Modified Sn-doped LaCrO_3 nanostructures: focus on their characterization and applications as ethanol sensor at a lower temperature

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Abstract

The present work emphasizes the effect of the use of Sn, with different concentrations, over the structural properties and sensing applications of LaCrO_3 . In this work, LaCrO_3 nanostructures were modified with different concentration of Sn (0.2 M %, 0.4 M %, 0.6 M % and 0.8 M %). Different modified Sn-doped LaCrO_3 was synthesized by sol–gel method and followed by preparation of thick films via a conventional screen printing approach. The characterizations done by means of X-ray diffraction (XRD), energy-dispersive X-ray (EDX), scanning electron microscopy (SEM) and transmission electron microscopy (TEM) revealed the confirmation of a Sn-doped LaCrO_3 crystal structure and its morphology, respectively. These oxides were formulated to identify various air pollutants such as CO_2 , ethanol, H_2S , NH_3 , NO_2 and acetone. The Sn-doped LaCrO_3 with 0.4 M % Sn displayed higher gas response to ethanol vapor at the range of 150–250 °C. The sensors additionally demonstrated proper recovery and acceptable stability.

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Graphic abstract

The graphical abstract demonstrates the in situ synthesis of Sn-doped LaCrO_3 by sol–gel method. Similarly, it shows its characterization and finally, the thick films of doped Sn demonstrate best selectivity for ethanol.

Keywords Sol–gel method · Sn-doped LaCrO_3 nanostructure · XRD · SEM · EDS · TEM · IR · Ethanol · Reproducibility and response–recovery

Introduction

The continuous increase in the release of the toxic pollutants from industries and vehicles in the environment has posed a threat to the human and other living beings surroundings globally. In these circumstances, measures to tackle this global problem are necessary. At this juncture, the significance of nanomaterial is crucial and there use is increasing day by day. The gas sensors designed using such nanomaterial play a vital role in human and environment safety.

The metal oxide gas sensors are utilized to recognize various poisonous gases which can pose risk to human health and surroundings [1]. Perovskite compounds, ABO_3 (in which A = cation of alkali, alkaline earth, or lanthanide steel and B = cation of transition metal), have novel synthetic and physical properties such as oxidative, magnetic, conductive, refractive, luminescent and catalytic. With these significant and interesting attributes, these

oxides have been widely used in electronic devices and plenty of other devices [2]. These oxides are also used in optoelectronic devices [3], hydrazine and ozone sensor [4, 5], tremendous magneto-resistance [6], magneto-electric [7], interconnect material [8], light-emitting material [9] and as a catalyst [10]. Perovskite structural material (ABO_3) can be prepared by mixing the lanthanide oxide and the oxides of the transition element. In the perovskite structure, the cations can fit into both the A and B sites [11]. These perovskites were blended using various methods such as hydrothermal [12–14], co-precipitation [15–17], sol–gel [18, 19]. Among these methods, the sol–gel method has been viewed and appreciated by various researchers due to excellent quality of the resulted nanomaterials. Besides this, this strategy is relatively cost effective [20]. The first use of $(\text{Ln}, \text{M})\text{BO}_3$ (Ln—lanthanide element, M—alkaline earth metal, and B—transition metal) perovskite as a potential ethanol sensor was proposed by Obayashi et al. [21].

According to OSHA, ethanol is a volatile, flammable and colorless liquid with a wine-like scent. It burns with a smokeless blue fire that is not visible in ordinary light. It is an excellent psychoactive drug. It can result in irritation of eyes, skin and upper respiratory tract mucous membrane. The primary metabolic results of ethanol in the liver are acetaldehyde is toxic, mutagenic and carcinogenic. Exposure of ethanol may be very harmful to the human being as it causes nausea and omitting. These types of signs and symptoms directly damage the liver. Therefore, it is important to screen and understand the fixation of ethanol for human safety and at last in the surroundings. One of the significant factors which influence the sensing property of gas sensors is introducing the dopants, catalyzers. Dopants are introduced to the metal oxide during the synthesis to change the electrical properties of the synthesized material. Dopant normally isolates along the grain boundaries in polycrystalline material and restricts grain development in subsequent annealing. By adding dopant it creates some kind of defects such as ionic and electronic. The Fermi energy level affected by such form of deformities helps to increase the gas sensitivity of the semiconductor oxides. Many researchers have introduced dopants to enhance the sensitivity and selectivity of the oxides. Since many years, researchers have been continuously showing an inclination towards preparing value-effective SnO_2 thin and thick films. In the field of gas sensing, the most commonly used metal oxide semiconductor is tin oxide. The reason behind it is the potential to recognize ignitable and polluted gases such as methane, LPG, CNG, CO, CO_2 , Cl_2 , H_2S , and so on [22, 23].

