



# Advances in electrochemical and optical sensing techniques for vitamins detection: a review

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## Abstract

Vitamins are essential nutrients that aid in metabolism, cell growth, and the appropriate functioning of other biomolecules. They are required for the proper functioning of various systems in human body. Both vitamin shortage and excess can pave the way for a variety of illnesses. They enter the body via food and supplements eaten, making it critical to measure the vitamin concentrations in food, medicines, and biological fluids. The concentrations of these vitamins are determined using a variety of techniques. The performance measure of the techniques like selectivity, sensitivity, and limit of detection is crucial in their utilization. Among the many techniques of determination, electrochemical sensing and optical sensing have garnered widespread interest because of their potential to improve performance. Additionally, the introduction of innovative materials has added a lot of benefits to sensing. The aim of this article is to summarize significant work toward recent improvements in electrochemical and optical methods for detecting different vitamins. Additionally, it attempts to assess the gaps in vitamin sensing in order to encourage researchers to fill such gaps that will benefit the community.

**Keywords** Vitamin · Electrochemical sensing · Optical sensing · Biomolecules · Biosensors

## Introduction

Vitamins are nutrients that the human body does not synthesize but are consumed through the food. It helps to sustain the growth of cells, tissues, and organs, as well as boost the immune system. It also helps in the conversion of food into energy, reducing illness risk, and promoting a healthy lifestyle. For optimal growth and metabolism, the body needs an appropriate supply of vitamins. Any departure from the recommended quantity might be a sign of illness in the long term. Vitamins are called

micronutrients as their requirement is less than 100 mg/day (Sami et al. 2014). Its measurement assists in determining the effects of vitamin shortage or toxicity in the human body (Bystrowska et al. Apr 2009). The body requires thirteen vitamins, which are divided into fat-soluble and water-soluble categories. Night blindness, scurvy, and rickets are few among the diseases caused by lack of these vitamins (Saenger et al. 2006). Pre-treatment and measurement are two important phases in the process of determining vitamin content. Because the sample obtained does not always meet the requirements of the quantification technique, pre-treatment converts the sample into a suitable form. These techniques of pre-treatment have been shown to improve analytical performance. Various determination techniques are employed to determine the precise concentration of the analyte. Liquid chromatography, colorimetry, electrochemistry, and fiber optic sensing are just a few of the techniques available. HPLC (high-performance liquid chromatography) is a commonly used method for quantifying vitamins, and it has been employed in a variety of studies to discover vitamins in dietary and biological materials (Sami et al. 2014; Bystrowska et al. Apr

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2009; Saenger et al. 2006; Mohamed et al. 2020; Fontannaz et al. 2006). Biosensors are devices that determine the presence or concentration of a biological analyte, such as a biomolecule, a biological structure, or a microbe. It composes bioreceptor, transducer, and the detector. It also allows to sense the vitamins, and depending upon the type of output signal from transducer, the different types of sensors exist. The transducer's output is then routed into a detector, which aids in determining the precise concentration of the target analyte. In this paper, the focus is on electrochemical and optical sensors.

When the output of the transducer is an electronic signal in terms of change in voltage, current, or conductance, it is known as voltammetric, amperometric, and conductometric sensing. The electrochemical sensing of vitamins is widely used by various researchers across the globe (Huang et al. 2021). It is used for finding the concentration of Vit A (Lv et al. 2017), Vit D (Sarkar et al. 2018), Vit K<sub>2</sub> (Jedlińska et al. 2018), and other vitamins.

Optical sensing, on the other hand, is when the output is an optical signal. The optical characteristics of signal-generated like fluorescence, absorbance, refractive index, and Raman scattering, are used to quantify and evaluate the output. Colorimetric, plasmonic, fluorescence, and spectrophotometric optical sensing are the most common types. Optical sensing, too, has gathered a lot of attention. Recent research could find colorimetric methods being used to determine Vit D (Lee et al. 2017; Keyfi et al. 2018), Vit C (Kalaiyarasan and Joseph May 2019), and B1 (Duenchay et al. 2020). Surface plasmon resonance (SPR) and localized surface plasmon resonance (LSPR)-based sensing have also generated a lot of interest for Vit A (Prakashan et al. 2019), Vit D (Jo et al. 2021), Vit C (Zhu et al. 2020a), and Vit B3 (Verma and Gupta 2013) detection. Both electrochemical and optical sensing techniques are in high demand due to their simplicity of use, low cost, and increased performance.

The aim of designing different sensors by various research group is to improve the performance that can be done by making it highly selective and specific to the target analyte and by improving the sensitivity. The use of different biorecognition elements like enzyme, antibody, and nucleic acid tends to make the sensors highly selective and specific to the target analyte. The transduction process in electrochemical and optical sensing is also one way of improving performance. Many researchers have utilized nanomaterials' unique optical, electronic, and catalytic properties for improved transduction process. Different nanostructures like nanotube (NT), nanoparticles (NP), nanofibers (nF), nanorods (NR), and nanocomposites have shown to enhance the performance of sensors (Sarkar et al. 2018) (Chauhan et al. 2018, 2019). Nanomaterials are also used in SPR- and LSPR-based sensors (Prakashan et al.

2019; Arduini et al. 2020). Sensitivity, selectivity, LOD, and the sensor's response time are all improved when an appropriate biorecognition element and a transducer are used together.

This review is intended to analyze the recent advancements in electrochemical and optical sensing used for detecting vitamins. The different techniques employed for sensing vitamins from various sources like food, drugs, and biological samples are discussed. This will help researchers to identify the gap and scope of the existing research.

