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Highly Sensitive Ammonia Gas Detection with a Silica Toroid Microcavity Packaged in a Box

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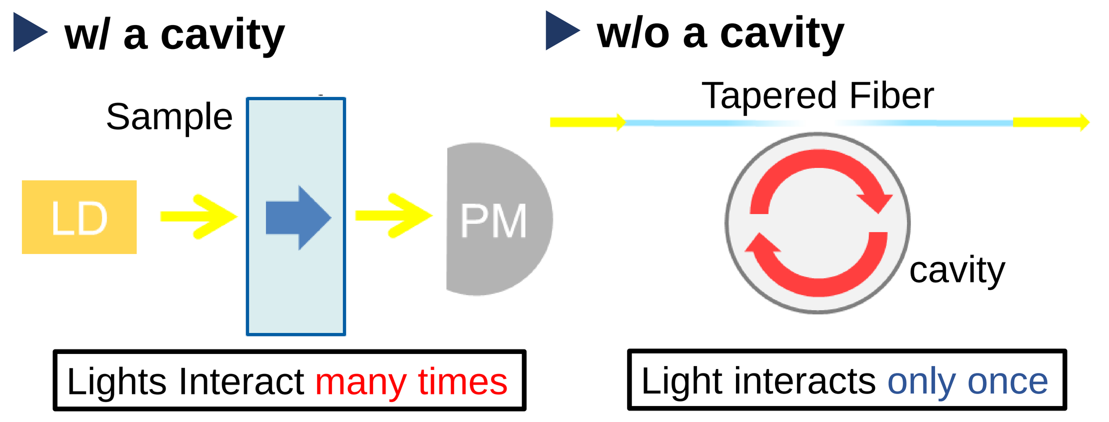
Abstract

We demonstrate highly sensitive ammonia gas (NH_3) detection with a packaged silica toroid microcavity coated with 20-PAA/PAH multilayers. Our experiment shows that a detection sensitivity of 450 ppb is achieved.

