Design and Development of High-Performance Hydrogel Gas Sensors

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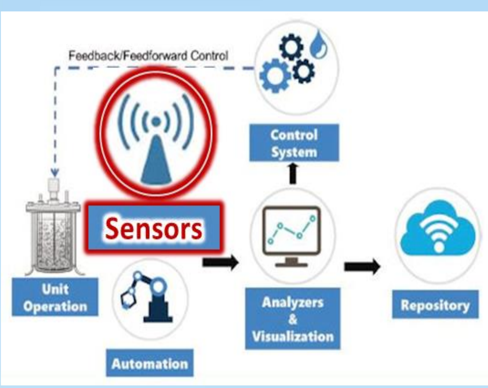
Abstract

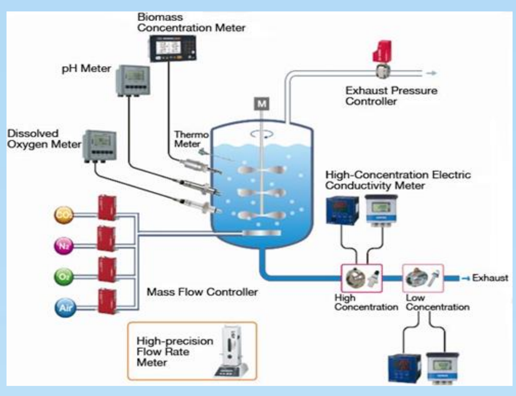
In order to achieve accurate monitoring of exhaust gas in bioreactor during biofabrication, this study presents a method for preparing a hydrogel containing dimethylamine and applies it to CO_2 detection at room temperature. By examining the structural characteristics and electrical response signals of the hydrogel, the CO_2 sensitivity mechanism of the dimethylamine-structured hydrogel is explored, providing guidance for the design and development of highly sensitive CO_2 sensors in room temperature environments. The results show that sensors made from the hydrogel material exhibit excellent CO_2 sensitivity at room temperature. Moreover, as the concentration of dimethylamine in the hydrogel solution increases, both the sensitivity and lifespan of the sensor are enhanced. This improvement is primarily due to the high selectivity of the dimethylamine structure in the hydrogel, which, with the assistance of water, can capture CO_2 gas molecules in the environment, thereby altering the hydrogel's conductivity. This study offers a novel approach for the design and development of CO_2 gas sensors with high sensitivity and long lifespan.

Introduction

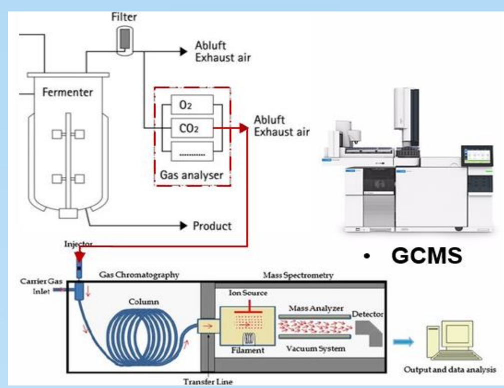
Background Accurate monitoring of exhaust gas in bioreactor during biofabrication