## Types of vitamins and detection techniques

### Fat-soluble vitamins

Vitamins A, D, E, and K are members of this category. Night blindness, xerophthalmia, increased oxidative stress, and many other diseases are caused due to deficiency of these vitamins (Albahrani and Greaves 2016). Research has also revealed a link between the vitamins, emphasizing the importance of keeping track of their levels (Ondreicka et al. May 1998). Table 1 gives the comparative analysis of fat soluble vitamins with respect to its performance parameters.

### Detection of Vit A

Vit A is crucial for many physiological processes, supports daily skin cell replacement, and is vital for vision. It helps maintain the immune system healthy, aids in growth, and is helpful for many other systems of the body. By using different materials over the surface of the electrode and employing different electrodes, electrochemical sensing can be improved.

An electrochemical sensor with a modified carbon paste electrode (CPE) using Pt:Co nanoalloy over the ionic liquid (IL) was developed specifically for sensing Vit A (Lv et al. 2017). Using the square-wave voltammetry (SWV) technique, the linear response was between 0.1  $\mu\text{M}$  and 100  $\mu\text{M}$ , with LOD of 0.04  $\mu\text{M}$ . The result showed improvement in performance in comparison with spectrophotometric and HPLC. This method can be used to determine Vit A in tablets and food samples.

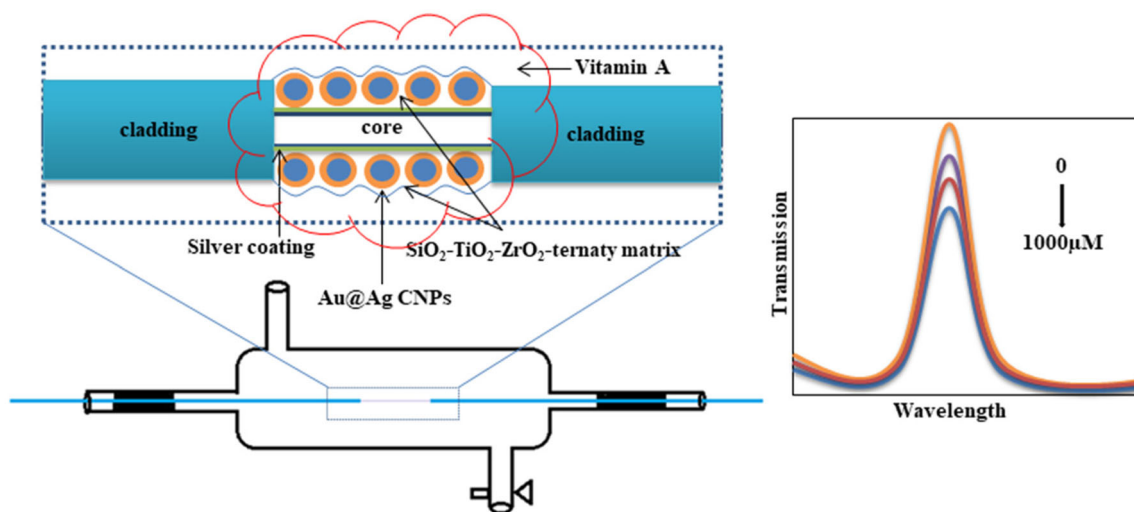
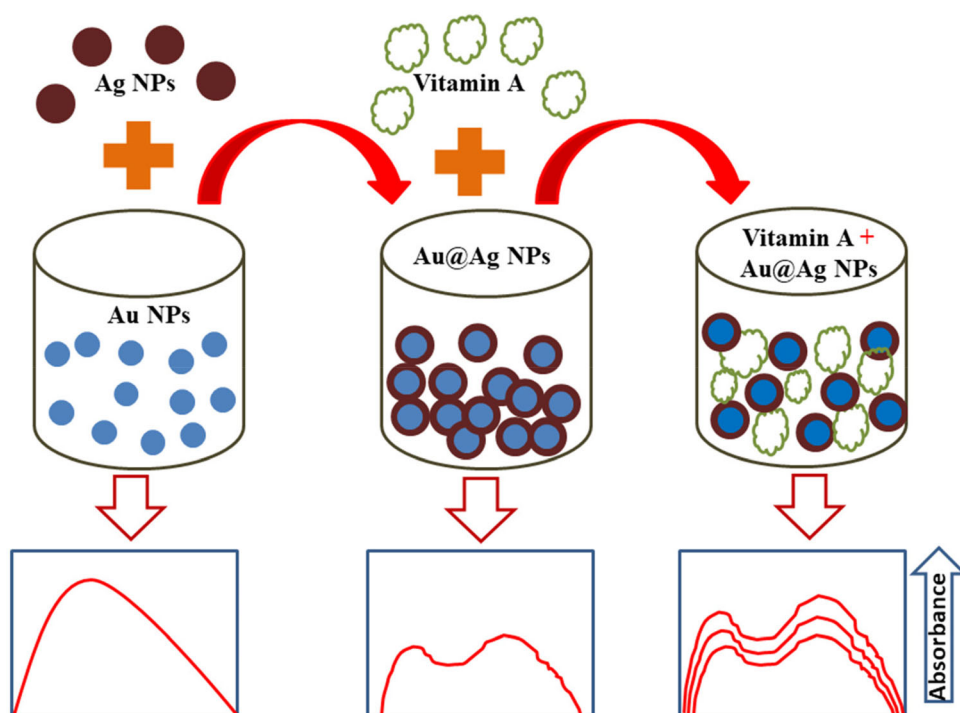
A SPR-based fiber optic sensor (FOS) with a linear response in the 10–1000  $\mu\text{M}$  range and a low LOD of 10 M has been proposed. Au@Ag core-shell NP(CNP) was doped into a SiO<sub>2</sub>-TiO<sub>2</sub>-ZrO<sub>2</sub> ternary matrix and coated over a plastic multi-mode step-index fiber to enhance performance. The 30-nm Au@Ag core-shell NP enhanced Vit A selectivity over other biomolecules (Prakashan et al. 2019). The effect of the interaction with CNP is explained in Fig. 1. Au@Ag CNPs increased the absorbance for

