Niobium oxide (Nb_2O_5) based Gas Sensor: A Literature Review

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Abstract: **The industrial advancement increased the various types of pollution, among them air pollution is major issue now a day's. For air quality monitoring, different types of hazardous gas pollutant detection is essential. As a result, gas sensors are the subject of extensive investigation by scientists around the globe. Due to its unique electrical, chemical and physical properties of niobium oxide has been acclaimed as a remarkable gas detection material. Niobium oxide (Nb_2O_5) is utilized as sensitive materials in the construction of gas sensors based on resistivity variation measurements. Due to the fact that certain materials are gas sensitive. We described the detecting method of an undoped and doped Nb_2O_5 thick and thin film gas sensor for a number of oxidising and reducing gases in the current study. Furthermore, discussed how dopant and other factors affect gas sensors performance. This paper covers the advances in the research of Nb_2O_5 based gas sensors.**

Keywords: Gas sensor, hazardous, sensitive materials, air quality, gas pollutant.

1. Introduction:

A better understanding of materials and processes at the nanoscale is made possible by advances in nanotechnology. Sensors are gaining a lot of attention due to their ability to instantly gather chemical information from their surroundings, and as a result, they will have an ever-increasing influence on daily life. Chemical sensors could be employed for atmospheric, healthcare, and wealth monitoring, food-chain regulation, and the detection of toxic analytes and explosions. They may also be integrated into security systems to shield personnel from hazardous exposures [1].

Niobium oxide (Nb_2O_5) is an n-type semiconducting metal oxide. It is a member of the group of transition metal oxides, in which the oxygen atoms get all of the d electrons from the transition metal atoms [2]. Nb_2O_5 has the capability to be an excellent material for semiconducting gas sensors. At its various stoichiometries, this material's physical and chemical properties can be favourably tailored to produce increased sensitivity to particular target gas species. High surface to volume ratios, adequate surface energies, and optimum spacing are all characteristics of highly organised nanostructured structures that enable interactions with numerous target gas molecules. As a result, the Nb_2O_5 was explored for use in gas detection. High surface to volume ratios and quantum confinement effects, in notably, are provided by nanostructured Nb_2O_5, which permits unusual physical and chemical interactions to take place at the surface [3, 4].

The interaction of the gas molecules with the Nb_2O_5 films modifies the number of charge carriers and the potential barrier of the Nb_2O_5 films, based on whether the gas species is reducing or oxidising. These have an impact on the physical and chemical characteristics of the films that relate to the gas elements introduced to the sensor [5]. The reversible modification of electric resistance in the presence of oxidising or reducing gases forms the foundation of this material's detecting principle. Nb_2O_5 has so far mostly been studied as a material for oxygen sensors. It is an n-type semiconductor, therefore when oxygen partial pressure rises, its resistivity increases [5, 6]. In Nb2O5, like other semiconductors, the concentration of charge carriers is directly correlated to the defect structure of the metal oxide which is dependent on temperature and oxygen pressure. The defects may be produced using doping as well as sintering of nanopower of metal oxide semiconductor materials [7, 8]. Current paper presented the previous work done by researcher on undoped and doped Nb_2O_5 gas sensors. Also gives the prospective of recent trends in Nb_2O_5 based gas sensors in brief.

2. Literature Survey:

Many alternative techniques have been used to synthesize Nb_2O_5, and the potential to fine-tune the material's characteristics is the main factor in selecting the best synthesis technique. In this section, we presented the two common ways of synthesis of Nb_2O_5 nanoparticles, first is undoped (pure Nb_2O_5) and second is (doped/additive Nb_2O_5) with their preparation of thick and thin films. Also reported their characterizations and gas sensing properties.

