacitive sensor for NH₃ detection at room temperature was demonstrated using reproducibility tests, through which the performance of the sensor for detecting two concentrations of NH₃, namely 10 and 25 ppm, over a testing period of more than two weeks (Figure 5). Clearly, the results showed that the detections levels were steady/stable and uniform, with a negligible variation over the range of various cycles for the tested period of time, attesting to the stability and durability of the NDC-Y-**fcu**-MOF capacitive sensor for NH₃ over this range of tested concentrations.

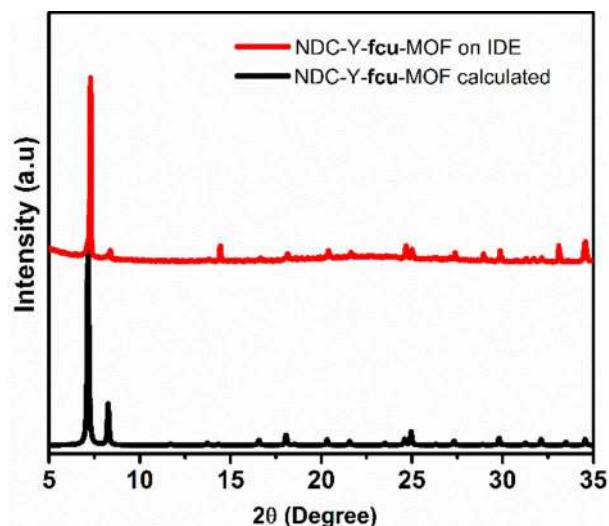


Figure 2. X-ray diffraction (XRD) patterns of NDC-Y-fcu-MOF, (black) calculated and (red) thin film grown on the IDE substrate.

To determine the effect of the relative humidity (RH) over the performance of our sensor, the response behavior of the NDC-Y-fcu-MOF thin film sensor was recorded upon exposure to 10 and 25 ppm of NH_3 , respectively under different RH levels and at room temperature (Figure 6). The results corroborate the performance of the NDC-Y-fcu-MOF sensor response within different RH levels ranging from 5–85 %, affirming the response of the sensor is stable and unchanged up to 30% RH as a result of the strong affinity of the NDC-Y-fcu-MOF sensor to NH_3 and the plausible displacement of the water molecules by NH_3 . However with increasing the RH levels above 30 %, we observe a relatively small increase with the sensor response, which may be attributed to the dissolution of more NH_3 molecules into physisorbed water on the MOF sensing layer. A similar behavior is observed in other ammonia and gas sensors.^{25,52,53}

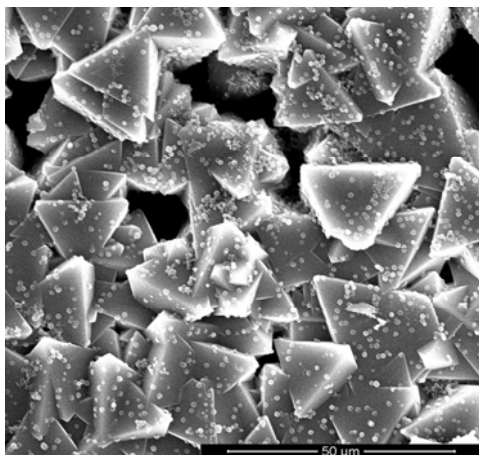


Figure 3. Top view SEM image of the NDC-Y-fcu-MOF thin film grown on the IDE substrate.

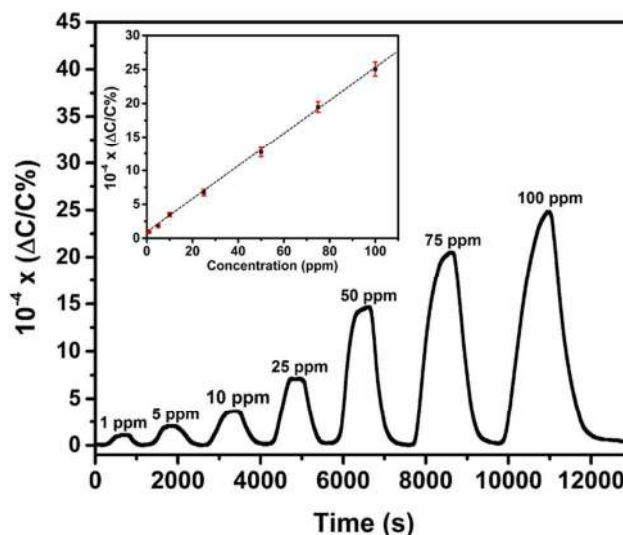


Figure 4. Detection of NH_3 in different ranges of ppm concentrations: from (1–100 ppm). Inset: Linear response for the NDC-Y-fcu-MOF in the corresponding range with error bars depicted in red.