**Table 1** Comparative table of sensors for fat-soluble vitamins

Vitamin	Materials used	Specimens tested	Sensitivity	LOD	Linear range	Method	Reference
A	Pt-Co/IL/CPE	Tablet and Food	n.r. <sup>a</sup>	0.04 μM	0.1–100 μM	Electrochemical (SWV)	Lv et al. 2017)
A	Au@Ag CNP embedded SiO <sub>2</sub> -TiO <sub>2</sub> -ZrO <sub>2</sub>	Biomolecules	n.r. <sup>a</sup>	10 μM	10–1000 μM	Fiber optic sensing (SPR)	Prakashan et al. 2019)
D <sub>2</sub>	BSA/Ab-VD <sub>2</sub> /CD-CH/ITO	Milk shakes	0.2 μA ng <sup>-1</sup> mL cm <sup>-2</sup>	1.35 ng/ mL	10–50 ng /mL	Electrochemical (DPV)	Sarkar et al. 2018)
D <sub>3</sub>	Anti-VD/Fe <sub>3</sub> O <sub>4</sub> -PANnFs/ITO	Human blood sample	0.90 μA ng <sup>-1</sup> mL cm <sup>-2</sup>	0.12 ng/ mL	10–100 ng /mL	Electrochemical (DPV)	Chauhan et al. 2018)
D <sub>3</sub>	BSA/Ab-VD/Asp-Gd <sub>2</sub> O <sub>3</sub> NRs/ITO	Blood serum	0.38 μA ng <sup>-1</sup> mL cm <sup>-2</sup>	0.10 ng /mL	10–100 ng/ mL	Electrochemical (DPV)	Chauhan et al. 2019)
D <sub>2</sub> , D <sub>3</sub>	AuPd nanodendrites/GCE	Drugs	n.r. <sup>a</sup>	0.05 μM, 0.18 μM	1–10 μM, 5–50 μM	Electrochemical	Men 2017)
D <sub>3</sub>	Cu-Ni NPs /reduced Fullerene-C <sub>60</sub> /GCE	Clinical and pharmaceutical samples	n.r. <sup>a</sup>	0.0025 μM	1.25–475 μM	Electrochemical	Anusha et al. 2020)
D <sub>3</sub>	p-phenylenediamine-resorcinol (MIP) / SPCE	Human plasma	n.r. <sup>a</sup>	1 × 10 <sup>-12</sup> M	1 × 10 <sup>-11</sup> –2 × 10 <sup>-9</sup> M	Electrochemical	Kia et al. 2019)
D <sub>3</sub>	BSA/ anti-25VD <sub>3</sub> / nCeO <sub>2</sub> /CC	Blood serum	2.08 μA ng <sup>-1</sup> mL cm <sup>-2</sup>	4.63 ng mL <sup>-1</sup>	1–200 ng /mL	Electrochemical	Chauhan et al. 2021)
D <sub>3</sub>	PEG-Free Gold NR based LSPR sensor	Blood serum	n.r. <sup>a</sup>	0.1 ng/mL	0.1–10 <sup>5</sup> ng/mL	LSPR based optical sensing	Jo et al. 2021)
E	Au/PAn/γ-Al <sub>2</sub> O <sub>3</sub>	Food, urea, biological fluid samples	n.r. <sup>a</sup>	0.06 μM	n.r. <sup>a</sup>	Electrochemical	Parvin et al. 2018a)
K <sub>1</sub>	MWCNT-CHIT over Ag layer	Blood samples	n.r. <sup>a</sup>	2.66 10 <sup>-4</sup> μg/l	0–10 <sup>-3</sup> g/l	Fiber optic SPR Sensor	Tabassum and Gupta 2016)
K <sub>3</sub>	PEDOT-MIP/GCE	Animal feedstuffs, livestock products and veterinary drugs	n.r. <sup>a</sup>	0.00031 μM	0.009–35 μM	Electrochemical (CV)	Zhang et al. 2017)
K	Silver NPs and 2-amino-5-chloro benzophenone/pencil graphite electrode	Human blood serum	n.r. <sup>a</sup>	16.58 nmolL <sup>-1</sup>	50–700 nmolL <sup>-1</sup>	Electrochemical (SWV)	Rostami-Javanroudi and Babakhani 2021)