In recent times, the majority of street accidents are resulting from drunken driving. Drunken drivers are in an unstable situation and so possibilities of an accident have been a major trouble; that is why the effective tracking of drunken drivers is a venture to the policemen and street safety officers. So the researchers have been continuously taking efforts on such type of sensors which are used for breath alcohol measurements. The primary benefit of this kind of sensors is the low cost and high sensitivity [36, 37]. The present work demonstrates the synthesis of ethanol sensor which plays a very important role to sense the breath alcohol. So we can control such kind of road accidents. This is the most important practical application for human being and his safety. The perovskite-undoped and -doped LaCrO_3 is a great material for detecting gases such as H_2S , acetone, and CO_2 , but the novelty of presented work is that the SnLaCrO_3 shows high sensitivity at lower temperature, i.e., 150°C , which is shown in Table 3.

This work has laid its emphasis on improving response, sensitivity, and selectivity through introducing tin oxide as a dopant. For this purpose, the sol–gel technique has been utilized for in situ synthesis. Moreover, the electrical, structural properties and its gas-sensing performance have been

observed comparatively by varying the dopant concentration of tin. The thick films of all these doped nanostructures were prepared with the help of conventional screen printing method and then used for numerous toxic gases such as ammonia, CO_2 , ethanol, H_2S , NO_2 , and acetone. All the information related to sensing was interpreted and compared to draw out the conclusion.

Materials and methods

Lanthanum nitrate [$\text{La}(\text{NO}_3)_3$], chromium nitrate [$\text{Cr}(\text{NO}_3)_3$], tin chloride [$\text{Sn}(\text{Cl}_2) \cdot 2\text{H}_2\text{O}$] and citric acid utilized in this synthesis are AR grade bought from Merck Chemicals and Modern Laboratories, Nashik, India. All these chemicals were utilized without any further refinement.

Synthesis of Sn-doped LaCrO_3 by sol–gel technique

We independently synthesized the Sn-doped LaCrO_3 nanoparticles at differed concentrations by means of straightforward and easiest sol–gel technique. For this synthesis we followed the same procedure according to our prior work [20], the blend of lanthanum nitrate [$\text{La}(\text{NO}_3)_3$] precursor, chromium nitrate [$\text{Cr}(\text{NO}_3)_3$] precursor and tin chloride [$\text{Sn}(\text{Cl}_2) \cdot 2\text{H}_2\text{O}$] precursor through utilizing variable concentrations of Sn (0.2 mol %, 0.4 mol %, 0.6 mol %, 0.8 mol %), and citric acid were used. The mixture of all four precursors was heated at 80°C with continuous stirring on magnetic stirrer to evaporate distilled water for a minimum of 2–3 h. Through stirring, a homogeneous thick gel is obtained having fascinating shades of green color. This gel initially dried under IR lamp for 1–2 h. Then hard particles had been crushed, and afterward calcined for 5–6 h at 550°C . We got a fine powder of Sn-doped LaCrO_3 with various shades of greenish color at different concentrations.

Preparation of thick films of Sn-doped LaCrO_3 nanoparticles

The thick film preparation method is a bit like our earlier work [20]. The powder of nanoparticle of Sn-doped LaCrO_3 changed into a thixotropic stick which ended up as thick films by a basic screen printing approach. The inorganic to organic material proportion was maintained at 70:30. The inorganic part consists of nanomaterial (SnLaCrO_3). The organic part consisted of 8% ethyl cellulose and 92% butyl carbitol acetate acts as a binder. The SnLaCrO_3 with ethyl cellulose (EC) was mixed all together in an acetone medium with mortar and pestle. A solution of BCA was added dropwise till a thixotropic paste was accomplished. Lastly, the thick film was prepared on a glass substrate by making use of a standard screen printing method. The film was dried

under IR lamp for 1 h to expel the organic volatile impurities and then fired at temperature 550 °C for 30 min in a muffle furnace. We have rehashed the same strategies for 0.2 M % Sn, 0.4 M % Sn, 0.6 M % Sn and 0.8 M % Sn individually.