2.1 Synthesis and preparation of undoped Nb_2O_5 gas sensor:

The Nb_2O_5 nanopowder was synthesized by Mokrushin, S. [9] via precipitation method. The synthesized nanopower as utilised to prepare thick films using screen-print technique. Prepared thick films were used as a gas-sensing element of a chemo resistive gas sensor. Nb_2O_5 responded to hydrogen sulphide at low concentrations of 4-100 ppm with a high and repeatable response at an

operational detection temperature of 250 °C. According to results the chemo resistive gas-sensing capabilities of Nb_2O_5, oxygen and hydrogen sulphide had the highest sensitivity among the gases examined including H_2, CO, NH_3, H_2S, and O_2.
Ruwer, Thais Lemes, et al. [10] used a microwave-assisted hydrothermal process to create uniform Nb_2O_5 nanorod arrays. Rather than using either a directing agent or the corrosive HF, niobium plates were employed as the raw material. The creation of organised nanorod arrays at 200 °C is visible in SEM pictures. The nanorods' optical band gap points to large-gap semiconducting behaviour. These findings show that the microwave-assisted hydrothermal approach produces uniform Nb_2O_5 nanorod arrays quickly and inexpensively.

Fig. 1 reveals the different types of synthesis methods of Nb_2O_5.

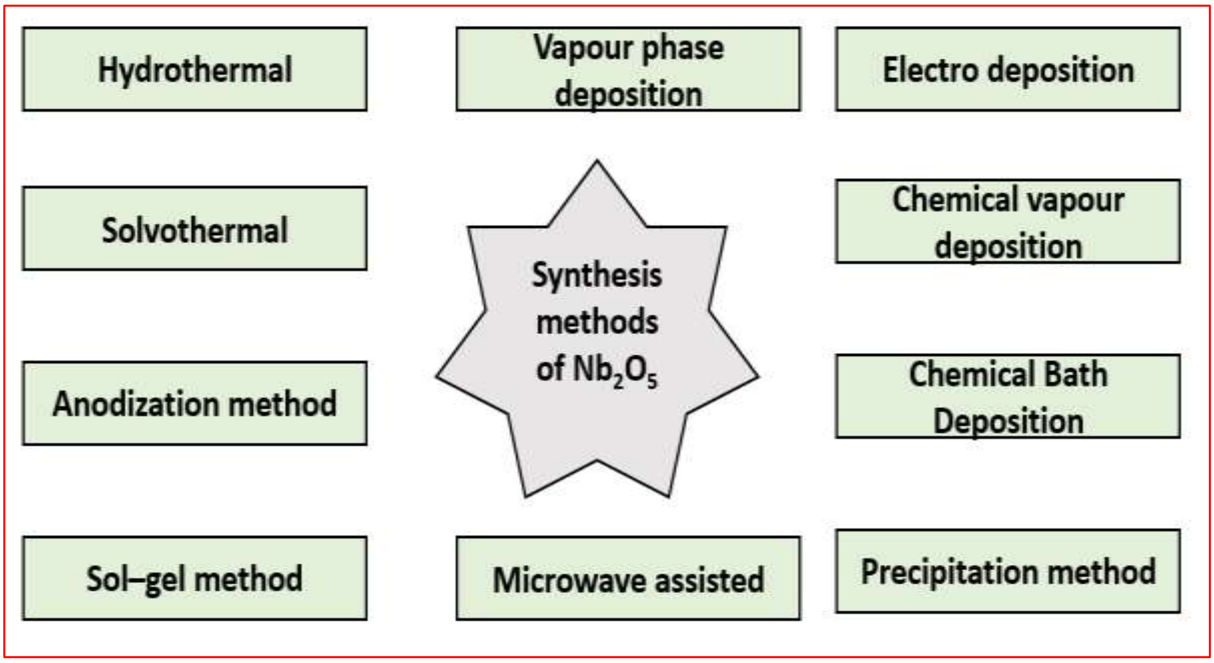

Figure 1: Synthesis methods of Nb_2O_5

After successfully synthesis of nanopowder or nanoparticles of Nb_2O_5 the next task is preparation of its films for various applications such as optical sensor, biosensor, gas sensing application etc. Basically thick and thin these two types of films mostly used in the sensor applications. The thickness of thick film was found to be in few micrometre range and thickness of thin film was found to be in nanometre range. The Fig. 2 shows that the different types of preparation techniques of Nb_2O_5.