<sup>a</sup>not reported

**Fig. 1** Effect on absorbance due to interaction between Au@Ag CNPs Vit A (Prakashan et al. 2019)

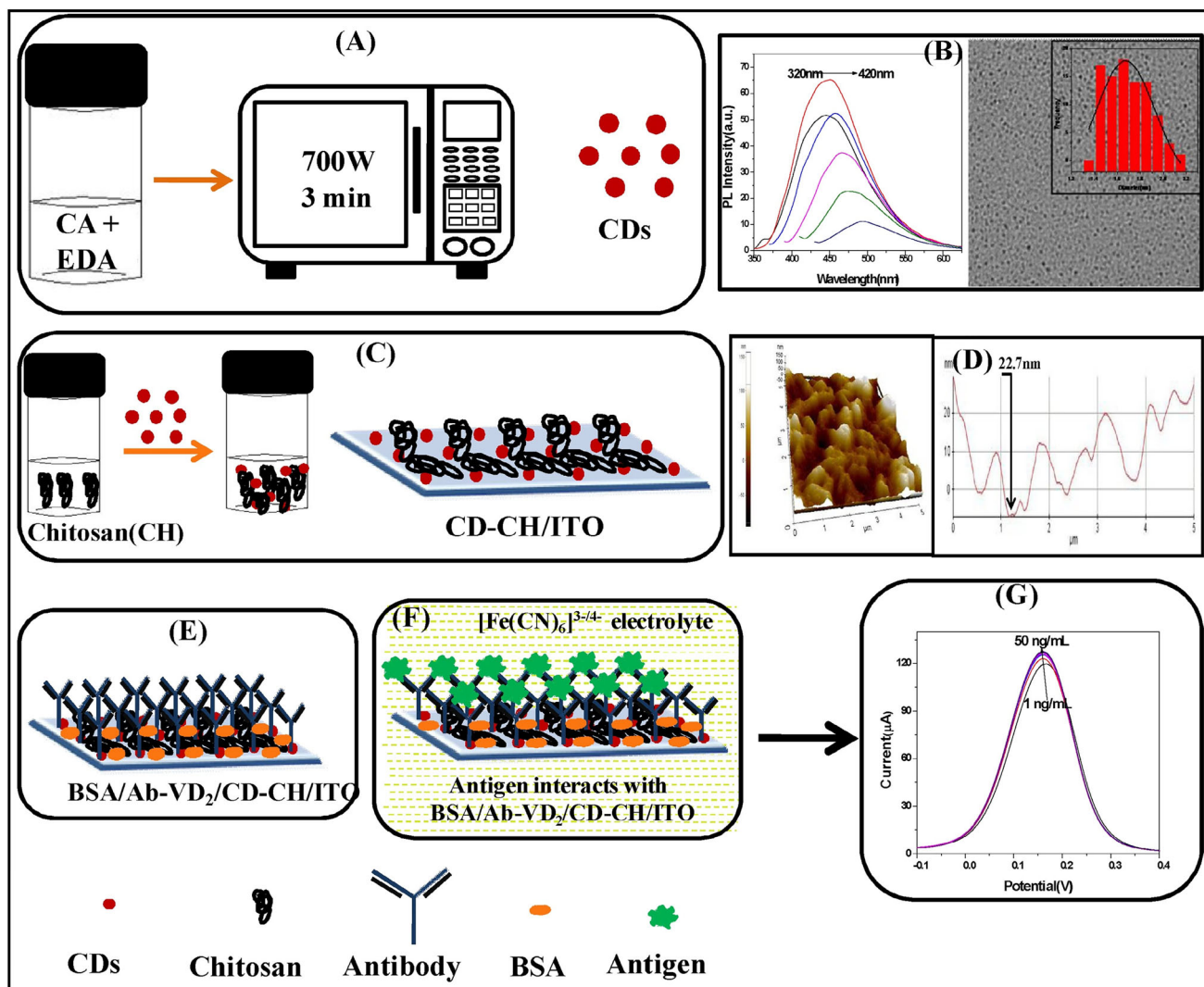


**Fig. 2** The fiber optic sensing mechanism of vitamin A (Prakashan et al. 2019)

biomolecules and simplified the sensor complexity. The fiber optic sensing mechanism for the proposed methodology is illustrated in Fig. 2. There are numerous potentials for researchers to investigate optical sensing as a means of detecting Vit A to improve findings. The research in this subject could potentially improve point-of-care (POC) testing, bringing up new avenues for commercial products.

#### Detection of Vit D

It is a fat-soluble vitamin that promotes bone health and lowers the risk of a number of chronic illnesses. Immunity has become a critical factor in the recent outbreak of COVID-19 disease. Vit D insufficiency has been linked to a variety of respiratory disorders, including COVID-19, according to multiple research. (Ali 2020). Treatment for Vit D insufficiency is shown to reduce respiratory tract



**Fig. 3** **A** CD synthesis; **B** photoluminescence spectra and transmission electron microscopy (TEM) images; **C** preparation of composite film; **D** atomic force microscopy study of CD–CH/ITO electrode; **E** Ab-VD<sub>2</sub> and BSA over CD–CH/ITO electrode; **F** interaction of Vit

D<sub>2</sub> with modified electrode; **G** differential pulse voltammetry response of the modified bioelectrode in the presence of Ag-VD<sub>2</sub> (Sarkar et al. 2018)

infection and mortality (Panagiotou et al. 2020). VD<sub>3</sub> (c-holecalciferol) and VD<sub>2</sub> (Vit D<sub>2</sub>) are the two isoforms found in the body (ergocalciferol). Ultraviolet-B-induced vitamin D makes up 80% of the body’s vitamin D supply, with the rest coming from diet. In the bloodstream, vitamin D<sub>2</sub> and vitamin D<sub>3</sub> combine to form 25 hydroxyvitamin D (25(OH)D), which is tested in a Vit D test. Because 25(OH)D has a longer life and a higher serum concentration than Vit D, it is the best indicator of Vit D supply in the body.