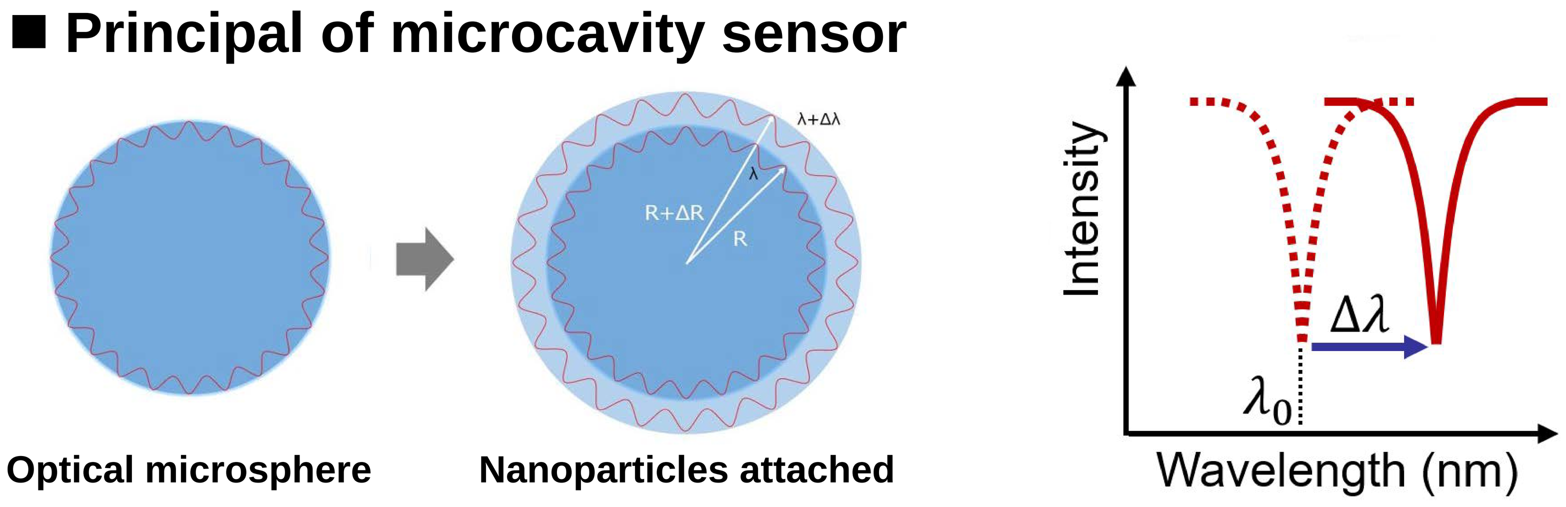
Background：Sensing w/ a WGM microcavity

- **Can realize downsizing and high sensitivity by using microcavity**



✓ Small size & sensitivity CANNOT coexist
✓ Small size & sensitivity CAN coexist

- **Principal of microcavity sensor**



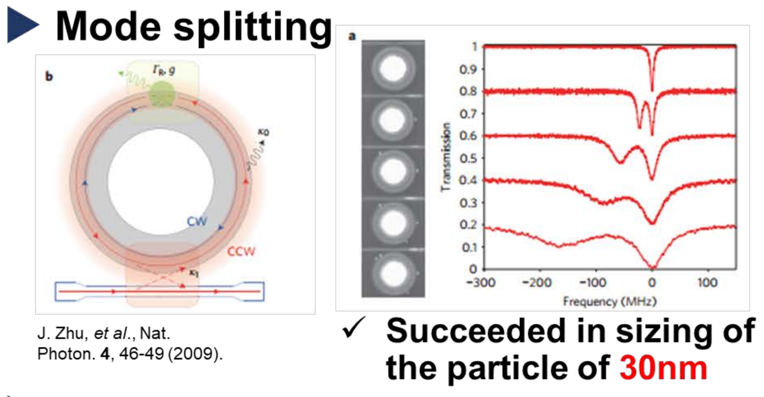
✓ **Cavity resonance shifts when nanoparticles attach to a microcavity**

Background：Previous research

- **There has been little progress with respect to practical use because it's hard to align a cavity and a tapered optical fiber**

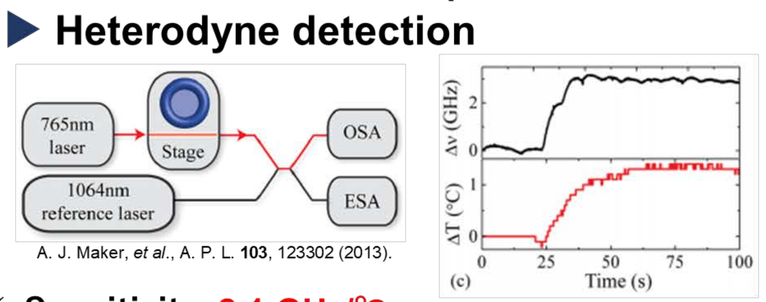
Highly sensitive

▶ Mode splitting



✓ Succeeded in sizing of the particle of 30nm

▶ Heterodyne detection



✓ Sensitivity: 2.1 GHz/℃
(exceeds wavelength shift by over 3 orders of magnitude.)

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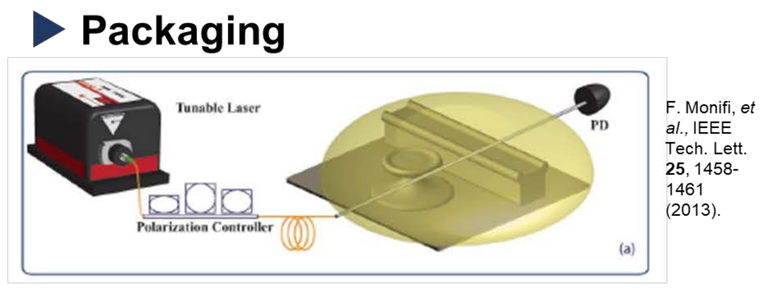
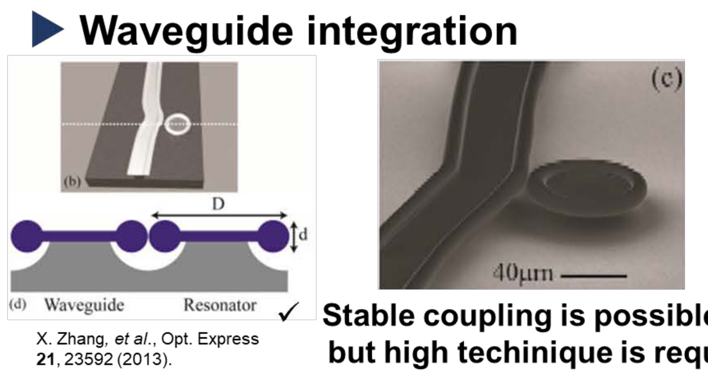
Practical use

▶ Packaging



✓ Cannot be used for gas sensor, it's difficult to apply it to particle sensing.