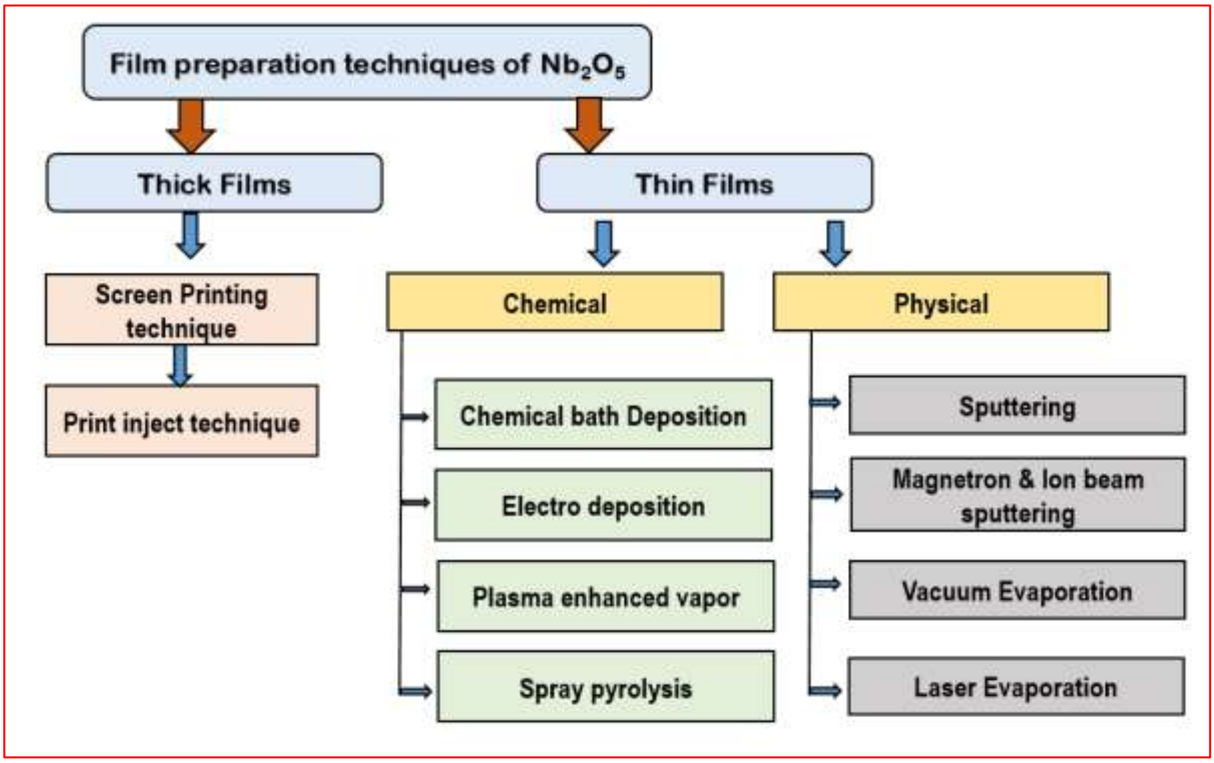

Figure 2: preparation techniques of Nb_2O_5

2.2 Synthesis and preparation of doped (nanocomposites) Nb_2O_5 gas sensor:

By using chemical vapor deposition, Raquel Fiz et al. [11] synthesized single-crystalline Nb_2O_5 nanorods and niobium-pentoxide-coated tin oxide (SnO_2/Nb_2O_5) heterostructures. According to structural characterizations, the Nb_2O_5 nanorods had a low defect density and high crystallinity, and they were very sensitive to humidity at low temperatures (60 °C). By creating SnO_2/Nb_2O_5 core-shell heterostructures, it is possible to incorporate the high moisture sensitivity of the Nb_2O_5 shell with its high electrical conductivity.

