

# Magnetic $Zn_xFe_{2-x}O_3$ Nanoparticles Enhanced Nanobiosensor Integrated with MOSFETs for Efficient Detections of Biomolecules and Cancerous Cells

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## Abstract

The human brain is mostly responsible for intelligence and consciousness. An artificial equivalence of this action is nanobiosensor, which is used in artificial intelligence. The need for nanodiagnosics platforms for detecting diseases at the genetic, molecular, and cellular level has triggered the development of nanobiosensors integrated with MOSFETs. This device enables simple, inexpensive rapid tests, accurate imaging methods, and accurate molecular diagnosis at point-of-care (POC). This device is seen as an innovative approach in detecting pathogens causing disease and drug discovery. In this paper, a magnetic nanoparticles-enhanced MOSFET-integrated nanobiosensor is presented. The MOSFET equation is formulated to explore the connection between various physical parameters. Then the impact of these parameters on the amplification and image resolution is discussed. The study revealed that MOSFET integrated magnetic  $Zn_xFe_{2-x}O_3$  nanoparticles-based nanobiosensors exhibit amplification, image resolution, sensitivity, and specificity in detecting biological organisms, biomolecules, and epidemic diseases, such as cancer.

**Keywords:** Nanobiosensor, nanoparticles, MOSFET,  $Zn_xFe_{2-x}O_3$ , cancerous cell

## INTRODUCTION

Magnetic nanostructures have been used as analytes for biosensors. It is designed to sense receptor cells, tissues, and biological organisms, such as enzymes and pathogens. The efficiency of the biosensors depends on field intensity, distance from the biological organism, and maybe surrounding temperatures and humidity. A nanobiosensor (NBS) is equipped for detecting infections disease, microbials, proteins, DNA, and biomolecules. They are also specialized instruments for detecting pathogens causing pain in human beings. Yu-Cheng Syu, et al. (2018) [1] highlighted that FET-based biosensors are promising candidates for applications that require ultra-sensitivity and rapid response times. Additionally, modern complementary metal-oxide semiconductor (CMOS) manufacturing

techniques offer benefits, such as miniaturization, sensing arrays, and the ability to integrate with electronic systems. The effectiveness of biosensors is measured by their efficiency. To enhance image resolution and amplification, field-effect transistors like metal oxide semiconductor field-effect transistors (MOSFETs) can relate to nanobiosensors. As the review of Bobby Reddy Jr., et al. (2011) [2] indicate, field effect transistors within the nanoscale dimension have emerged as a good label for free biological and chemical sensors. In this section, we will explore the nature of metal oxide field effect transistors (MOSFETs)-based biosensor detection processes.

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At present, one of the greatest challenges of designing nanobiosensors is the direct and fast transformation of a magnetic signal. As demonstrated by Jered B. Haun, et al. (2010) [3], the fundamental principle of diagnostic magnetic resonance involves using magnetic nanoparticles as proximity sensors that alter the spin-spin relaxation time of adjacent water molecules. This principle can be quantified by clinical MRI scanners or bench top nuclear magnetic resonance (NMR) relaxometers.  $ZnFe_2O_4$  and  $Zn_xFe_{2-x}O_3$  on magnetic glass carbon electrodes are used for biosensors and glucose sensors. There is a case where the biosensing activity of magnetic nanoparticles can be controlled by magnetic field and gravity. This effect is supported by the experimental work of Cody J. Landry, et al. (2008) [4] as the way of controlling biosensing of bacteria and fungi by the combined effect of magnetic field and gravity.

Yang Y, et al. (2023) [5] confirmed that biosensors incorporating photonic crystals are utilized to monitor changes in the proliferation and apoptosis of breast cancer cells. Nanobiosensors based on nanomaterials, such as nanorodes and nanoparticles provide very fast response, low-cost, and high efficiency. As the research of Ali Ramzannezhad, et al. (2021) [6] presented, magnetic iron oxide-based biosensors can detect the presence of proteins and functions based on interaction between nanorodes and proteins. Due to their controllable size and biocompatibility, the nanostructure of metal oxides is recognized for biosensing applications. Substitution of Zn into  $\alpha Fe_2O_3$  as a host matrix modifies the crystal structure of  $\alpha Fe_2O_3$  to enhance the biosensing application.

$Zn_xFe_{2-x}O_3$  nanoparticles are advantageous for biosensors since they modify optical properties, rate of charge carrier's transfer, and catalytic activity. According to research by Feng L., et al. (2023) [7], the enhanced optical properties of  $Zn_xFe_{2-x}O_3$  enable accurate and ultra-sensitive detection of neurotransmitters and specific markers for diseases, such as cancer and Alzheimer's disease. Ahmed Touhami, et al. (2024) [8] described the applications of multiferroic affinity biosensors in detecting cardiac disease, cancerous cells, and single-cell markers.