Characterization techniques

The prepared compound was characterized in powder form for FTIR by means of the use of Shimadzu IR-affinity 1S. The XRD spectra of doped and undoped nanostructures were recorded by means of X-ray diffractometer Cu/40 kV/40 mA, from Goniometer: Ultima IV and X-ray diffractometer [Bruker D8, Advance, Germany] using CuK α radiation ($\lambda = 1.5409 \text{ \AA}$), respectively. The crystal structure was analyzed for the 2θ range from 20 to 80, the field emission scanning electron microscopy (SEM) was performed on FEI NOVA SEM 450 and transmission electron microscopy (TEM) was performed on SJeol/JSM 2100.

Results and discussion

X-ray diffraction (XRD)

The X-ray diffraction pattern was recorded on-ray diffractometer Cu/40 kV/40 mA, from Goniometer: Ultima IV and X-ray diffractometer [Bruker D8, Advance, Germany] using CuK α radiation ($\lambda = 1.5409 \text{ \AA}$) to investigate the structural properties of the doped and undoped nanostructures. The spectrum was recorded by following the range of 2θ degrees between 20 and 80 to know the crystallite size and crystal structure of nanostructure. Figure 1a, b shows the XRD pattern of SnLaCrO₃ nanostructure where the observed diffraction peaks of LaCrO₃ correlated well with the reported data of LaCrO₃ (JCPDS card no. 33-0701). It resembled the standard orthorhombic phase. The higher peak intensities of the XRD spectrum was because of better crystallinity with preferred orientation along the (121) plane. The average crystallite size was calculated by Debye–Scherer formula: $D = \frac{K\lambda}{\beta \cos \theta}$, where K is constant (0.89–1.39), λ is radiation of wavelength (1.54 Å), β is FWHM (full-width half-wave maxima), θ is the Bragg angle in degree, and D is the particle size. The crystallite size of undoped LaCrO₃ was found to be 13.04 nm. But for doped nanostructure, it gets slightly increased. Typically for 0.2Sn size found to be 38.40 nm, for 0.4Sn it found to be 39.54 nm, for 0.6Sn and 0.8Sn size found to be 40.19 nm and 40.21 nm, respectively. It is well documented that as the dopant added in base material the grain size is increased [24]. The electronic conductivity of the ABO₃ (Perovskite) type LaCrO₃ is improved by doping with divalent ion on either A La (1.15 Å) site or B Cr (0.67 Å) site. Sn doping favors substitution at B site, i.e.,

Fig. 1 **a** XRD spectrum of Sn-doped LaCrO₃ nanostructures; **b** XRD spectrum of undoped LaCrO₃ nanostructure

chromium site as the ionic radii of Cr is close and slightly greater than Sn (0.71 Å) so with substitution of Sn at chromium site the volume of the unit cell is increased as compared to undoped LaCrO₃ and hence the crystallite size is increased with the concentration substituting Sn ion.

SEM analysis

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning the surface with a targeted beam of electrons. This image demonstrates the surface texture and its porosity. Figure 2a–d shows the SEM images of Sn-doped LaCrO₃ nanostructure with varying concentration of 0.2 mol %, 0.4 mol %, 0.6 mol %, 0.8 mol %, respectively, which was performed on FEI NOVA SEM 450. Images shown the agglomerated particles with different ranges that looks in random distribution and also shows the porous nature which is truly appropriate for sensing purpose because that voids can act as an adsorbent for different gaseous species [25, 26]. The particle size of synthesized Sn-doped LaCrO₃ nanoparticles was observed to be between 27 and 33 nm for **0.2Sn**, 25 and 38 nm for **0.4Sn**, 26 and 40 nm for **0.6Sn** and 26 and 43 nm for **0.8Sn** with distorted

Fig. 2 SEM images of **a** 0.2 M % SnLaCrO₃, **b** 0.4 M % SnLaCrO₃, **c** 0.6 M % SnLaCrO₃, **d** 0.8 M % SnLaCrO₃

spherical morphology. Scanning electron microscopy also revealed the increase in particle size as the concentration of Sn increased.

The specific surface areas of 0.2 M %, 0.4 M %, 0.6 M %, 0.8 M % Sn doped LaCrO_3 films was calculated using BET method for spherical particles using following equation. The details of surface area, particles etc. is mentioned in Table 1.

$$S_w = \frac{6}{\rho x d},$$

where S_w is the surface area, 6 (six) is the constant, ρ is the composite density of the materials, d is the average particle size of functioning material.