The development of a polypyrrole (PPy)/niobium pentoxide (Nb_2O_5) nanocomposite as a room-temperature liquefied petroleum gas (LPG) sensing device is described by Kotresh, S., et al. [12]. A cost-effective spin coating technique was used to create the thin films on a glass substrate. The sample was taken in the form of powder, dissolved in m-cresol, and then coated on a glass substrate to form a thin film of the composite at room temperature. The room temperature response of the composite to LPG, CO_2 and NH_3 gases at a gas concentration of 500 ppm have also been tested. , the composite is more selective towards LPG than to CO_2 and NH_3 gases. With a response time of 75 seconds and a recovery time of 98 seconds, the maximum sensing response of 38.125% was noted at 500 ppm of LPG at ambient temperature.

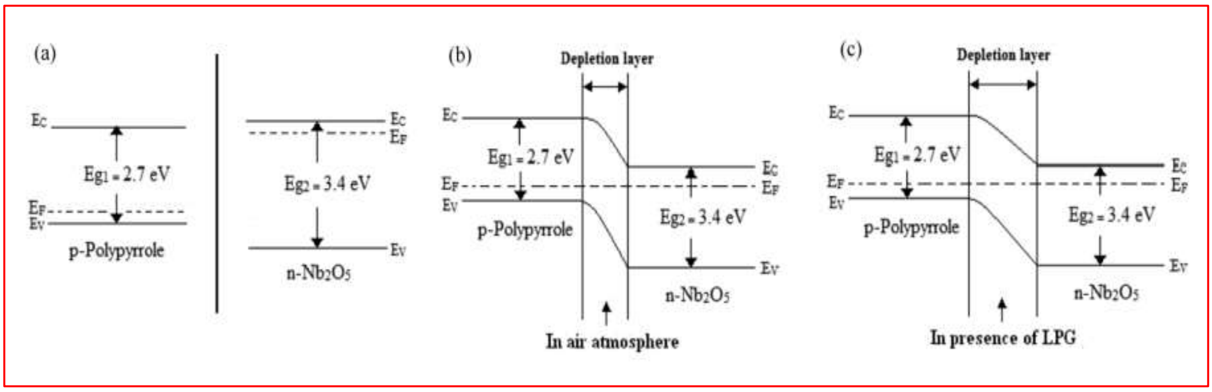

Figure 3: (a) energy band diagram of pure PPy and Nb_2O_5 (b) in presence of air energy band diagram for PPy/Nb2O5 and (c) in presence of LPG gas energy band diagram for PPy/ Nb_2O_5.

The sensing mechanism of composite is in the form of variation of energy band diagram presented in Figure 3 (a), (b) & (c) for pure PPy and Nb_2O_5, in presence of air and in presence of LPG gas molecules respectively. When LPG interacts with PPy, the reducing gas preferentially adsorbs on the PPy that has embedded Nb_2O_5 nanoparticles and donates electrons to the PPy matrix, increasing the space charge area at the PPy and Nb_2O_5 interface. As a result, the depletion layer's width widens, increasing the composite's resistance and raising the composite's sensitivity. From the current results of current paper it conclude that the dopant increase the gas response of the film at low operating temperature which is good for development of gas sensor.

The examinations of the capabilities of metal catalyst- and porous Nb_2O_5 -based Schottky diode-based devices for ethanol sensing were reported by Ab Kadir, Rosmalini, et al. [13]. Comprehensive research has been done on how Pd, Pt, and Au metal catalysts affect the contacts' barrier heights and sensing capabilities. According to the data, it was determined that the sensor with the Pd catalyst had the optimum performance. They offered the highest level of sensitivity. With Pd catalyst, quick response times and recovery times were also attained. The features of the Pd catalyst, which enabled more effective breakdown of the ethanol molecules and better solubility of the H atoms, were credited with the improved performance of the Pd- Nb_2O_5 gas sensor, which produced the highest Schottky barrier change. The analysis described here offers a thorough understanding of how different catalytic metals interact with Nb_2O_5 to create Schottky connections and how well they function as sensors for ethanol vapour. Comparing the sensing capabilities of very porous Nb_2O_5 Schottky-based sensors made with various catalytic metals. The materials used to make the sensors are a porous Nb_2O_5 that is somewhat organised and resembles a nano-vein. The variations in Schottky barrier height and the characteristics of the metal catalysts were explored in relation to the sensing behaviours.