Numerous nanomaterials have been investigated for vitamin D sensing. Vit D was detected by a research group using a member of the carbon nanomaterial family, carbon dots (CD), and chitosan (CH) which are both suited for nanomaterial dispersion. The electrochemical capabilities of CDs were

combined with the unique chemical and biological features of chitosan to create the composite. A thin layer of CD–CH composite was deposited on an indium-tin-oxide (ITO) glass substrate, as shown in Fig. 3. Vit D<sub>2</sub> antibody was used to immobilize it (Ab-VD<sub>2</sub>), and to block nonspecific sites, bovine serum albumin (BSA) was employed (Sarkar et al. 2018). Similarly, on the ITO glass electrode, polyacrylonitrile nanofibers (PANnFs) with magnetite NPs were utilized. PANnFs have superior solubility, thermal stability, and mechanical characteristics, while magnetite (Fe<sub>3</sub>O<sub>4</sub>) nanoparticles are biocompatible and nontoxic. BSA as a blocking agent was used to immobilize the Ab-VD<sub>3</sub> on the Fe<sub>3</sub>O<sub>4</sub>-PANnFs/ITO (Chauhan et al. 2018). Electrochemical experiments revealed better results for Vit D<sub>3</sub> detection. Another sensor used gadolinium oxide NRs (Gd<sub>2</sub>O<sub>3</sub>NRs) functionalized with

aspartic acid (Asp-Gd<sub>2</sub>O<sub>3</sub>NRs) and deposited on an ITO-coated glass substrate. The modified electrode was subsequently immobilized with a monoclonal antibody against vitamin D<sub>3</sub> (Ab-VD) (Chauhan et al. 2019). The three sensors mentioned above utilized various nanostructures, such as nanocomposite, NPs, and NRs, over the same electrode type and utilized the same biorecognition components.

Au–Pd bimetallic nanodendrites (Men 2017) and fullerene-C<sub>60</sub> along with copper–nickel bimetallic NPs nanocomposite film over glassy carbon electrodes have been investigated to detect Vit D (Anusha et al. 2020). Both utilized electrochemical methods and demonstrated improved results. The sensor was evaluated for clinical and pharmaceutical samples using a nanocomposite film of fullerene-C<sub>60</sub> with copper–nickel bimetallic NPs. Kia et al. developed the first molecularly imprinted polymer (MIP)-based Vit D detection technique in human plasma samples. Binding sites for the target molecule are generated via MIP recognition, which enhanced the sensor's LOD and selectivity. The MIP of p-phenylenediamine–resorcinol combination was coated on the screen-printed carbon electrode (SPCE), and different variables affecting response current were investigated and tuned to provide a linear response range of  $1 \times 10^{-11}$ – $2 \times 10^{-9}$  M and a lower LOD of  $1 \times 10^{-12}$  M (Kia et al. 2019).

An immunosensor based on carbon cloth (CC) was investigated in a recent publication. Cerium (IV) oxide (nCeO<sub>2</sub>) nanostructure was formed on carbon cloth (CC) by electrophoretic deposition, resulting in the nanoplatform (nCeO<sub>2</sub>/CC). Anti-25VD<sub>3</sub> and BSA on top of this, the BSA/anti-25VD<sub>3</sub>/nCeO<sub>2</sub>/CC nanobioplatform enhanced Vit D<sub>3</sub> detection (Chauhan et al. 2021). Aptamer with polyethylene-glycol (PEG)-free gold NR (AuNR) was used for sensing. The LSPR phenomenon due to PEG-free AuNR significantly improved the results. This method shows the prospect of an aptasensor in the detection of vitamins (Jo et al. 2021).

Lee et al. developed aptamers that can bind 25-Hydroxyvitamin D<sub>3</sub> in a very precise and selective manner. The exact sequencing was determined using the graphene oxide-based systemic evolution of ligands by exponential enrichment (GO-SELEX) method. Based on an AuNPs-based colorimetric approach, the LOD was 1 μM, and it may be used to detect Vit D using other methods. Aptamers tend to be a potential recognition element for the detection of vitamins (Lee et al. 2017).

### Detection of Vit E

Vitamin E is a category of antioxidant compounds that are fat-soluble. Two of the eight naturally occurring vitamin E forms found in serum and red blood cells are alpha- and gamma-tocopherols. Alpha-tocopherol has the highest