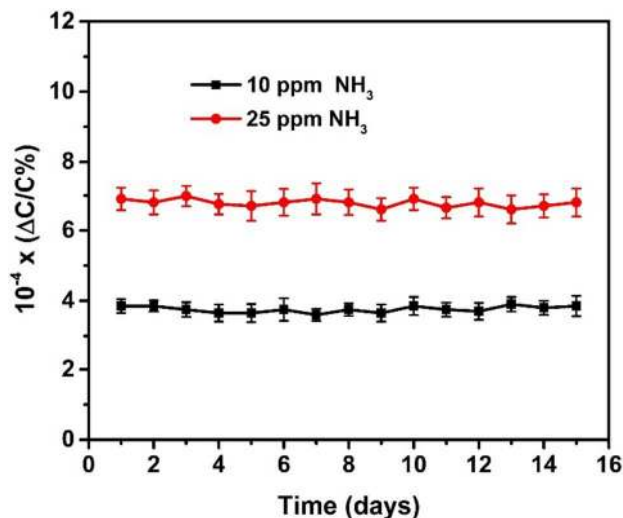


Figure 5. Stability performance for Y-NDC-fcu-MOF capacitive sensor upon exposure to 10 and 25 ppm of NH_3 over a 15-days' time period.

The temperature (T) dependence on NH_3 sensitivity for our NDC-Y-fcu-MOF capacitive sensor was investigated up to 80 °C, as shown in Figure 7, where a decrease in the sensitivity with the increase of the NDC-Y-fcu-MOF sensitive layer temperature was observed. The best sensitivity was obtained at room temperature, and shown to be lessened with the increase of temperature from 22 °C to 80 °C. This drop in the sensitivity response of the sensor can be attributed to the reduced sorption/interaction capability of the active sites in the NDC-Y-fcu-MOF capacitive sensor at relatively elevated temperatures. The adsorption/interaction of the gas in the sensing film strongly decreases with the temperature, reducing thus the capacitance shift. This observed behavior is in good agreement with other reported gas sensors.^{51, 54,55}

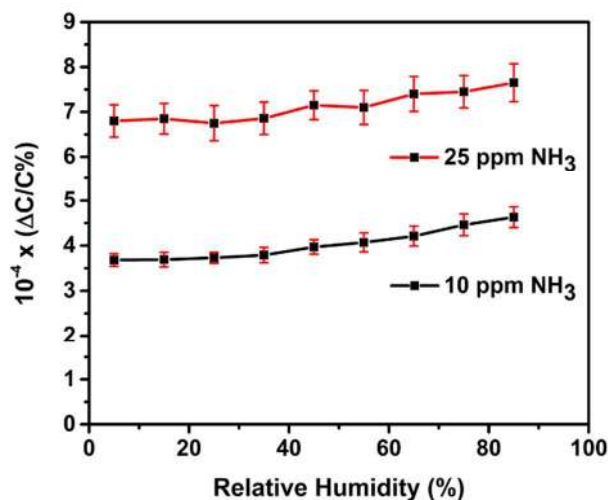


Figure 6. Stability of ammonia detection for Y-NDC-fcu-MOF upon exposure to 10 and 25 ppm of NH₃ at variable relative humidity (RH) %.