Nanobiosensor based on nanowires, such as carbon nanotubes can also be used for smart health care testing, disease diagnosis, and environmental monitoring. Research by Shrestha Tyagi, et al. (2022) [9] realized that metal oxide-based gas sensors are useful in environmental monitoring, public security, automotive, air conditioning for airplanes and spacecraft's, houses and sensors networks. In this circumstance, doping with iron, Fe, will reduce the cost and widen its access.

Advanced technology of iron-based nanomaterials involves the ability to use artificial intelligent devices for medical diagnosis, scientific analyzer, and engineering. The working substances for nanobiosensor are organic biosystems namely skin, blood, proteins, DNA, etc. Biosensors made of ZnO nanoparticles are used for detecting biological molecules, like enzymes and pathogens. Nanosensors and sensor networks as a diagnostic tool may also include nanoenabled motes or advanced nanosatellites. Therefore, it is important to consider the physio-bio-chemical properties of this matter while designing nanobiosensors.

### **MOSFET Integrated Nanobiosensor (NBS)**

Different biosensors had been identified by different research groups. Primary Kanchan Karki, et al. (2019) [10] had briefed amperometric, conductometric, electrochemical, immuno-optical, piezoelectric, and potentiometer biosensors. As Bergveld Piet (1985) [11] reviewed, MOSFETs-based biosensors include enzyme-modified field effect transistors (EFET) and immunologically modified FET (IFET). As Schöning, et al. (2002) [12] discussed, BioFETs, such as DNA field effect transistors (DNA FET), gene modified FET (GENFET), and cell potential, BioFETs (CPFET) had been developed by the early 2000s.

The zinc oxide matrix exhibited a phonon structure that enabled efficient luminescence upon doping with foreign ions. A nanobiosensor made of ZnO NRs is not efficient to catalyze glucose oxidation. Due to this weak response time and relaxation time, it is important to modify its auto-response time by

developing new mechanisms. This is usually done by doping with magnetic elements from transition metals or rare earth metals to form metal oxide nanostructures. Alternatively, forming a series of reactions with iron-based oxides, such as Fe<sub>2</sub>O<sub>3</sub>, NPs, or Fe<sub>3</sub>O<sub>4</sub>, NPs, mediates the heterogeneity of chemical oxidation/reduction of glucose. Milo Ognjanović, et al. (2018) [13] have discussed the potential applications of Zn<sub>x</sub>Fe<sub>3-x</sub>O<sub>4</sub>/carbon paste electrodes for glucose sensors.

P. Boisseau and B. Lou Baton (2011) [14] explained that monitoring of circulating molecules plays a vital role in detecting chronic diseases, such as diabetes or AIDS. MOSFET integrated biosensors bear's ultra-sensitive detections mass productions and has high capability at detecting DNA coding, HIV, and Alzheimer disease. However, there are challenges related to the utilization of nanomaterials. This might require active sensitivity of the sensor for time-dependent gradual process. To meet this requirement, nanobiosensors based on graphene and carbon nanotubes are important. This is because carbon nanomaterials are used in carbon dating and decay processes.

Thus, the calibrating process of Zn<sub>x</sub>Fe<sub>2-x</sub>O<sub>3</sub> based nanosensors should contained points labeled biomarkers, which function based on human organic fluids with a periodically varying time scale. Fe<sub>3</sub>O<sub>4</sub> NPs based biosensor show a linear relationship between electromotive force (emf) and sample concentration. However, up on Zn doping α-Fe<sub>2</sub>O<sub>3</sub> exhibits an exponential and slowly growing curve. Gennady Evtugyn, et al. (2014) [15] showed that DNA intercalation can improve the stability of electrodes. These actions effectively help in fabricating and manufacturing the desired nanobiosensor for detecting and treating cancer cells. They are applicable for detecting organic systems, including proteins, glucose, DNA, and human genomes. A segmented gate MOSFETs, referred to as charge coupled device (CCD) is used for image sensing.

### MOSFET Equation

As stated in the S. Khan and S. A. Mahmoud (2020) [16] work, MOSFETs modeling has three major approaches namely threshold, the inversion charge model, and surface potential model. We consider an n-channel MOSFETs and parameters contributing to biosensing applications. In the first order MOSFETs theory, the equation for drain current I<sub>D</sub> in the unsaturated region, V<sub>D</sub> < V<sub>G</sub> - V<sub>T</sub> is

$$I_D = \mu C_{ox} \frac{W}{L} \left[ (V_G - V_T) V_D - \frac{1}{2} V_D^2 \right] + I_{in} \quad (1)$$

Where μ, is the electron mobility of the channel, C<sub>ox</sub> the oxide capacitance per unit area, W/L the channel width-to-length ratio, V<sub>G</sub> and V<sub>D</sub> are the applied gate-source and drain-source voltages respectively. V<sub>T</sub> is the threshold voltage, which can be described as follows.