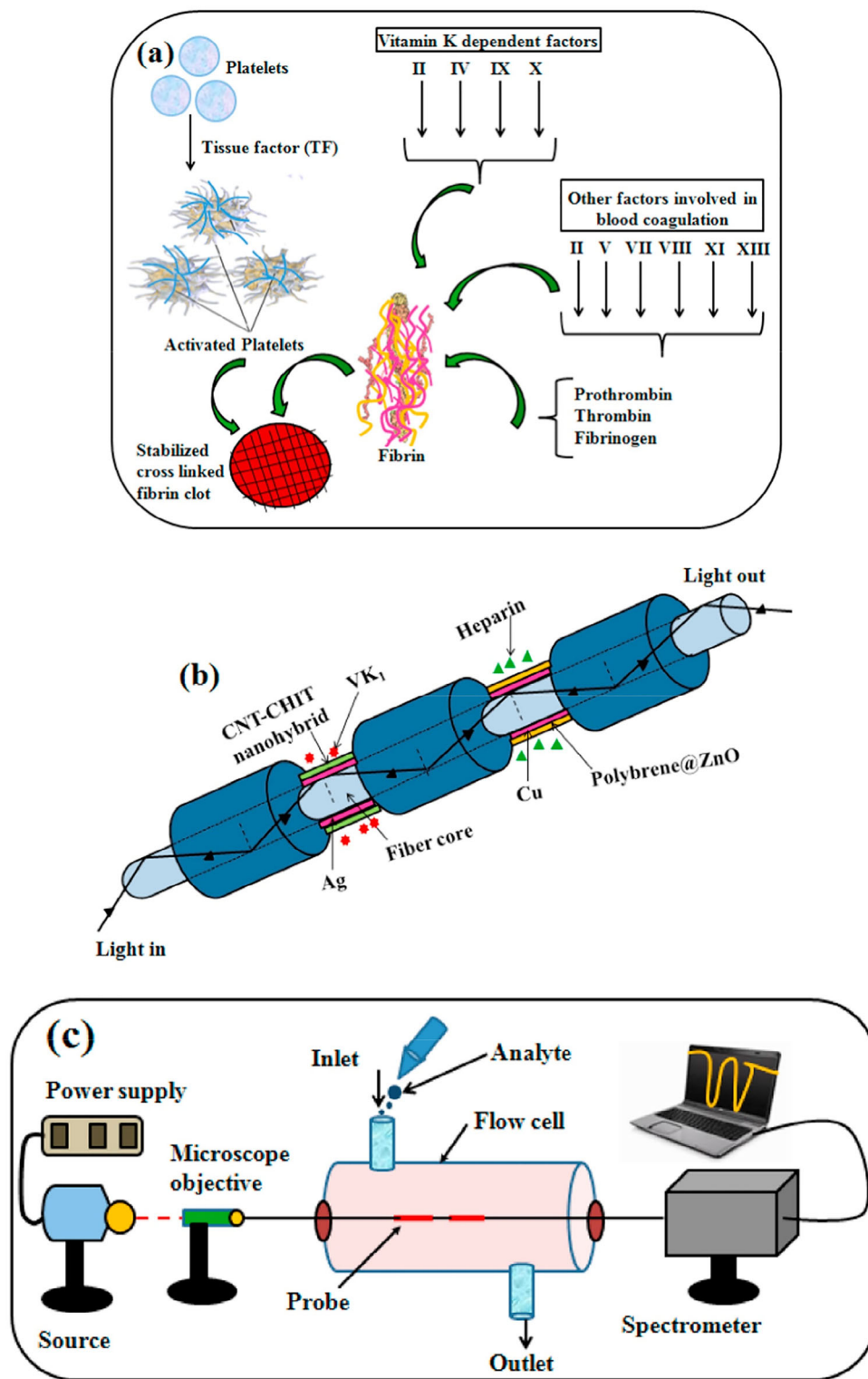
concentration of vitamin E. It is required for oxidative stress prevention, cell membrane protection, and platelet function regulation (Rizvi et al. 2014). Due to its antioxidant properties, immune-enhancing action, and involvement in anti-inflammatory processes, it also aids in the prevention of a variety of illnesses. Vit E may help prevent illnesses including cardiovascular disease, cataracts, and cancer, to name a few. Parvin et al. modified Au electrodes with polyaniline (PAn) and gamma aluminum oxide (γ-Al<sub>2</sub>O<sub>3</sub>) nanocomposites to detect Vit E. PAn/γ-Al<sub>2</sub>O<sub>3</sub> nanocomposites were synthesized using an electropolymerization method and coated on the electrodes in situ. Because of the γ-Al<sub>2</sub>O<sub>3</sub> NP, aniline's performance improved (Parvin et al. 2018a). For dietary supplements, a technique for evaluating Vit E and K at the same time has been developed. Adsorptive stripping SWV on glassy carbon electrode was used. It turned out to be a low-cost straightforward technique of analyzing dietary supplements. Quinones and tocopherols, the physiologically active forms of E and K, were identified with excellent sensitivity in a short linear range (Kastrati et al. 2020).

### Detection of Vit K

Vitamin K is necessary for the body's proteins to operate properly. Vitamin K<sub>1</sub> (phylloquinone) and Vitamin K<sub>2</sub> (menaquinone) are naturally occurring forms. (DiNicolaantonio et al. 2015). To detect Vit K<sub>1</sub> and heparin at the same time, a FOS based on the SPR phenomena has been proposed. Cascaded channels were prepared for K<sub>1</sub> and heparin with silver and copper, respectively. Unclad optical fiber was coated with silver and multi-walled carbon NT in chitosan (MWCNT-CHIT) for K<sub>1</sub> detection. It is a low-cost sensor that may be used for remote sensing and monitoring (Tabassum and Gupta 2016). Figure 4 depicts the FOS structure as well as the experimental setup for detecting Vit K and heparin together. The poly(3,4-ethylenedioxythiophene) (PEDOT) imprinted sensor was used to create a voltammetric sensor for detecting K<sub>3</sub> in poultry medication samples. Imprinted electrodes can be used to provide a potential sensing platform for detecting VK<sub>3</sub> levels as shown in Fig. 5 (Zhang et al. 2017).

For the first time, the Refreshable Silver Liquid Amalgam Film multi-electrode (RAGLAFm-E) was used to quantify Vit K<sub>2</sub> (menaquinone). The electrochemical behavior of Vit K<sub>2</sub> was investigated using cyclic voltammetry (CV), and it was effectively utilized to detect Vit K<sub>2</sub> in pharmaceuticals and food samples (Jedlińska et al. 2018). In recent years, many electrochemical sensors for detecting Vit K have been developed, but fiber optic sensors have not received much attention (Tabassum and Gupta 2016). This expands the possibilities for fiber optic sensing research.

**Fig. 4** **a** The factors involved in blood coagulation and its mechanism **b** FOS structure, and **c** characterization of the FOS (Tabassum and Gupta 2016)



**Water-soluble vitamins**

Water-soluble vitamins include vitamin C and vitamin B. The Vitamin B group includes B<sub>1</sub>, B<sub>2</sub>, B<sub>3</sub>, B<sub>5</sub>, B<sub>6</sub>, B<sub>7</sub>, B<sub>9</sub>, and B<sub>12</sub>. These vitamins must be taken on a regular basis

since they are essential and cannot be retained in the body for long duration. Table 2 gives the comparative study of water soluble vitamins.