Energy-dispersive X-ray spectroscopy (EDS)

The energy-dispersive X-ray spectroscopy was used to examine the elemental composition of both doped and undoped nanostructures. In the case of undoped LaCrO_3 , the sharp peak was found to be at 4.8 keV for lanthanum and at 5.4 keV for chromium in the EDS spectrum which we have presented previously. Figure 3a–d demonstrates the case of Sn-doped EDS spectrum, in which sharp peak was found to be at 4.8 keV for lanthanum, 5.4 keV for chromium and at 0.6, 3.4 keV for tin, all this information was obtained from EDS and for all concentration of Sn which is found to be near about same [20, 27, 28].

Table 1 Surface area and particle size calculated using BET method for spherical particles from SEM data

Functioning material	Firing temperature (°C)	Crystallite (grain) size, D nm (XRD)	Specific surface area in m^2/g
0.2 M % Sn doped LaCrO_3	550	38.40	6.7708
0.4 M % Sn doped LaCrO_3	550	39.54	6.7816
0.6 M % Sn doped LaCrO_3	550	40.19	6.7924
0.8 M % Sn doped LaCrO_3	550	40.21	6.8032

Fig. 3 **a** EDAX image of 0.2 M % Sn-doped LaCrO_3 , **b** EDAX image of 0.4 M % Sn-doped LaCrO_3 , **c** EDAX image of 0.6 M % Sn-doped LaCrO_3 , **d** EDAX image of 0.8 M % Sn-doped LaCrO_3

Also, Table 2 shows the elemental composition of doped and undoped nanostructures with respect to elemental weight percent.

Mapping

The mapping was also done to investigate the exact dopant concentration. Figure 4a–d clearly shows the concentration of Sn doped with LaCrO_3 . The figure showed that as the concentration of tin increased, the dot is also increased. That dot is nothing but the concentration of tin.

High-resolution transmission electron microscopy (HR-TEM)

The images by TEM (transmission electron microscopy) organized for 0.4% Sn-doped LaCrO_3 nanostructure are shown in Fig. 5a, b. The images showed the spherical, rod-like and polycrystalline-shaped particles. These particles are well spread on the surface of the micrograph.

Selected area diffraction pattern (SAED)

SAED pattern (selected area electron diffraction) of 0.4 M % Sn-doped LaCrO_3 nanostructure is shown in Fig. 5c; in SAED, the crystallinity of the sample is shown by the bright concentric spots. We can see that the bright spots were arranged in a ring-like pattern. These data which are

Table 2 Elemental composition of undoped LaCrO_3 and Sn doped with LaCrO_3

Sr. no.	Element	Elementary weight % calculated from EDS				
		Undoped	0.2 Mol %	0.4 Mol %	0.6 Mol %	0.8 Mol %
1	Oxygen	78.21	76.76	75.39	75.50	77.56
2	Chromium	10.46	10.79	12.08	11.50	10.22
3	Lanthanum	11.33	12.38	12.41	12.81	11.99
4	Tin	–	0.07	0.12	0.19	0.23
Total		100	100	100	100	100

Fig. 4 **a** 0.2 M % dopant concentration, **b** 0.4 M % dopant concentration, **c** 0.6 M % dopant concentration, **d** 0.8 M % dopant concentration

Fig. 5 **a, b** 0.4% Sn doped with LaCrO_3 , **c** 0.4 M % Sn doped with LaCrO_3

obtained from SAED are combined with the diffraction data from XRD [29].

FT-IR analysis

On a basic level, FTIR examination in the material field is utilized to evaluate the useful functional groups that are the stretching frequency of functional groups present in the synthesized material in relation to the documented compound [11]. The FTIR for undoped LaCrO_3 nanostructure shows strong absorption bands at 594.08 cm^{-1} for La–O stretch and 420.48 cm^{-1} for Cr–O stretch [20]. In the case of Fig. 6, the La–O stretch is at $592\text{--}602$ and for Cr–O, the wavenumber is observed at $416\text{--}430$. The additional wavenumber is assigned for all Sn-doped with various concentrations which is shown in Fig. 6 at the range $771\text{--}773\text{ cm}^{-1}$. The

wavenumber at $1486\text{--}1493$ is observed as a water deformation peak. The peak observed at $2350\text{--}2400$ is an H–O–H stretch for absorbed or free water [30].