$$V_T = \varepsilon + V_{FB} - V_T + \frac{Q_B}{C_{ox}} + 2\phi_f \quad (2)$$

$$V_{FB} = \frac{\phi_m}{q} - \frac{\phi_{zn}}{q} + \frac{Q_{it} + Q_f}{C_{ox}} \quad (3)$$

Φ<sub>m</sub> and Φ<sub>si</sub> are the metal and iron work functions, respectively and Q<sub>if</sub> and Q<sub>f</sub> are the charge of the interface traps and fixed oxide charges, respectively, both per unit area. In the saturated region Equations (2) and (3) are still valid, but Equation (1) is replaced by

$$I_D = \mu_o C_{ox} \frac{W}{L} (V_G - V_T)^2 \quad (4)$$

To study the biosensing applications of MOSFETs, it is important to study the environmental conditions and parameters contributing to these conditions. The resulting sensors are so sensitive to temperature, electric field, etc.

$$V_G - V_T = \vec{E}L \quad (5)$$

$$I_D = \mu_o C_{ox} \frac{W}{L} (\vec{E}L)^2 \quad (6)$$

Assuming the distance between the two layers,  $d = \frac{\epsilon_0 A}{C}$  and drain current,  $I_D = \mu_0 C_{ox} \frac{\epsilon_0 V \bar{E}^2}{C}$ ;

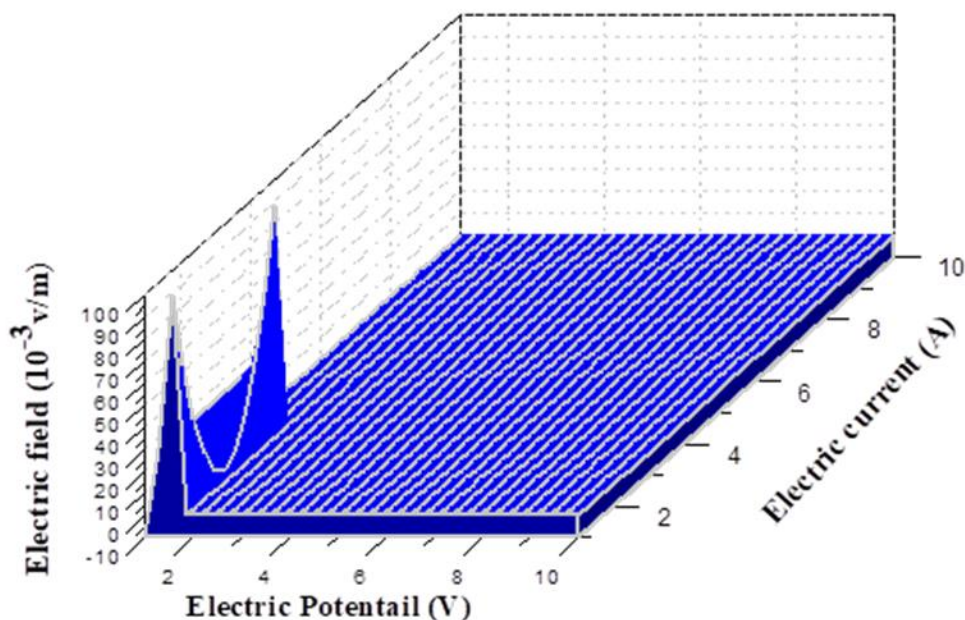
$$I_D = \frac{\mu_0 \epsilon_0 V \bar{E}^2}{\xi} \quad (7)$$

$$I_D = \frac{1.1 \times 10^7 (S^2/m) V \bar{E}^2}{\xi} \quad (8)$$

The relation between drain current,  $I_D$ , and square of electric field,  $\bar{E}^2$  is illustrated in figure by generating data for the values  $\xi = 30$ . The ratio of initial capacitance to capacitance, i.e., after insertion of dielectric Zn<sub>x</sub>Fe<sub>2-x</sub>O<sub>3</sub> is:

$$\frac{1}{\xi} = \frac{C_{ox}}{C}$$

Where,  $\mu_0 = 4\pi \times 10^{-7} \text{H/m}$ ,  $\epsilon_0 = 8.85 \times 10^{12} \text{F/m}$ ,  $C$  is the capacitance after dielectric field different from air is field;  $C_{ox}$  is the capacitance of thin oxide layer for air filled capacitor and  $C$  is the capacitance after the introduction of dielectric which is obtained by P-Spice MOSFETs model.  $\xi$  is the relative permittivity, and  $\bar{E}$  is the electric field vectors. By decreasing the relative permittivity, as  $\xi$  decrease gradually, the drain current can be increased slowly. When the MOSFET is in the write mode ( $R/\bar{W} = 0$ ), the input buffer is enabled. When it is in read mode, ( $R/\bar{W} = 1$ ), output buffer is enabled.