The current article by BC Yadav et al. [14] compares the effectiveness of n-type ZnO, ZnO-TiO_2, and ZnO- Nb_2O_5 nanomaterials as humidity sensors. ZnO was synthesized via the hydroxide method. To increase sensitivity, TiO_2 and later Nb_2O_5 were utilized as additions. The average sensitivity for the n-type ZnO annealed at 550 °C was 8 M%RH. TiO_2 chemical mixing enhanced the sensitivity to 18 M/%RH, and Nb_2O_5 chemical mixing improved it to 19 M/%RH.

Patil, A. V., et al [15] studied the influence of Nb_2O_5 doping on ZnO thick film gas sensors. The thick films were prepared on alumina substrates using a screen printing technique. 1 wt. %, 3 wt. %, 5 wt. %, 7 wt. % and 10 wt. % concentrations of additive (Nb_2O_5) were used. When exposed to ethanol gas, thick films lose some of their surface resistance. Compared to pure ZnO film, the Nb_2O_5 doped films exhibit much greater sensitivity to ethanol gas. 3 wt%. With a quick response and recovery period, it was discovered that Nb_2O_5 -doped ZnO film was more sensitive (84%) to ethanol gas exposed at 300° C than other additive concentrations. According to the author's described sensing mechanism, Nb_2O_5 doped ZnO thick films are formed up of several Nb_2O_5 and ZnO grains that are joined to one another via grain boundaries. In the absence of the desired gas, this causes barrier height to build between the grains and raises resistance. The charge-carrier production mechanism brought on by the electronic flaws could be the cause of the Nb_2O_5 doped ZnO's dramatic improvement in electrical conductivity. Conductivity will rise as a result of the formed electrons and donor levels in ZnO's energy band gap.

Gaiardo, et al. [16] in this study, niobium oxide (Nb_2O_5) nanoclusters that were produced by magneton sputtering onto powdered graphene with a few layers will be tested for their gas sensing capabilities. Investigations into the sensing capabilities of films on alumina substrates were done for CO, H_2S, butanol, and NO_2 among other gases. This material demonstrated good NO_2 detection capabilities in both dry and moist air at room temperature. Nb_2O_5/graphene has greater NO_2 sensitivity. The electrical characterization demonstrated that the magnetron sputtering deposition parameters had an impact on the gas sensing capabilities of the Nb_2O_5/graphene layers.
C. G. Dighavkar et al. [17] conducted an experiment using pure and Nb_2O_5 doped TiO_2 thick films for various concentrations, reporting the influence of H_2S gas on sensing performance of the addition of Nb_2O_5. Screen printing was used to develop the film. After preparation, the films were exposed to an oxygen (O2) atmosphere and fired at 800 °C for two hours. Exposure to H_2S lowered the surface resistance of thick films. Author reported 1 % Nb_2O_5 doped TiO_2 films showed maximum selectivity for H_2S at 200 °C against all other tested gases including NH_3, LPG, CO_2, NO_2 and Ethanol.

3. Important factors influences on Nb_2O_5 gas sensor performance:

Nb_2O_5 belongs to the family of metal oxide semiconductors. There are number of parameters/ factors impact on the gas sensing properties of pure and Nb_2O_5 gas sensors. The parameters including structural, morphological, doping by nobel material, humidity, temperature, microstructure, dislocation density, lattice distortions, specific surface area, crystallite size, quantum effects, surface to volume ratio, calcination during synthesis, annealing temperature, film deposition techniques, synthesis technique, grain size, agglomeration of nanoparticles, porosity, voids, homogeneous and heterostructure junctions, spill over effect, porous structure, and electrical [18-21]. Figure 4 reveals different factors influences on Nb_2O_5 gas sensing performance.