Electrical properties

The Sn-doped LaCrO_3 nanostructure, with its variable concentration, has been tested for electrical characterization so as to check its semiconducting nature. The semiconducting behavior of Sn-doped nanostructure has been checked in a closed glass-dome chamber by verifying electrical resistance with the help of static gas sensing system as shown in Fig. 7 by applying 30 V bias potential to the Sn-doped films and the cycle was performed without interference (i.e., the cycle becomes accomplished only in the

Fig. 6 FT-IR spectra of Sn-doped LaCrO_3 nanostructure with 0.2 M %, 0.4 M %, 0.6 M % and 0.8 M % Sn concentration

Fig. 7 Static gas sensing system

presence of air from 350 to 40 °C temperature), of any gas. The test confirmed that with the increase in temperature there is a linear decrease in resistivity in the semiconducting behavior of all Sn-doped samples. The reason behind a decrease in resistivity with increment in temperature is the increment in the thermally activated drift mobility of charge carriers as per the hopping conduction mechanism [31, 32]. The temperature dependence of dc resistivity, i.e., its typical semiconducting behavior is shown in Fig. 8a–d for 0.2 M %Sn, 0.4 M %Sn, 0.6 M %Sn and 0.8 M %Sn, respectively.

Sensitivity and selectivity of Sn-doped LaCrO_3

Gas sensing performance of Sn-doped LaCrO_3 nanostructure thick films

Gas sensing was performed in a similar fashion by utilizing a static gas sensing system and by applying 30 V bias potential to films, as shown in Fig. 7. In this system, the oxide sensor is fixed in a closed glass chamber having a

Fig. 8 a–d Variation of temperature against resistance for 0.2 M %Sn, 0.4 M %Sn, 0.6 M %Sn and 0.8 M %Sn, respectively

capacity of 15 L. While measuring the response (resistance) of the suitable sensor, the gas at ppm level is injected inside the glass chamber at a different temperature range from 50 to 400 °C. The resistance of the films was measured with the help of a digital multimeter. This measured resistance can help us to check the performance of various sensors. Using this device, the sensing performance of Sn-doped LaCrO_3 nanostructures at all concentrations was calculated at different temperatures. The sensitivity of the 0.2 M %, 0.4 M %, 0.6 M %, and 0.8 M % Sn-doped LaCrO_3 nanostructures was investigated using different gases such as CO_2 , ethanol, H_2S , NH_3 , acetone, and NO_2 using the following equation [33, 34]:

$$S = \frac{R_g - R_a}{R_a},$$

where R_g is the resistance of the thick films in the presence of gas and R_a is the resistance of the thick films in air.

The sensitivity for different gases such as H_2S , NH_3 , ethanol, acetone, CO_2 , and NO_2 for 0.2 M %, 0.4 M %, 0.6 M %, and 0.8 M % of Sn doped at fixed concentration, 1000 ppm, is shown in Fig. 9a–d, respectively. All figures interestingly demonstrated that the highest gas response was observed for ethanol at 150 °C in the presence of other gases for 0.4 M % Sn. The higher response may be assigned to films which had the optimum porosity and more effective surface area available to react to the species of gas.

The response is due to adsorption–desorption type of sensing mechanism [35]. The gas response for ethanol is

based on the changes in resistance because of the amount of chemisorbed oxygen at the surface. At low temperature, the reaction products do not desorb from the sensor surface. The species cowl the sensing sites at the sensor surface, which prevents the further reaction among ethanol vapors and chemisorbed oxygen. Therefore, there might be an increase in resistance slightly. At most appropriate temperature, the reaction products become desorbed, allowing sensing sites on the sensor to react with new gas species. So this temperature is more effective for the reaction between ethanol vapors and chemisorbed oxygen. Subsequently, the resistance of the sensor increases significantly. Consequently, we got the highest response. At a temperature higher than the optimal temperature, the adsorbed gas begins to desorb. Fewer amounts of ethanol vapors react with chemisorbed oxygen, which leads to a small change in resistance of the sensor [38].