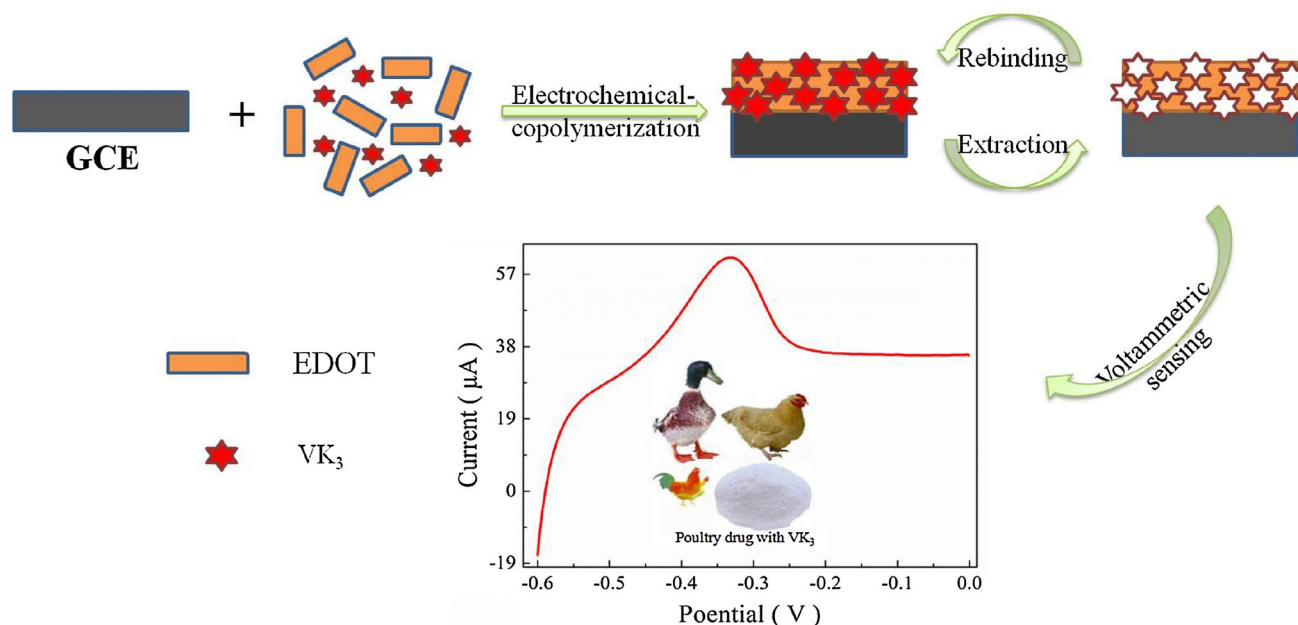


Fig. 5 The process of modifying GCE using PEDOT-MIP detection of Vit K3 (Zhang et al. 2017)

### Detection of Vit C

Vit C (ascorbic acid) is required in small amounts by the body to function and stay healthy. It helps the body in fighting against infections, healing wounds, and keeping the tissues healthy. Recent research has shown the role of Vit C in preventing and treating infection against the coronavirus (Hoang et al. 2020). Hydroxyapatite-ZnO-Pd NPs on CPE were used for the determination of Vit C. The performance of the modified CPE was studied for determination of Vit C and arbutin (AT) simultaneously (Shahmirifard and Ghaedi 2019).

A FOS was designed based on LSPR using a tapered fiber. The tapered area of an LSPR-based tapered FOS with gold NPs (AuNPs) and zinc oxide NPs (ZnO-NPs) was used to detect AA. The designed sensor spanned the whole spectrum of vitamin C present in human bodies and performed admirably in terms of stability, repeatability, reusability, and selectivity (Zhu et al. 2020a). A probe with high germanium (Ge)-doped photosensitive fiber (PSF) and single-mode fiber was used to construct another FOS (SMF). As illustrated in Fig. 6, the fiber was spliced together, and gold NPs were immobilized. Over the gold NPs, graphene oxide (GO) was applied (Kumar et al. 2021). A multi-tapered optical fiber sensor was designed with AuNPs and GO using SMF. Figure 7 shows the tapered structure of the FOS. The effect on the performance measure by varying the number (four, five, and eight) of tapering was studied. The sensor's performance with an optimum number of tapering was found to be improved (Zhu et al. 2020b).