**Figure 1.** Variation of drain current as a function of electric field as shown in Figure 1, the drain current is directly proportional to the square of the electric field and inversely proportional to the dielectric constant. However, it is directly proportional to the electric potential. This is because Zn<sub>x</sub>Fe<sub>2-x</sub>O<sub>3</sub> nanoparticles have high dielectric value and require a high energy cost for the current to cross insulated the depletion layer.

## **Properties of MOSFETs Integrated Nanobiosensor (NBS)**

### ***Biocompatibility***

Biocompatibility of nanomaterials is its ability to interact easily with living tissues, cells, and body fluids. It is equated with strength, resistance, and sensitivity in performing therapeutic, imaging, and diagnostic processes. For effective *in vivo* and *in vitro* detection among molecular interactions, nanosensor should exhibit a high degree of biocompatibility, sensitivity, and specificity. Research by Ahmad Taufiq, et al. (2021) [17] verified that nanoparticles with high biocompatibility are promising safety agents in living organisms. As noted by George Kasparis, et al. (2023) [18], the biocompatibility of  $Zn_xFe_{2-x}O_3$  nanoparticles (NPs) can be assessed through metabolic activity, membrane integrity, and clonogenic assays. This shows that Zn doped iron oxides can replace the functionality of  $Fe_3O_4$  with modified properties. MOSFETs bearing nanobiosensor should be designed from composites of  $Zn_xFe_{2-x}O_3$  nanoparticles. Most of the time advisable nanomaterials for making  $Zn_xFe_{2-x}O_3$  composites are polymers, such as chitin, chitosan, hydrogel, and carbon nanotube. These nanomaterials have high mechanical strength, particularly high young's modules. They are also characterized by fluorescence. Hence, coating  $Zn_xFe_{2-x}O_3$  nanoparticles with these nanomaterials will greatly improve the biocompatibility of biosensors while the MOSFET part amplifies signals. Besides, it increases the cell viability.

### ***Sensitivity***

Many factors determine the working mechanism and functionality of nanobiosensor. Among these factors the most pillars are sensitivity, linearity, reproducibility, specificity, and amplification factor. In turn, four important factors determine the sensitivity of  $Zn_xFe_{2-x}O_3$  based nanobiosensor. These are its adaptability with human body tissue, its reactivity at nanoscale, its surface area to volume ratio, and strain. Tripathy and Kim (2018) [19] demonstrated that functionalizing metal oxide nanostructures not only enhances stability but also improves selectivity and sensitivity while reducing the detection limits of the targeted biosensor. Metal oxides can be doped to form nanohybrid structures. These hybrid structures have high sensitivity. Hence, doping can improve the sensitivity of nanoparticles and composites to a greater extent.

Immunosensors made by either doping of ZnO with iron (Fe) or doping  $\alpha Fe_2O_3$  with Zn cations can meet such requirement since both Zn and Fe are isoelectronic to their respective host matrix. Other materials are available for sensing biomolecules, such as glucose and the acidity of body fluid. For a typical justification, MW Akram, et al. (2019) [20] verified that CH- $Fe_3O_4$  based sensor are applicable for clinical diagnosis. Ping Chia Su, et al. (2020) [21] revealed that silicon nanowire field effect transistor can function as biosensing transducers, which are used for ultrasensitive monitoring of charged bio molecules and signal transformation. Shih Mein Chang, et al. (2020) [22] have noticed that the use of silicon nanowire-field effect transistor (Si NW-FET) in detecting cardiac troponin in obesity induced myocardial injure. Silicon-based metal oxide semiconductor field effect transistors (MOSFETs) can also serve as immunosensors. However, silicon-based FETs can be damaged by exposure to solutions containing ions.

Emerging technologies like nanobiosensor exhibit field enhanced sensitivity, stability, and optical and field response. Biosensors have clinical applications due to their excellent anti-interference ability in samples of human serum. FET biosensor could provide a more accurate diagnosis result. Biosensors based on ion-sensitive field effect transistors (ISFET) have good reliability and sensitivity for the analysis of biomolecules, such as proteins, DNA, enzymes, and cells. For exemplifications, the sensitivity of ZnO FET and  $Zn_xFe_{2-x}O_3$  FET biosensors is better than that of  $TiO_2$  and  $Al_2O_3$  biosensors. Therefore, by carefully controlling the stability, sensitivity, and linearity of MOSFETs integrated biosensors, it is possible to detect, image, and take information about abnormalities in human body metabolism. As shown by Chii Wann Lin and Chia Chen Chang (2011) [23], multi-analytic surface plasmon resonance (SPR) biosensors enable the concurrent detection of various cancer markers.