This response is varied for all concentrations of Sn-doped LaCrO_3 . As the concentration of Sn was slightly increased from 0.2 to 0.4 M %, the response was also slightly increased. But, as the Sn doping increased beyond 0.4–0.6 M and 0.8 M, the response was again diminished. The highest gas response for ethanol at 0.4 M % Sn of 84.18 was observed. Among ethanol and acetone, all four samples showed the response for H_2S gas at 200 °C which was earlier recorded for base material LaCrO_3 nanostructure. Figure 10a clearly shows the 100% selectivity for ethanol in the presence of other gases at 0.4 M %Sn as compared with other concentrations. Figure 10b shows ethanol sensing at

Fig. 9 a–d Gas sensing performance of Sn-doped LaCrO_3 films in the presence of various gases at different temperatures with 0.2 M %, 0.4 M %, 0.6 M %, 0.8 M % concentration, respectively

Fig. 10 **a** Selectivity for ethanol at 0.4 M %Sn-doped LaCrO_3 nanostructure. **b** Ethanol sensing at various mole concentrations of Sn. **c** Gas sensing response for 0.4 M %Sn at various concentrations of ethanol

various mole concentrations of Sn. The highest response was observed for ethanol at 0.4 M %Sn. Figure 10c shows the gas sensing response for 0.4 M %Sn at 150 °C at various concentrations of ethanol such as 1000 ppm, 500 ppm, 300 ppm, and 100 ppm. The gas response was registered as 84.18, 75.25, 62.33 and 53.75, respectively, at the above concentrations of ethanol.

Response and recovery

Response and recovery are significant parameters while studying the characteristics of the sensor. Sn-doped LaCrO₃ nanostructure demonstrates the quick response in 41 s and recovery time is 37 s for ethanol as shown in Fig. 11.

Reproducibility

It is additionally one of the significant factors to confirm the stability of the sensor. For this confirmation, we performed the repeated cycles up to 45 days, i.e., one and a half months. We tested the 0.4 M %Sn-doped LaCrO₃ sensor at 1000 ppm of ethanol. As shown in Fig. 12, we saw that the gas response for 0.4 M %Sn is slightly diminished after a month as the concentration of gas remains the same. It implies no impressive change is observed even after the period of 45 days; henceforth, the material showed 97–98% response of its prior response. So we can confirm the stability of our sensor.

Conclusions

1. The doped 0.2 M %Sn, 0.4 M %Sn, 0.6 M %Sn and 0.8 M %Sn with LaCrO₃ nanostructure were prepared using a simple and cost-effective sol–gel technique. The thick films of all Sn-doped nanostructures were prepared by a conventional screen printing method.

Fig. 11 Response and recovery graph for ethanol at 0.4 M %Sn

Fig. 12 Reproducibility graph for ethanol at 0.4 M %Sn

2. Characterization was done by means of XRD, from which crystallite size was calculated. For 0.2Sn, the size was observed to be 38.40 nm, for 0.4Sn, it was found to be 39.54 nm and for 0.6Sn and 0.8Sn, the sizes were found to be 40.19 nm and 40.21 nm, respectively. It implies that with the increase in the concentration of dopant, increase in the grain size takes place. Similarly, SEM revealed that increase in particle size takes place with the increase in the concentration of Sn.
3. The Sn-doped LaCrO₃ nanostructure at 0.2 M %Sn, 0.4 M %Sn, 0.6 M %Sn and 0.8 M %Sn concentration demonstrated higher gas response to ethanol for 0.4 M %Sn at 1000 ppm. The response was registered up to 84.18 at 150 °C.
4. The best response to un-doped LaCrO₃ nanostructure was registered for H₂S gas at 200 °C temperature at 1000 ppm gas concentration.
5. Addition of the dopant resulted in an increase in the gas response. Moreover, its influence on selectivity is noticed.
6. Sn-doped LaCrO₃ nanostructure showed quick response in 41 s and recovery time was 37 s for ethanol. Finally, the stability of sensor was proved with the help of reproducibility factor.
7. The perovskite-undoped and -doped LaCrO₃ is a great material for detecting the gases such as H₂S, acetone, CO₂, but novelty of the presented work is that the SnLaCrO₃ shows lower operating temperature, i.e., 150 °C, than others which is shown in Table 3.

Table 3 Comparative gas response of pure LaCrO₃ and doped LaCrO₃ at various temperature

Metal oxide	Gas	Operating temperature (°C)
LaCrO ₃ [20]	H ₂ S	200
LaCrO ₃ [38]	Acetone	200
LaSrCrO ₃ [39]	H ₂ S	210
LaCrO ₃ [40]	CO ₂	360

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