Bio-manufacturing

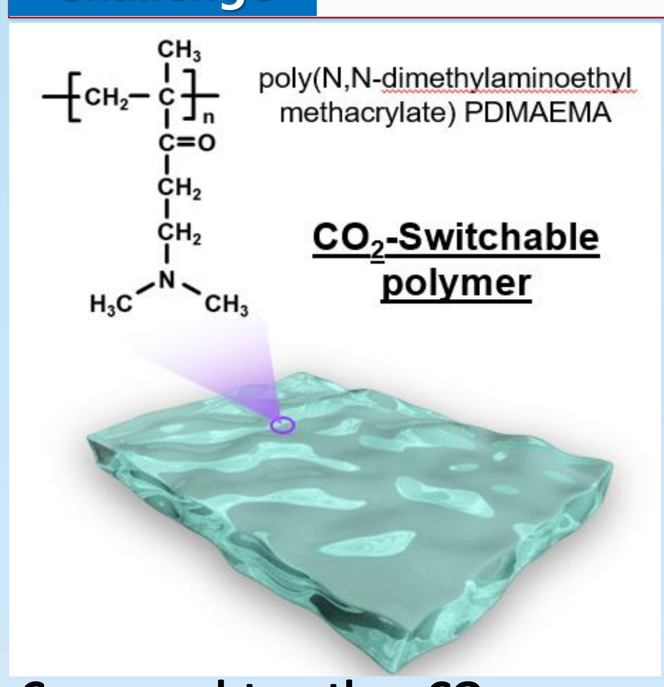


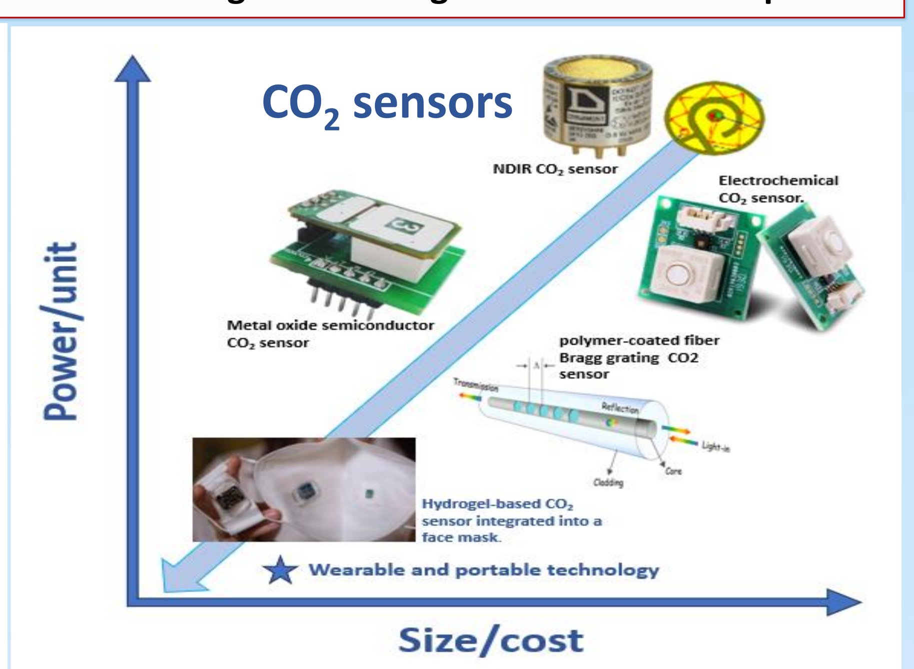
Process Monitoring



Emission Monitoring

Challenge Realize real-time online monitoring of exhaust gas in biofabrication process



