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# Enhanced Sensing Performance of Pt-decorated Al-doped ZnO Nanoparticles for detection of Acetone

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**Abstract:**

We report the excellent sensing performance of Pt-decorated Al-doped ZnO (Pt-AZO) nanoparticles (NPs) for the detection of the hazardous gas acetone ($CH_3COCH_3$). The Al-doped ZnO (AZO) NPs were synthesized using a hydrothermal method in an aqueous solution containing Al. Platinum was deposited on the surface of the AZO NPs during sputtering, spontaneously stirring the AZO NPs in an agitated vessel. Under the exposure to 10 ppm acetone at 450°C, the Pt-AZO NPs exhibited a remarkably enhanced sensing response ($R$) and response time ($t_R$) compared to those of the AZO and the pure ZO NPs: (i) $R$ = 421 and $t_R$ = 2.9 s for the Pt-AZO, (ii) $R$ = 56 and $t_R$ = 15 s for the AZO, and (iii) $R$ = 17 and $t_R$ = 51 s for the pure ZO. Furthermore, the sensing properties of the Pt-AZO NPs to 10 ppm acetone was superior to previously reported acetone sensors that are based on semiconducting metal oxides. From physical and chemical analytic measurements, we found that the Pt NPs in the Pt-AZO NPs play a crucial role in improving the acetone sensing performance. The spillover effect, which is also called as the catalytic effect of the Pt NPs, can be ascribed to the greater number of oxygen vacancies, higher carrier concentration, and larger specific surface area in the Pt-AZO NPs than in the AZO NPs, providing more active adsorption sites as well as enhancing the kinetics of the surface reaction.

**Key words:** Al-doped ZnO, Pt decoration, acetone, spillover effect, gas sensor

## Background and Motivation

As a by-product of industrialization, large amount of hazardous gases, such as acetone, benzene, toluene, ammonia, and many other gases are released into the atmosphere, causing environmental pollution and posing risks to human health. In particular, acetone is a very volatile substance that is extensively used in laboratories and industrial applications [1]. Therefore, the development of gas sensors for the rapid and selective detection of acetone has attracted substantial interest in recent years.

Among the various sensing materials of semiconducting metal-oxides, ZnO has been extensively investigated as a particularly promising candidate owing to its magnificent characteristics of low cost, preparation simplicity, high chemical and thermal stability, and favorable sensing properties. Many experimental studies have been focused on improving the sensing properties of ZnO by designing various structures, doping of metals, and loading of noble metal. In this work, we developed an acetone sensor by decorating Pt NPs on the surface of AZO NPs.

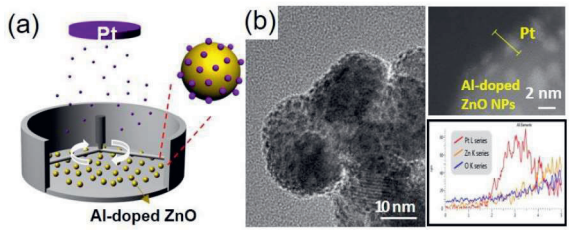


*Fig. 1. (a) Schematic image of an apparatus for decorating Pt nanoparticles and (b) high resolution TEM images and EXD line profiles of Pt-AZO.*

## Results and Discussion

The un-doped ZO and AZO NPs were synthesized by a hydrothermal method as described in our previous reports [2]. To synthesize the Pt-AZO NPs, the platinum was coated on the surface of the as-synthesized AZO NPs, placed in an agitated vessel (See the left of Fig. 1(a)) for 2 min at deposition rate of

6−7 nm/min using a DC magnetron sputter. The AZO powder was continuously stirred by a rotating impeller which homogenously decorated the Pt NPs on the surface of the AZO NPs, as shown in Fig. 1(b).

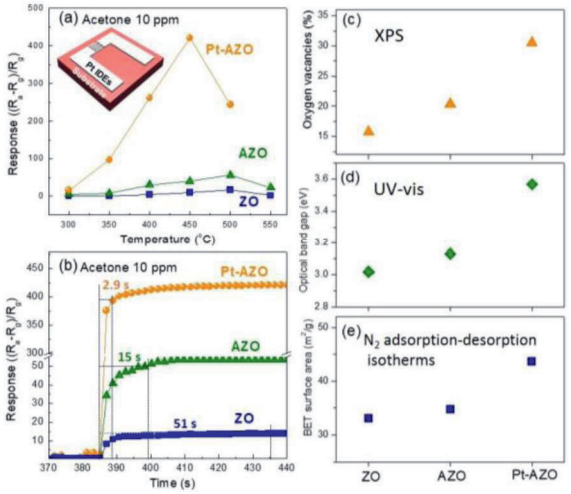


*Fig. 1. (a) Maximum sensing responses measured in the operating temperature range of 300–500 °C at 10 ppm acetone (Inset: schematic image of an actual sensor device), (b) response times, (c) oxygen vacancies, (d) optical band gaps, (e) BET surface areas for ZO, AZO, and Pt-AZO.*