▶ Waveguide integration

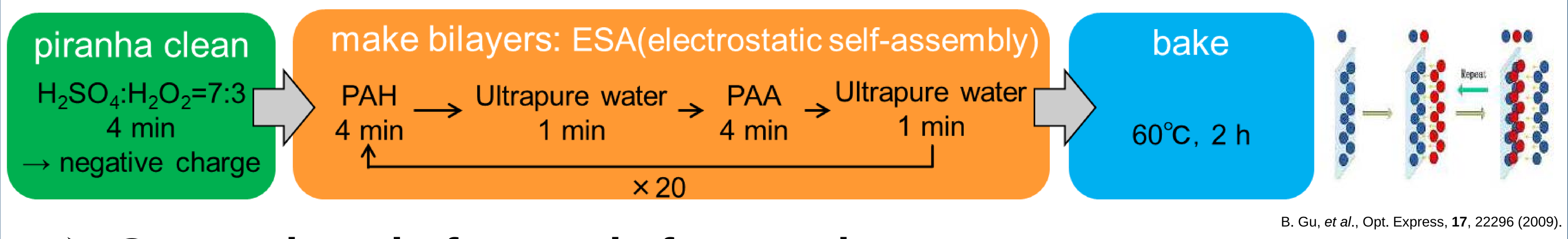


✓ Stable coupling is possible, but high techinique is required

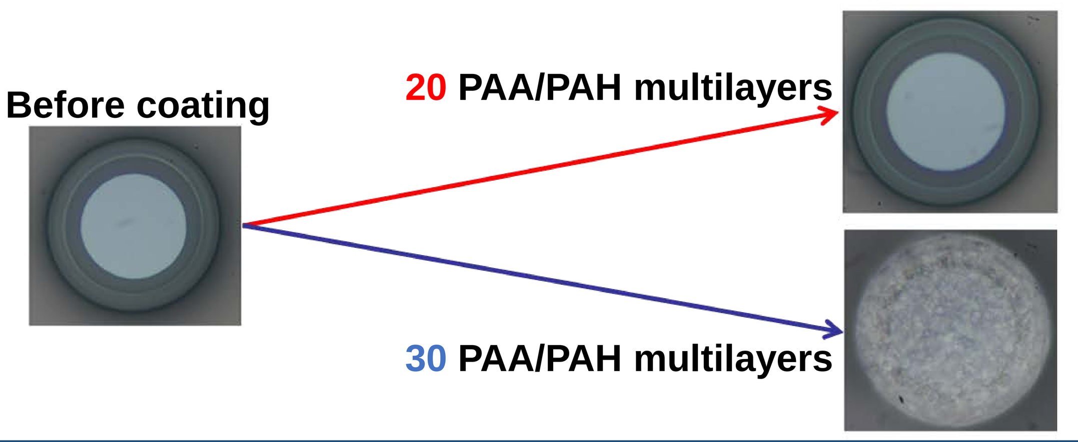
Surface treatment for sensitivity improvement

- **Bare silica toroid microcavity is inactive with the ammonia**
  ⇒ We used PAA/PAH multilayers to raise reactivity
  ✓ PAA/PAH multilayers：Multilayer thickness changes in respect to pH