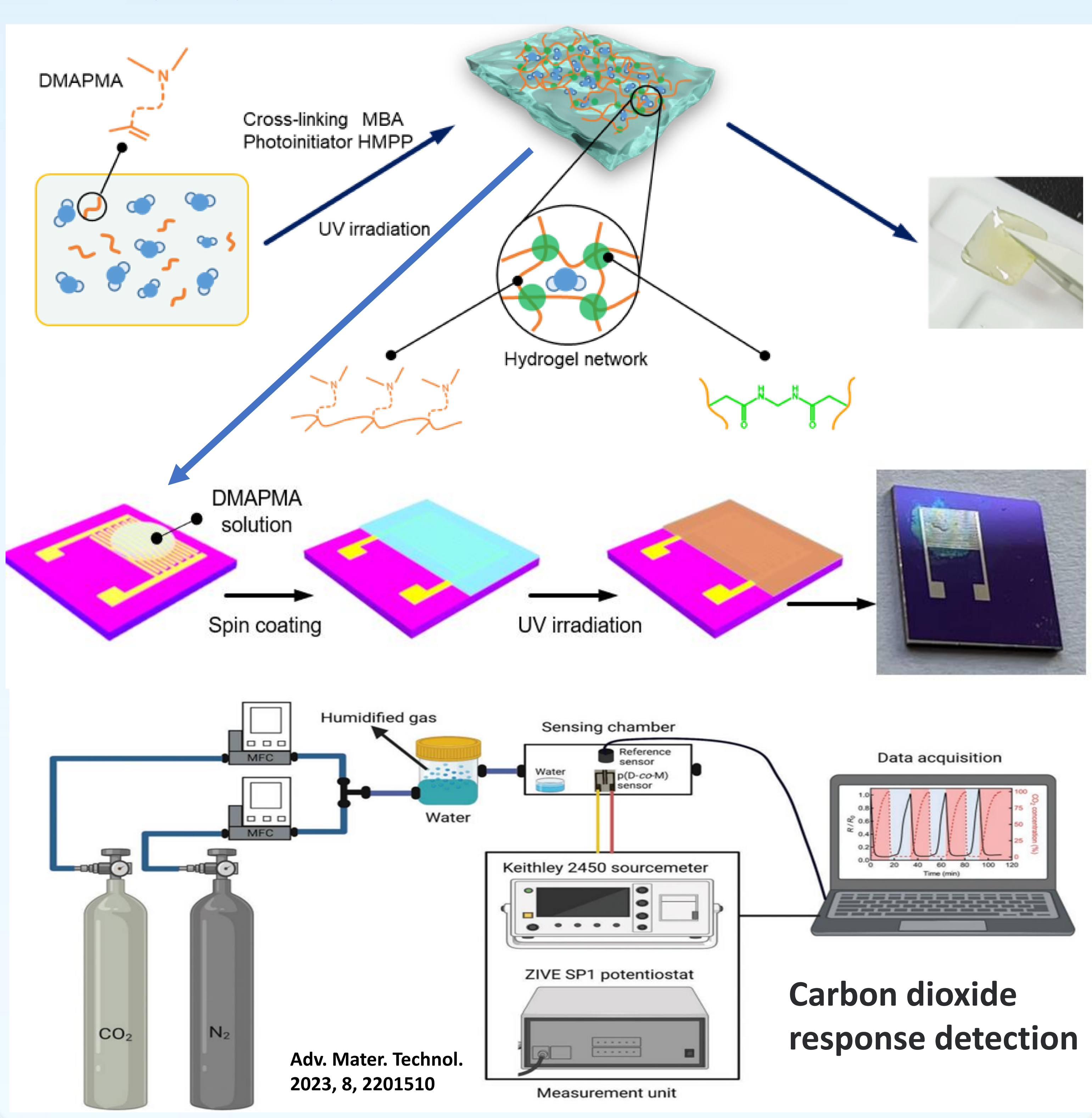


Compared to other CO_2 sensors, the hydrogel sensor with high-performance response has small device size and lower energy consumption, making it a promising choice for real-time online monitoring in biofabrication process.