The exceptional sensitivity of surface plasmon resonance (SPR)-based sensors offers promising opportunities for the early detection of breast cancer and its treatment. However, the sensitivity of nanobiosensors varies depending on the specific semiconductors used in their construction. This variation arises from differences in the band gap of the semiconductors and the strength of the fields involved.

### Amplification

The ferromagnetic semiconductors allow spin current signal amplification rather than electron current amplifications. This is done by (1) reinforcing the alignment of spins in the same direction as the applied magnetic field, (2) promoting giant magneto resistance and Faraday rotations, and (3) reducing the moisture content there by cooling a cell to create uncomfortable conditions for bacterial and viral growth.

Unlike silicon chips, MOSFETs reduce the dielectrics since their oxide layer forms an insulating layer due to the generation of uniform and long-term polarization. Thus, its electric charge storing capacity is reliable. In order to increase its amplification factors, it is important to (1) decrease its relative permittivity, (2) add filler materials, such as chitosan, conduct polymers, and (3) coating them with carbon nanotube.

Functional nanobiosensor must possess: (1) recognition element (enzyme, antibody, DNA, etc.), (2) signal transducer structure (electrical, optical, or thermal), and (3) amplification or processing element. To reduce the nanoparticles agglomeration,  $Zn_xFe_{2-x}O_3$  is preferred as a recognition element, while MOSFETs are preferred as an amplification element. As the research by E. Macchia, et al. (2019) [24] indicates, EGOFETs and OECTs exhibit an amplification factor that is 1000 greater than homologous potentiometer electrochemical sensors and immunometric sensors.

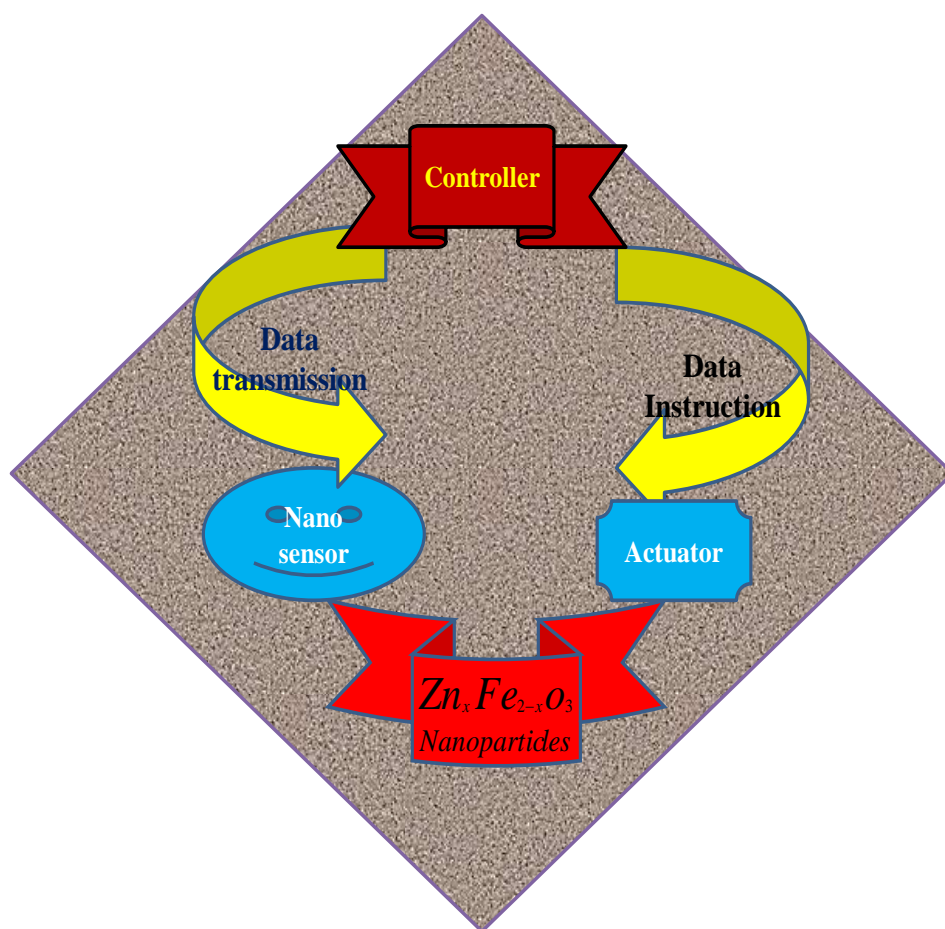
Most Nanobiosensor are made of semiconductor nanostructures. This is because the charge carrier, electron density, energy band, and optical properties of semiconductor nanostructures can be modified by external agents, such as field and temperature. Nanobiosensor based on magnetic  $Zn_xFe_{2-x}O_3$  nanoparticles has high absorption power and signal amplifications. As Hasanzadeh M., et al. (2015) [25] demonstrated, numerous strategies have been developed for signal-amplification. Among these strategies, chemical, immune, DNA, enzyme, and aptamers based biosensors are encouraged. In addition, surface amplified nanobiosensor is usually sandwiched by biomolecules, antibiotics, organic compounds, and  $Zn_xFe_{2-x}O_3$  for detecting viruses. Biosensors integrated with either MOSFETs or POSFETs derive high signal amplification and resolution.