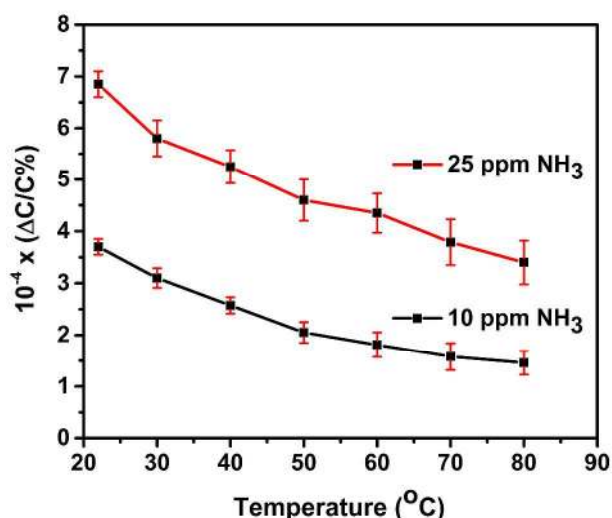


Figure 7. Stability of ammonia detection for Y-NDC-fcu-MOF upon exposure to 10 and 25 ppm of NH₃ at variable under different temperatures.

Appealingly, as depicted in Figure 8a, the NDC-Y-fcu-MOF proved to express excellent selectivity for NH₃ in the presence of other tested gases/vapors, although a slight cross sensitivity with NH₃ was observed in cases of NO₂, CH₄, and C₇H₈. As shown in Figure 8a, the response signal of the NDC-Y-fcu-MOF to NH₃ was nearly four-fold the corresponding signal for NO₂, and noticeably negligible signals were observed for the other evaluated gases and vapors (e.g., CH₄, H₂, and C₇H₈). The observed enhanced selectivity of NH₃ over CH₄ and H₂ can be attributed to the insignificant adsorption of the CH₄ and H₂ molecules by the MOF due to the lack of any interaction between the MOF surface and the nonpolar and weakly interacting molecules. On the hand the selectivity of NH₃ over C₇H₈ and C₃H₈ is supported by the associated big size of these molecules, prohibiting their diffusion/passage through the triangular window of the evaluated fcu-MOF. It is to be noted that the triangular opening is the sole entrance/access to the fcu-MOF pore system. In this case the pore-aperture is not large enough to allow the gases/vapors to adsorb/diffuse into the pores without resistance. In addition, the C₇H₈ and C₃H₈ molecules do not have specific functionalities to promote interactions with the MOF.

On the other hand, the polar NH₃ and NO₂ molecules can easily be adsorbed by the MOF and interact with the MOF surface which encompasses polar hexanuclear moieties. The better selectivity of NH₃ over NO₂ can be attributed to the favorable interaction of NH₃ lone pairs with the unsaturated metal sites exposed on the MOF pore system. In addition H-bonding between the adsorbed NH₃ molecules can also help significant the adsorption of NH₃ and hence the better observed sensitivity. These aforementioned features are not available in the case of the NO₂ molecules and thus the less observed sensitivity for the evaluated fcu-MOF.

These results pinpoint the great sensing/selectivity of the NDC-Y-fcu-MOF for NH₃ even in the presence of other gases/vapors with different physical and chemical properties.^{56,57}

Comparatively and in order to bring to the fore the unique ammonia sensing performance of The NDC-Y-fcu-MOF, we assessed the sensing potential of distinct MOFs like HKUST-1, Cu(bdc)·xH₂O and ZIF-8 for ammonia down to 1 ppm under the same conditions. As clearly depicted in Figure 8b, the performance of the aforementioned other three MOFs was dramatically inferior to that of the NDC-Y-fcu-MOF. This observed poor performance is directly correlated to the degradation/low-stability of the evaluated MOF in the presence of ammonia, especially in the case of HKUST-1 and Cu(bdc)·xH₂O. Specifically as evidenced and depicted in Figure 8b, the detection signal for the NDC-Y-fcu-MOF is noticeably much higher (i.e., three times) than the signal for the other three tested MOFs, attesting to the distinctive high affinity of the NDC-Y-fcu-MOF for NH₃. Markedly, the noted sensing from the realized tests corroborate the stability of the NDC-Y-fcu-MOF as an effective ammonia sensor with superior NH₃ detection than the evaluated MOFs at room temperature, in accordance with the low NH₃ stability of the associated bulk MOFs like HKUST-1 and Cu(bdc)·xH₂O and the low NH₃ affinity for ZIF-8.⁵⁸ Comparing the performance of our NDC-Y-fcu-MOF capacitive sensor with the performance of other different sensors being applied in different fields, revealed that prominently, the NDC-Y-fcu-MOF offers the prospective to detect ammonia at room temperature and at a relatively low concentrations in contrast to the mixed metal oxide WO₃-SnO₂ hierarchical nanostructured material, necessitating a relatively higher temperature around 300°C for a detection limit of only about 400 ppm of ammonia.²¹ In addition, our MOF based sensor revealed a comparable detection concentration of 1 ppm as in the case of polyaniline nanoparticles, but at room temperature instead of 80°C.²² Moreover, our MOF based sensor performed better than optical detection method of ammonia, which is based on absorption of evanescent waves by organometallic reagent and was able to only detect down to 30 ppm.²³ Notably, Our NDC-Y-fcu-MOF based sensor performed equally in the same concentration range reported (which is about 1 ppm) recently for some MOFs by Dinca *et al.* but at room temperature instead of at 100 °C.^{41,42}