Methods

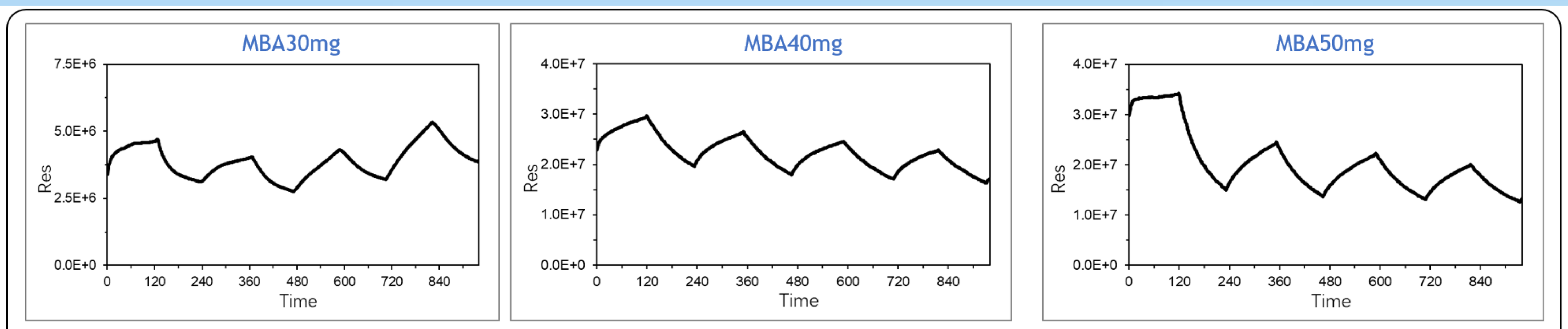
- **Reaserch steps**
  - Analysis of DMAPMA hydrogel sensing performance
    - Study on the response and selectivity of hydrogels to CO_2 molecules
    - The device design of sensors
  - Performance analysis of hydrogel sensor devices
    - Preparation of sensors
    - Sensor performance test

The materials for the preparation of hydrogel: DMAPMA, MBA, HMPP, deionized water.