➢ **Method（ESA：Electric self-assembly）**



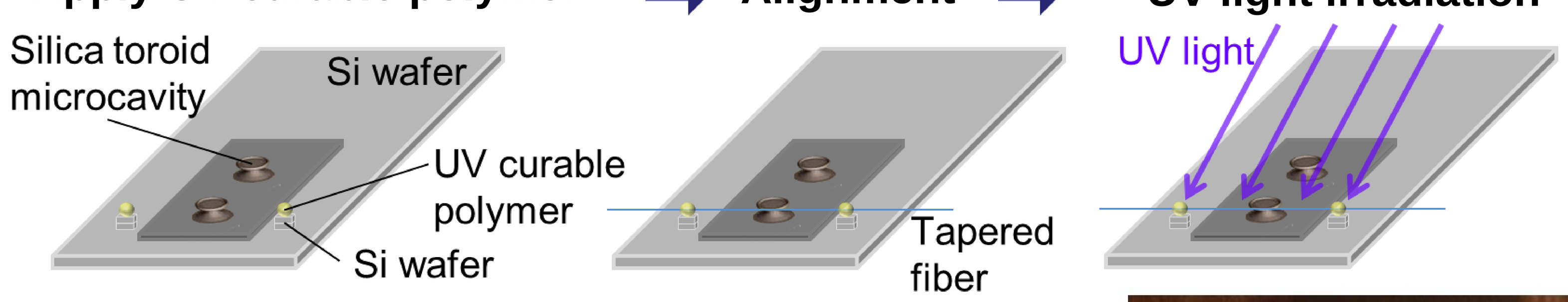
➢ **Comparison before and after coating**



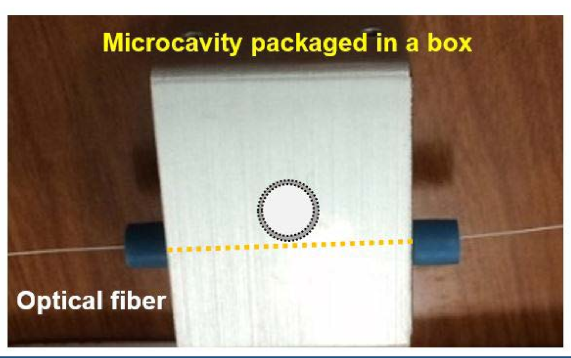
✓ thickness of a layer 20 nm~30 nm
✓ Quality factor $6.2\times10^6 \Rightarrow 7.5\times10^5$

Unmeasurable

Microcavity packaging

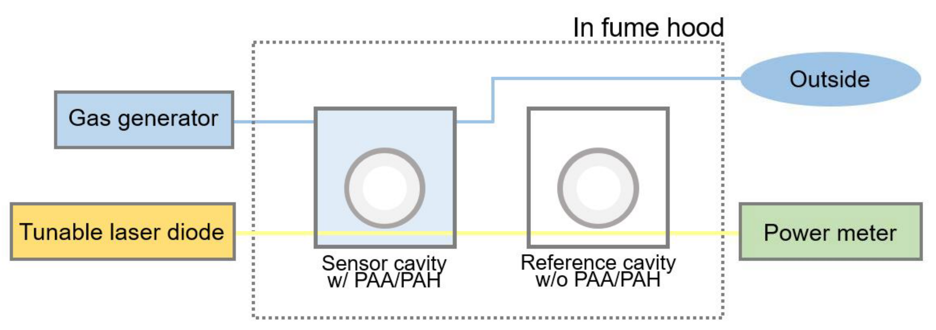


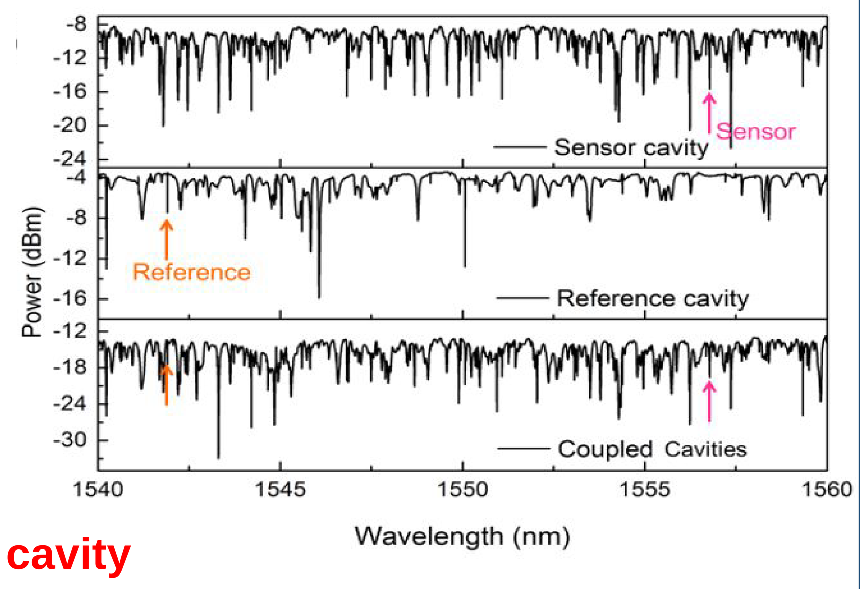
✓ **UV curable polymer does not cover the silica toroid microcavity**
⇒ We can measure the resonance after a several month