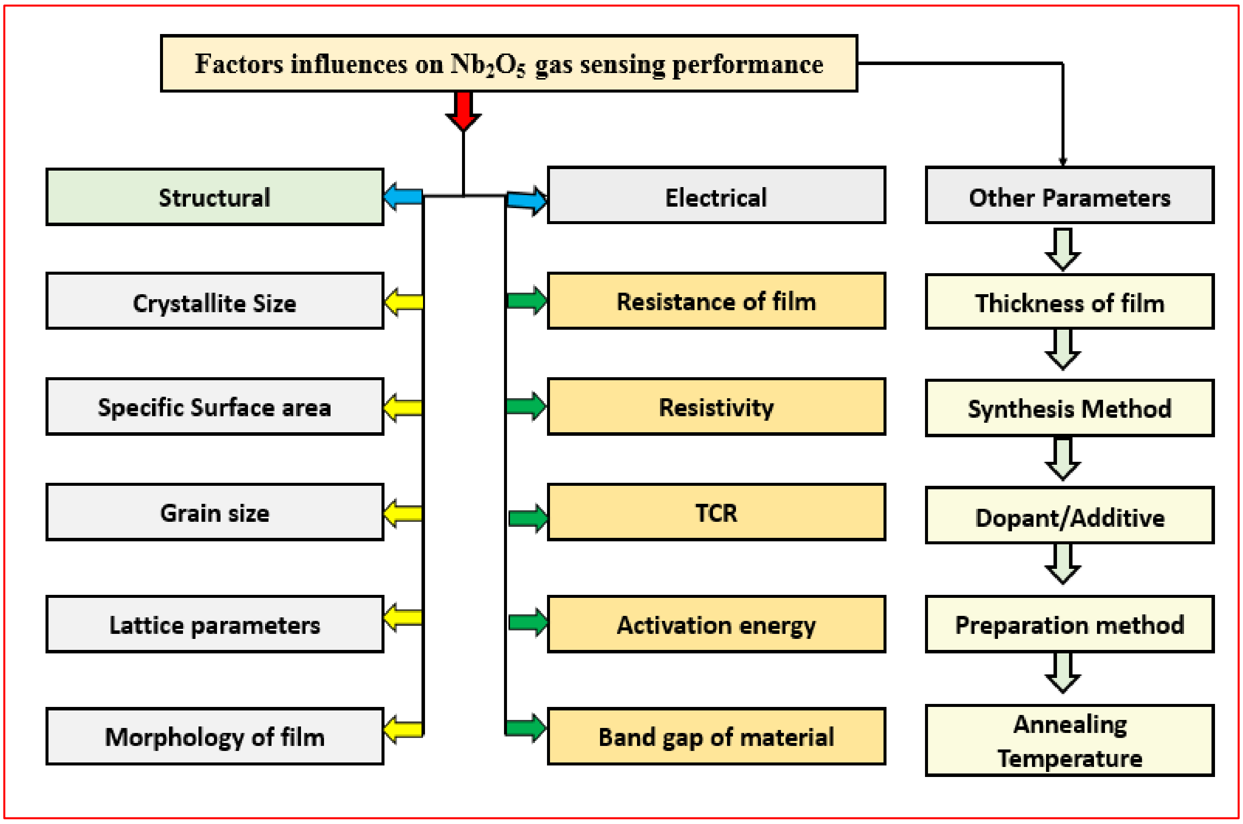

Figure 4: Parameters influence the Nb_2O_5 gas sensing performance.

4. Conclusion and future Scope:

In this review, we have presented the various synthesis techniques of pure and doped Nb_2O_5 nanoparticles. We also discussed the various pure and doped Nb_2O_5 thick and thin films preparation techniques. In addition, we also discussed undoped and different dopant variation Nb_2O_5 gas sensing mechanism gas sensor application. In gas sensor applications the gas sensing mechanism of Nb_2O_5 to reducing and oxidising gases were explained in brief. Additionally, the influence of structural and electrical parameters of Nb_2O_5 on gas sensing also explored in the current research paper.

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