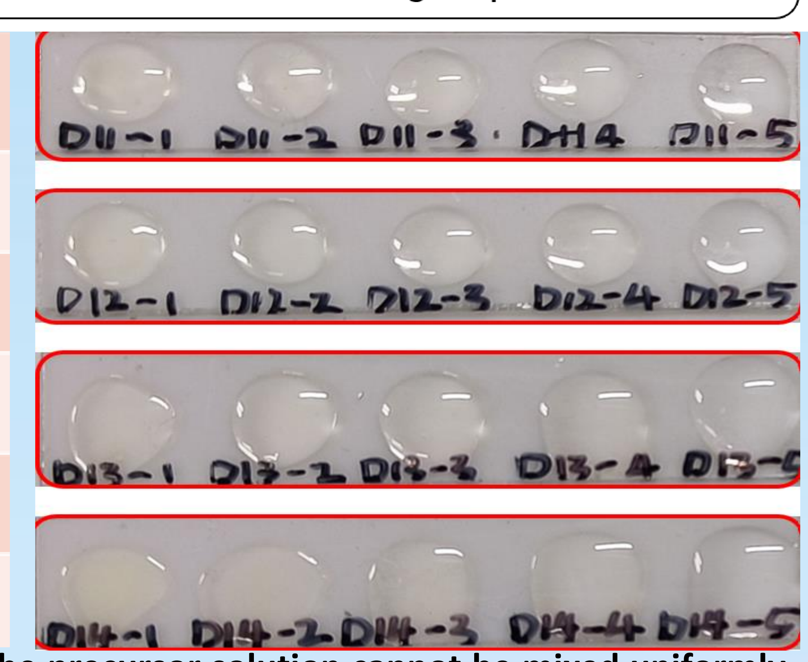
Results

The analysis of hydrogel polymerization

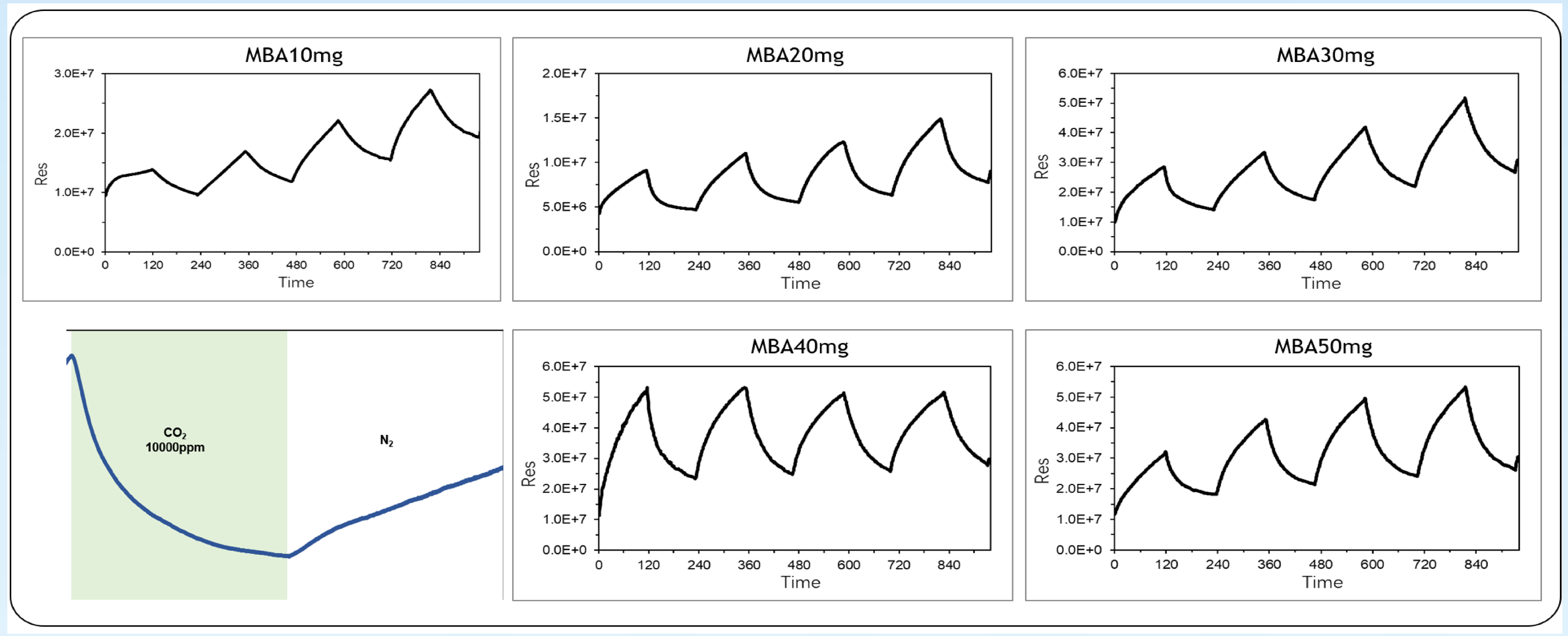


When the illumination time exceeds 10 minutes, the water content of the hydrogel decreases, the performance deteriorates, and the response curve does not return to the original peak

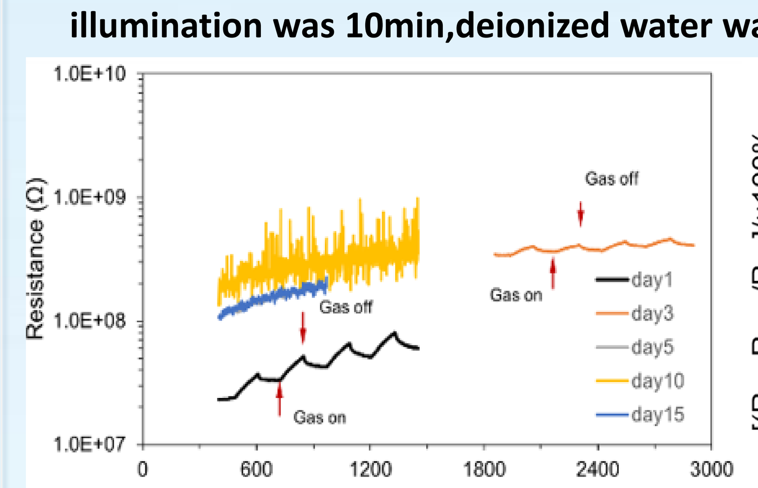
	DMAPMA(μl)	deionized water(μl)		MBA(mg)		HMPP(μl)		polymerization time(min)
A	100		1	10	1	5	1	5
B	200		2	20	2	10	2	10
C	300	1000	3	30	3	20	3	15
D	500		4	40	4	50	4	20
E	1000		5	50	5	100	5	30