MOSFETs or POSFET integrated biosensors with functional  $Zn_xFe_{2-x}O_3$  nanocomposite are widely used in detection purposes. The detection limit and efficiency of nanobiosensor can be modified by connecting it with POSFET of defined gain current. Zn doped iron oxide nanoparticles coated with polycyclic aromatic hydrocarbon have improved sensing efficiency. In addition, integrating sensors with transducers or transistors, such as MOSFETs will increase the biosensing capacity of nanosensors. As Brandon Ortiz-Casas et al. 2021 [26] verified, Zn doped iron oxides nanoparticles can be employed to capture cancer-infected proteins, circulating DNA tumors, and exosomes by coating with antibiotics, peptides, and moieties. As discussed by V. Sebastian & M. Gimenez (2016) [27] nanobiosensor take advantage of the special properties of the nanoparticles for non-invasive diagnosis of diseases to determine pollutants in water or to detect antibiotics or allergens in food.

Typical biosensors designed for cancer diagnosis and detection are as follows (Figure 2).

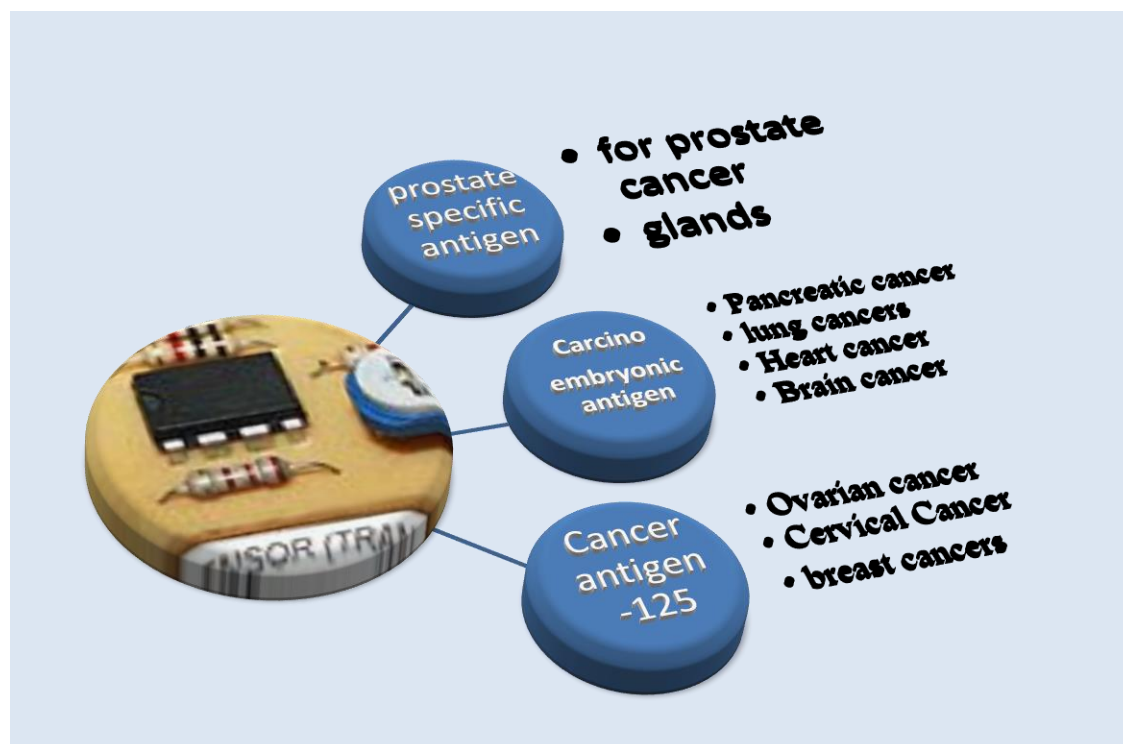
The piezoelectric polymer semiconductor field-effect transistor (FET) layer situated between the metal gate and the oxide layer of MOSFETs functions as an acoustically sensitive transducer, enabling its application in ultrasound imaging. Ravinder S. Dahiya, et al. (2009) [28] have shown the capability of POSFET to convert directly the force into voltage that is comparable with mechanoreceptors.