Encouraged by the Y-NDC-fcu-MOF distinctive ammonia sensing capabilities, we assessed the performance of this unique MOF sensor for the ammonia detection using cross-over sensitivity testes like in a simulated breathing system in the presence of a mixture of carbon dioxide (CO₂) and humidity.^{14,49} We have tested the Y-NDC-fcu-MOF capacitive sensor using two concentrations of NH₃ 1 and 10 ppm. Certainly the results as depicted in Figure 9, revealed the excellent performance of the NDC-Y-fcu-MOF sensing ammonia in the presence of the mixture of carbon dioxide and/or humidity (water vapor), with no major alteration in the detection signal being observed for both evaluated ammonia of 1 ppm and 10 ppm. Tests on CO₂ and water vapor separately, with same previous amounts, results not presented here, showed also very good stability. Remarkably, the stability of the NDC-Y-fcu-MOF sensor for NH₃ detection at room temperature was validated by performing reproducibility cycles (the inset of Figure 9),

evidently confirming that the detections levels were steady/stable and uniform over the range of various cycles.

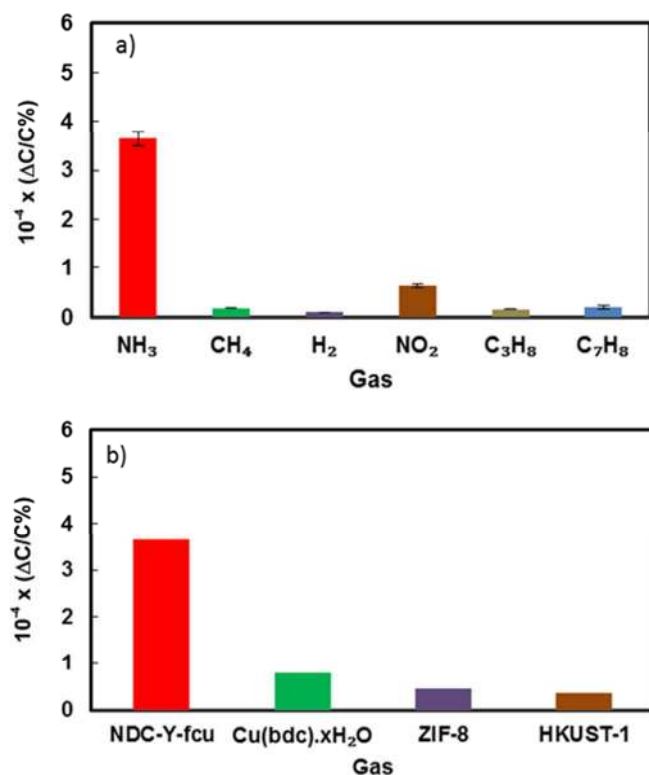


Figure 8. (a) Selectivity of the NDC-Y-fcu-MOF sensor to NH_3 with respect to CH_4 , H_2 , NO_2 , C_3H_8 and C_7H_8 at 1 ppm. (b) Selectivity of the NDC-Y-fcu-MOF sensor to NH_3 with respect to $\text{Cu}(\text{bdc}) \cdot x\text{H}_2\text{O}$, ZIF-8 and HKUST-1 .