Results : Ammonia gas sensing

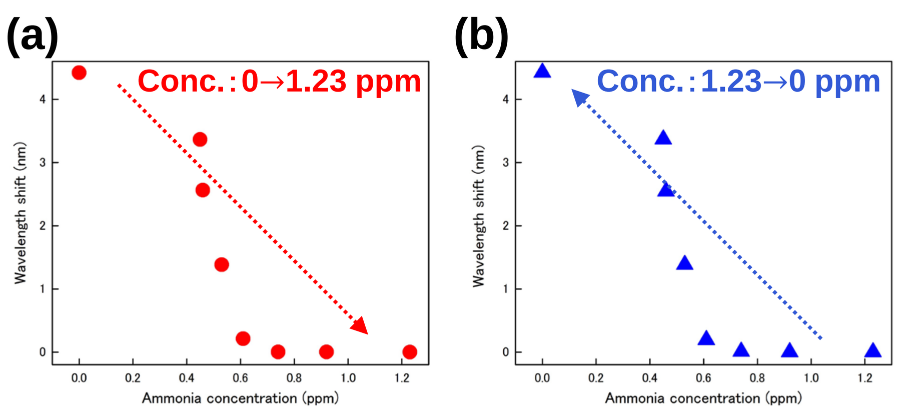
➢ **Experimental setup**

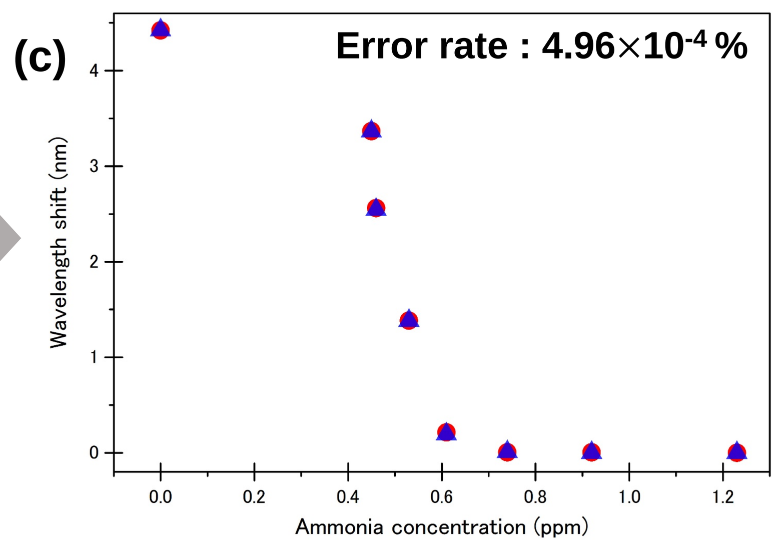




✓ **Cancel the influence of temperature and fluctuation of laser by using a reference cavity**

➢ **Experimental results**





✓ **450 ppb detection limit is achieved (limited by the gas generator)**

✓ **1.67 ppb detection resolution is achieved**

$$\text{Detection resolution} = \frac{\text{(Fluctuation of wavelength)}}{\text{(Sensitivity)}\times(Q\text{ factor})}$$

✓ **From (c), the relationship between gas concentration and wavelength shift is almost the same in case of increasing or decreasing gas concentration**

Type of sensors	Detection limit	Detection resolution
Semiconductor	1 ppm	1 ppm
Graphene	2 ppm	200 ppb
Optical fiber	20 ppm	-
Silica toroid microcavity	450 ppb	1.67 ppb

Conclusions

- We experimentally demonstrated highly sensitive and practical ammonia gas (NH_3) detection with a packaged silica toroid microcavity with PAH/PAA multilayers, and obtained a lower detection limit and higher detection resolution than other types of ammonia gas sensors.
- Because the *Q* factor of the silica toroid microcavity in this study was not high, we can expect to fabricate a more highly sensitive ammonia gas sensor by using a silica toroid microcavity with a higher *Q* factor.

Acknowledgements

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