Nanotechnology helps with the real time monitoring of agrochemicals *via* nanobiosensor. Proteins and macromolecules are continuously released by cancer cells and can be detected by biomarkers, most of which are designed to identify specific cancer types. These biomarkers are useful for detecting and imaging metastatic brain tumors. In clinical and therapeutic contexts, pathway-level biomarkers are commonly used. However, Rotem Ben-Hamo, et al. (2020) [29] pointed out that identifying pathway-based biomarker expression is limited due to the insufficient availability of large-scale gene expression data from various cancer cell lines and their varying sensitivity to a broad range of anti-cancer drugs (Figure 3).



**Figure 2.** Working mechanism of  $Zn_xFe_{2-x}O_3$  nanobiosensors.

According to Ionel, Serban, and Alexandra Enesca (2020) [30], ZnO is adaptable as a permanent human sensor for chronic diseases like diabetes and cancer due to its non-toxicity and compatibility with human skin. Recent research, particularly by Adaora Nwosu, et al. (2022) [31], has demonstrated the development of microbioelectronic devices with sensor-bearing pills capable of detecting cancerous DNA, gases released by gut microbes, stomach bleeds, body temperature, and oxygen levels. Zn doped iron oxides have potential to interact with enzyme like nanomaterials referred to as nanoenzymes. Hence, by performing chemical reactions between the two entities, it is possible to perform multi function's including detection, sensing, and medical treatment. As Hongzhi Liang, et al. (2020) [32] presented, nanoenzymes are commonly used in immunosensors due to their good stability, biocompatibility, and relatively low cost. Nanoenzymes are used for detecting and treating Covid-19 and cancerous cells. Research by Ashis Tripathy et al. (2021) [33] demonstrates that enzyme-based biosensors are used for detection of  $H_2O_2$  Glucose, immunobiosensors, DNA biosensors, and cells.



**Figure 3.** Nanosensors (infrared sensors) for detecting different cancers.

### $Zn_xFe_{2-x}O_3$ Nanobiosensor for Sensing Biomolecules

Substitutions of Zn into  $Fe_2O_3$  matrix increase its crystal structure and the radiation absorption capacity. Due to its absorption capacity at a visible wavelength,  $Zn_xFe_{2-x}O_3$  regulates climate perturbation caused by dust aerosols. Besides, their high adsorption capacity enables removing heavy ions, such as  $Pb^+$  and  $Cl^-$ , etc., from industrial waste and the environment. According to Mina Adampourezar, et al. (2023) [34], magnetic nanoparticles can be easily functionalized with various organic and biological molecules, such as aptamers, polymers, enzymes, and antibodies, and can serve as signal tags in various applications. These nanomaterials are widely used in sensing oxygen, ammonia, and photocatalysis.

The use of  $Zn_xFe_{2-x}O_3$  nanoparticles is not limited to only nanosensors but also is a primary important materials in nanomedicine. Biosensors based on  $Zn_xFe_{2-x}O_3$  nanoparticles are widely used for bioelectronics, detecting biomolecules, and imaging. Magnetic field guided (MFG)  $Zn_xFe_{2-x}O_3$  nanobiosensor is used for sensing remote cell, tissue, and DNA damage. Nanobiosensors are also used for sensing biomolecules, such as oligonucleotides, tumor proteins, and genes. Besides, Banigo et al. 2020 [35] outlined that the use of nanobiosensors for detecting biomaterials, such as drugs, cholesterol, enzymes, blood, glucose, RNA, DNA, and protein. L. Crossely, et al. (2019) [36] revealed field effect transistor (FET) sensors are used for detecting tumors and tumor proteins,  $PT_{53}$ .

Nanobiosensors are made of  $Zn_{0.4}Fe_{1.6}O_3$  serves as an antenna for far place media, sensing magnetic minerals, detecting pains, and human feeling. Field enhanced biosensors are used for sensing gas and thin films, such as hydrogen films. They are used to detect the formation of hydrogen films around the leans of lung, kidney, liver, and abdomens. As identified by Kefeng Wei, et al. (2019) [37] Zn doped  $\alpha-Fe_2O_3$  nanorodes is used for high-hydrogen gas sensing due to its fast mass transport. Besides, research, such as Kyung Taek Rim, et al. (2013) [38] and Mousavisani, et al. (2018) [39] have revealed the ability of DNA/Au biosensors for detecting DNA damage. Moreover, MOSFETs or POSFET integrated nanobiosensor are preferred for detecting such carcinogens. This is because like any other semiconductor device, MOSFETs/or POSFETs based nanobiosensor have high sensitivity to stimulus,

such as temperature, electric field, and magnetic fields. Currently, graphene field effect transistors are widely used for detecting and monitoring cancers.

### **MOSFETs integrated Biosensors for Medical Imaging**

Many iron-based ferromagnetic oxides are adaptable to human body cells and tissues. This is due to two reasons (1) a standard human body temperature is 37°, which is comparatively in the same range as the Curie temperatures of oxide based diluted magnetic semiconductors, (2) the human body contains hemoglobin's which is enriched with oxygen and iron. Hence, it is compatible and can easily interact with iron containing ferromagnetic oxides.