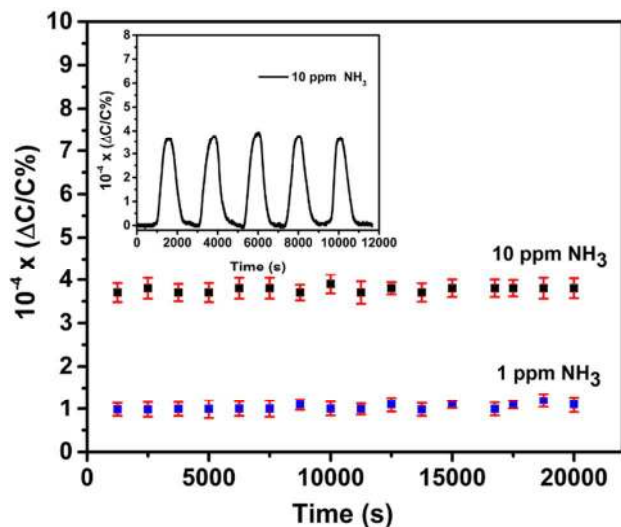


Figure 9. Stability of ammonia detection for Y-NDC-fcu-MOF at 1 ppm and 10 ppm in the presence of 5.3 $\text{CO}_2\%$ + 6.2% H_2O . Inset: reproducibility test of the sensor at 10 ppm of Ammonia

CONCLUSIONS

The performance of the NDC-Y-fcu-MOF as a sensing layer on a capacitive IDE sensor, for NH_3 detection at room temperature was successfully demonstrated. Principally, the NDC-Y-fcu-MOF offers a distinctive NH_3 detection down to concentrations down to around 1 ppm with a limit of detection of about 100 ppb. The stability of the NDC-Y-fcu-MOF sensor was affirmed and supported using different methods, corroborating its excellent chemical stability as compared to various other MOFs, e.g. ZIF-8 and $\text{Cu}(\text{bdc}) \cdot x\text{H}_2\text{O}$. Markedly, the NDC-Y-fcu-MOF distinct sensing prospective for ammonia was sustained with precision, even at relatively low concentration, in the presence of various gases and/or vapors such as water vapor, carbon dioxide nitrogen oxide, methane, hydrogen, and toluene. The presented NDC-Y-fcu-MOF exhibited a comparable stability with time and under variable humidity conditions compared to other reported sensors. The NDC-Y-fcu-MOF based sensor exhibited excellent performance for sensing ammonia for simulated breathing system, with no major alteration in the detection signal being observed. Prominently, the revealed distinctive and remarkable sensing selectivity of the NDC-Y-fcu-MOF for NH_3 paves the way for the deployment of MOFs as practical sensors for various prominent applications.

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Notes

The authors declare no competing financial interests.

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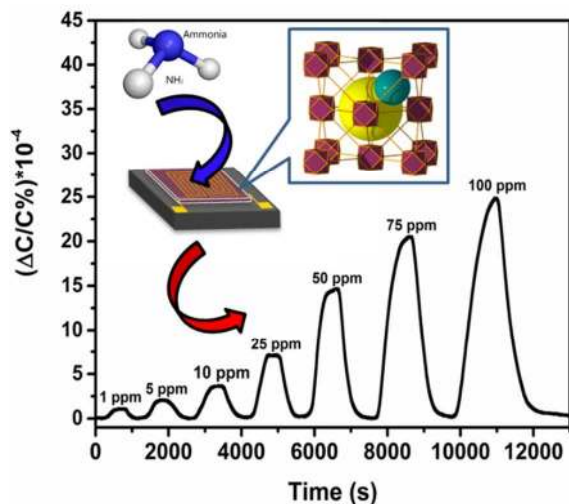
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“for TOC only”



This work reports on the fabrication of an advanced sensor using thin films of rare-earth based metal-organic frameworks (MOFs) for the detection of toxic gas, namely ammonia (NH₃) at room temperature. The NDC-Y-**fcu**-MOF sensor exhibits the highly desirable detection selectivity towards NH₃ vs. CH₄, NO₂, H₂ and C₇H₈ as well as an outstanding NH₃ sensing stability as compared to other reported MOFs.