The sensing properties of the synthesized NPs were measured using the sensor device fabricated on an interdigitated Pt electrode patterned on a $SiO_2$ substrate, as shown in the inset of Fig. 2(a). The sensing response ($R$) of the acetone gas is defined as $(R_a-R_g)/R_g$, where $R_a$ and $R_g$ are the resistance of the sensors in air and in the environment containing acetone, respectively. The response time ($t_R$) is defined as the time required to reach 90% of the total resistance change upon exposure to the test gas and was estimated from the plots of response variation as a function of time. The maximum sensing response and response time of ZO, AZO, and Pt-AZO are presented in Fig. 2(a) and Fig. 2(b), respectively. The values of 10 ppm acetone at the optimal working temperature are obtained to be (i) $R$ = 421 and $t_R$ = 2.9 s for the Pt-AZO, (ii) $R$ = 56 and $t_R$ = 15 s for the AZO, and (iii) $R$ = 17 and $t_R$ = 51 s for the pure ZO. The Pt-AZO showed the highest sensing properties to 10 ppm acetone compared to other metal-oxide sensing materials reported so far. The comparison between the pure ZO and the AZO NPs, and between the AZO and the Pt-AZO NPs shows that both Al doping and Pt NPs dispersion increase the number of oxygen vacancies (Fig. 2(c)), optical band gap (Fig. 2(d)), and specific surface area (Fig. 7(e)) with respect to the initial state of the materials.

The sensing mechanism for acetone detection with ZO, AZO, and Pt-AZO NPs is illustrated in Fig. 3. According to the sensing mechanism, the higher sensing performance is closely related to an increased thickness of the depletion layer in the initial state, resulting in significantly increased number of absorbed oxygen ions. The donor Al atoms in the AZO NPs can provide additional carriers compared to the pure ZO NPs, and the Pt NPs in the Pt-AZO NPs can trap more electrons from the AZO NPs due to the higher work function of Pt metal compared to the AZO. Therefore, it can be noted that the Al atoms in the AZO NPs and the Pt NPs in Pt-AZO supply more electrons to form a thicker depletion layer.

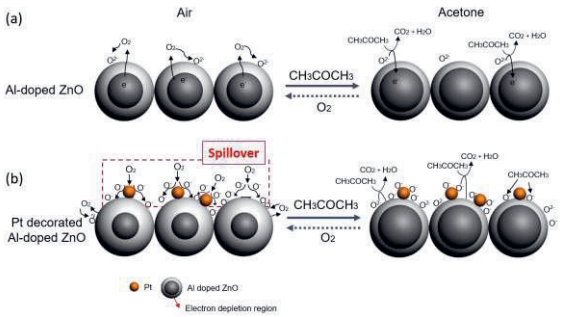


*Fig. 2. Schematic diagram of the sensing reaction mechanism of the AZO and Pt-AZO sensors (a) in air and (b) in acetone*

In addition, the catalytic effect of the Pt NPs on the surface sensing reaction was demonstrated by two phenomena: the shortened response time and the enhanced kinetics of the surface reaction by reducing the activation energy. Thus, the significantly enhanced sensing performance of the Pt-AZO NPs can be attributed to the synergistic physical and chemical effects originated from the increase in number of oxygen vacancies, optical band gap, specific surface area, and the enhanced reaction kinetics caused by the spillover effect and catalytic effect of the Pt NPs. Therefore, the superior sensing performance of Pt-AZO NPs can pave the way towards practical applications as an acetone sensor in the environmental and industrial monitoring systems.

## References

[1] Jia. Q, Ji. H, Zhang. Y, Chen. Y, Sun. X, Jin. Z. Rapid and selective detection of acetone using hierarchical ZnO gassensor for hazardous odor markers application, J. Hazard. Mater. 276, 262-270 (2014); doi:10.1016/j.jhazmant.2014.05.044

R. Yoo, D. Lee, S. Cho, W. Lee. Doping effect on the sensing properties of ZnO nanoparticles for detection of 2-chloroethyl ethylsulfide as a mustard simulant, Sens. Actuators B: Chem. 254, 1242-1248 (2018); doi:10.1016/j.snb.2017.07.084.