The transmission of electron-chemical impulse between brain and body muscles might interrupt body cells and tissues. Bursting tumor cells or any abnormalities in tumor growth either can cause impairment or injuries. The interruption of signal transmission between brain and muscle are causes for coordination problems. This problem is detectable by the help of nanobiosensor.

MOSFETs are used for cancer cell imaging. MOSFETs enhance the generation and detection of radio frequency signals for magnetic resonance imaging with good resolution quality. As Vivek Mishra, et al. (2021) [40] presented, MOSFETS are used as radiation dosimeters for cancer therapy. Moreover, the ultrasound imaging process is affected by the potential of MOSFETS at converting electrical energy to sound energy in diagnosis procedures. Experimental observation of N. Mendiratta, et al. (2020) [41] shows that decreasing threshold voltage by increasing the dielectric constant between threshold double gate current. MOSFETs are reliably used in radiotherapy, radiology, and real-time readout dosimeter detectors. To sum up, MOSFETs or POSFET integrated nanobiosensor presents a good detection capability and therapeutic action.

### **Magnetic Field Guided (MFG) Nanobiosensor for Detecting Carcinogens**

Electromagnetic and nuclear radiation can contribute to cancer.  $\text{TiO}_2$ ,  $\alpha\text{-Fe}_2\text{O}_3$ , and  $\text{ZnO}$  nanoparticles are separately used to block UV-radiations. This shows that  $\text{Zn}_x\text{Fe}_{2-x}\text{O}_3$  can block UV-rays since it can be chemically prepared by the reaction of these nanoparticles in definite proportion. As a result, it can help protect body tissues and cells from developing cancer. According to M. T. Islam and M. A. Uddin (2017) [42], biosensors play a significant role in diagnosing infectious diseases. Immunosensor arrays are particularly useful for immunophenotyping and the qualitative measurement of cardiac markers in undiluted serum samples. Nanobiosensor and nano biomarkers enable easily monitoring and prominent cancer therapy. Biomarkers are specialized for predicting therapeutic response and diagnosis of serum or tissue cancer. The reliability of biomarkers is an important factor for decision-making while its validity is very important for laboratory and epidemiological issues. As interpreted by Anant Narayan Bhatt, et al. (2010) [43], biomarkers based on genomics and proteomic diagnostic technology perform complex mathematical algorithms and analysis big experimental data for diagnosis process. The efficiency of biomarkers can be improved by smart fluids.

### **Advantages of Nano Biosensors over Mammography**

Mammography is a low-dose X-ray technique used to visualize the internal structures of the breast. Reports, such as American Cancer Society (2017) [44] indicate that almost (80%) of breast cancers are invasive, or infiltrating. In this circumstance, mammography is used in early cancer detection. Digital mammography, especially 3D mammography, offers high-resolution images, computer-assisted detection of abnormalities like cancerous tumors, and the convenience of easily sharing digital files with others. Additionally, digital mammography minimizes the risk of radiation exposure to tissues and the placenta Hassani, et al. (2020) & Fadeyev, et al. (2022) [45, 46]. Contrast-enhanced (CE) digital mammography offers more accuracy and diagnostic than mammography and ultrasound in dense breasts. Mammography has some drawbacks. Some of the disadvantages of mammography are radiation dose, virtual digital alarm integration, and overdiagnosis. To this end, nanobiosensors are encouraged since they enable ultrasensitive diagnosis, detection, therapy, and drug delivery.

## CONCLUSIONS

Magnetic Zn<sub>x</sub>Fe<sub>2-x</sub>O<sub>3</sub> nanoparticles have distinguished bio-physical properties. It is biocompatible, biodegradable, sensitive, and has a high surface area to volume ratio. It also exhibits pronounced electrical, magnetic, optical, and thermal properties. It is also seen that Zn<sub>x</sub>Fe<sub>2-x</sub>O<sub>3</sub> nanoparticles have a high dielectric value. This property makes Zn<sub>x</sub>Fe<sub>2-x</sub>O<sub>3</sub> as an efficient electrode material in MOSFET integrated nanobiosensor. These properties also enable enhanced detection/sensing of biomolecules, biological organisms, and enhanced disease treatment. Moreover, the magnetic field enhanced Zn<sub>x</sub>Fe<sub>2-x</sub>O<sub>3</sub> nanobiosensor exhibit strong detection and remote sensing of cancerous cells, damaged cells, DNA, and tissue. The research demonstrates that MOSFET integrated nanobiosensor exhibit better efficiency, image amplifications, resolutions, and detections. It also demonstrates superior imaging capabilities for breast cancer when compared to mammography. In the future, this study will provide versatile material for efficient bioelectronic medicine.

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