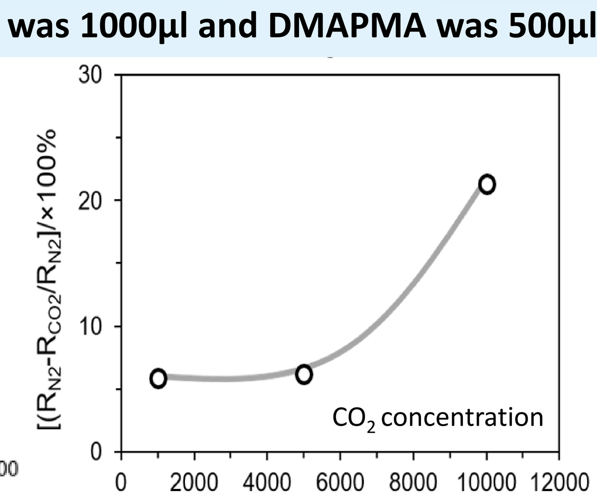
According to the experiments, when the volume of HMPP is ≥50μl, the precursor solution cannot be mixed uniformly, and when the mass of MBA is ≤10mg, the hydrogel does not polymerize. The most suitable illumination time is 10 minutes, less than 10 minutes of non-condensation, more than 10 minutes of hydrogel moisture reduction, resulting in poor device performance; The performance is directly related to the amount of DMAPMA and MBA.



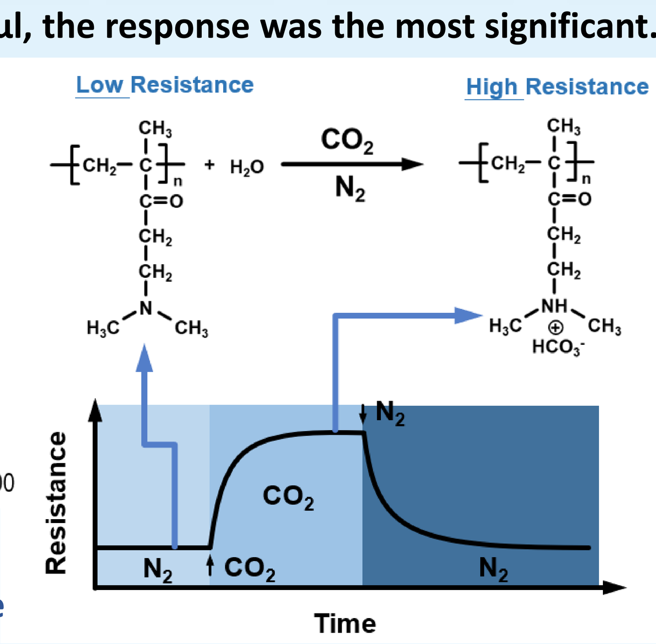
Nitrogen and carbon dioxide were injected alternately for 120s. When MBA was 40mg, HMPP was 20μl, illumination was 10min,deionized water was 1000μl and DMAPMA was 500μl, the response was the most significant.



Performance lifespan of hydrogel sensors



Response testing for different concentrations of carbon dioxide



The increase in DMAPMA's concentration in the hydrogel solution leads to a higher concentration and total amount of polymers, which helps to improve the sensor's response to carbon dioxide and extends the sensor's lifespan. In the presence of water molecules, CO_2 molecules can undergo a reversible adsorption-desorption reaction with organic molecules containing a dimethylamine structure, demonstrating specific CO_2 molecular recognition capability.

Conclusion

1.When the volume of HMPP is below 50μl and the amounts of MBA are above 10mg, the hydrogel polymerization can achieve great performance under 10 minutes of ultraviolet light.

2.With the volume of HMPP and deionized water kept constant at 20μL and 1000μL, respectively, the sensitivity is most pronounced when MBA is 40mg and DMAPMA is 500μL.

3.As the concentration of DMAPMA increases, the lifespan of the hydrogel carbon dioxide sensor significantly improves.