### Detection of Vit B

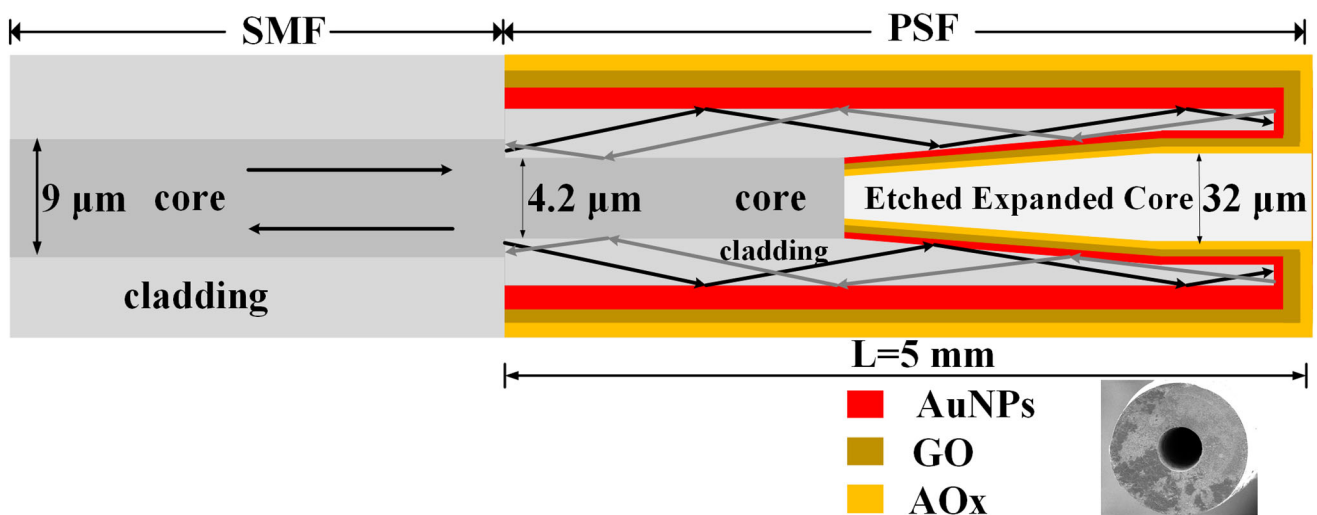
The B group of vitamins comprises the eight water-soluble vitamins that are closely related to their functioning. They also act as co-enzymes in various catabolic and anabolic enzymatic reactions. Plants typically synthesize these vitamins except B<sub>12</sub>, which is synthesized by bacteria (Kennedy 2016). The consumption of Vit B<sub>1</sub> above the prescribed level may lead to poisoning or hypervitaminosis. Hence, a highly selective sensor is needed for determining Vit B<sub>1</sub> in food and pharmaceutical preparation (Gong et al. 2019). Figure 8 shows the modified GCE for detection of Vit B<sub>2</sub> using electrochemical method and Fig. 9 illustrates the schematics for detection of Vit B<sub>3</sub> using fiber optic sensing. The deficiency of Vit B<sub>12</sub> is expected due to its malabsorption and the source mainly being animal foods. The concentration of methylmalonic acid (MMA) can be an early indicator of Vit B<sub>12</sub> deficiency. A carbon fiber paper (CFP) was modified using polypyrrole (PPy) and then by electrodeposition of palladium-gold (PdAu) NPs, an electrochemical sensor was developed. This method was able to determine a deficient level of MMA in urine and blood serum samples. The performance study was done using DPV, and it showed good selectivity in the presence of other substances (Akshaya et al. 2020). Similarly, ferromagnetic nanoparticle with triazine dendrimer (FMNPs@TD) has been used for detecting Vit B<sub>12</sub> (Parvin et al. 2018b). For detection of Vit B<sub>12</sub>, a fluorescent carbon dot label-free nanosensor was proposed. In the inner filter effect (IFE), carbon dots were employed as fluorophores. The fluorescence intensity of



**Table 2** Comparative table of sensors for water-soluble vitamins

Vitamin to be sensed	Materials used	Specimens tested/useful for	Sensitivity	LOD	Linear range	Method	Reference
C	HAP- ZnO–Pd NPs/ CPE	Fruit juice, cream samples	0.94 $\mu\text{A}/\mu\text{M}$	19.4 nM	0.12–55.36 $\mu\text{M}$ and	Electrochemical sensor (DPV)	Shahamirifard and Ghaedi 2019)
C	AuNPs and ZnO-NPs	Vit C artificial sample	5.7 nm/mM	12.56 $\mu\text{M}$	500 nM–1 mM	Fiber optic sensing	Zhu et al. 2020a)
C	AuNPs decorated with GO	Human blood serum	3.5%/mM	15.12 $\mu\text{M}$	1 $\mu\text{M}$ –1 mM	Fiber optic sensing	Kumar et al. 2021)
C	Periodically tapered structure with gold NP and graphene oxide	Artificial sample	8.3 nm/mM	51.94 $\mu\text{M}$	10 $\mu\text{M}$ –1 mM	Fiber optic sensing	Zhu et al. 2020b)
B <sub>1</sub>	SPCE	Commercial supplements	0.0298 $\mu\text{A}$ $\mu\text{g}/\text{ml}$ ,	0.1 $\mu\text{g}/\text{ml}$ ,	15–110 $\mu\text{g}/\text{ml}$ , 0.1–20 $\mu\text{g}/\text{ml}$ , and 2–80 $\mu\text{g}/\text{ml}$	Electrochemical (CV)	Westmacott et al. 2018)
B <sub>2</sub>			4.105 $\mu\text{A}$ $\mu\text{g}/\text{ml}$ ,	3.5 $\mu\text{g}/\text{ml}$ ,			
B <sub>6</sub>			0.375 $\mu\text{A}$ $\mu\text{g}/\text{ml}$	0.4 $\mu\text{g}/\text{ml}$			
B <sub>1</sub>	L-cysteine modified silver NPs	Food and water samples	n.r. <sup>a</sup>	7.0 $\mu\text{g mL}^{-1}$	25–500 $\mu\text{g mL}^{-1}$	Colorimetric	Khalkho et al. Feb 2020)
B <sub>2</sub>	Dendritic CeO <sub>2</sub> /GCE	n.r. <sup>a</sup>	93.55 $\mu\text{A}$ $\mu\text{M}^{-1} \text{cm}^{-2}$	1.8 nM	0.005–1.5 $\mu\text{M}$	Electrochemical	Manoj et al. 2021)
B <sub>12</sub>	PdAu-PPy/CFP	Human blood serum and urine samples	n.r. <sup>a</sup>	1.32 pM	4.01 pM–52.5 nM	Electrochemical (DPV)	Akshaya et al. 2020)
B <sub>3</sub>	Colloidal templating and MIP hydrogel on Ag layer	Pharmaceuticals and food	1.483 nm/ (mg/ml)	n.r. <sup>a</sup>	0–10 mg/ml	Fiber optic sensing	Verma and Gupta 2013)
B <sub>12</sub>	Carbon dots	Injections	n.r. <sup>a</sup>	0.1 $\mu\text{M}$	0 to 60 $\mu\text{M}$	Fluorescence	Ding et al. 2018)

<sup>a</sup>not reported



**Fig. 6** Structure of AA sensor probe with highly Ge dopes PSF spliced with SMF (Kumar et al. 2021)

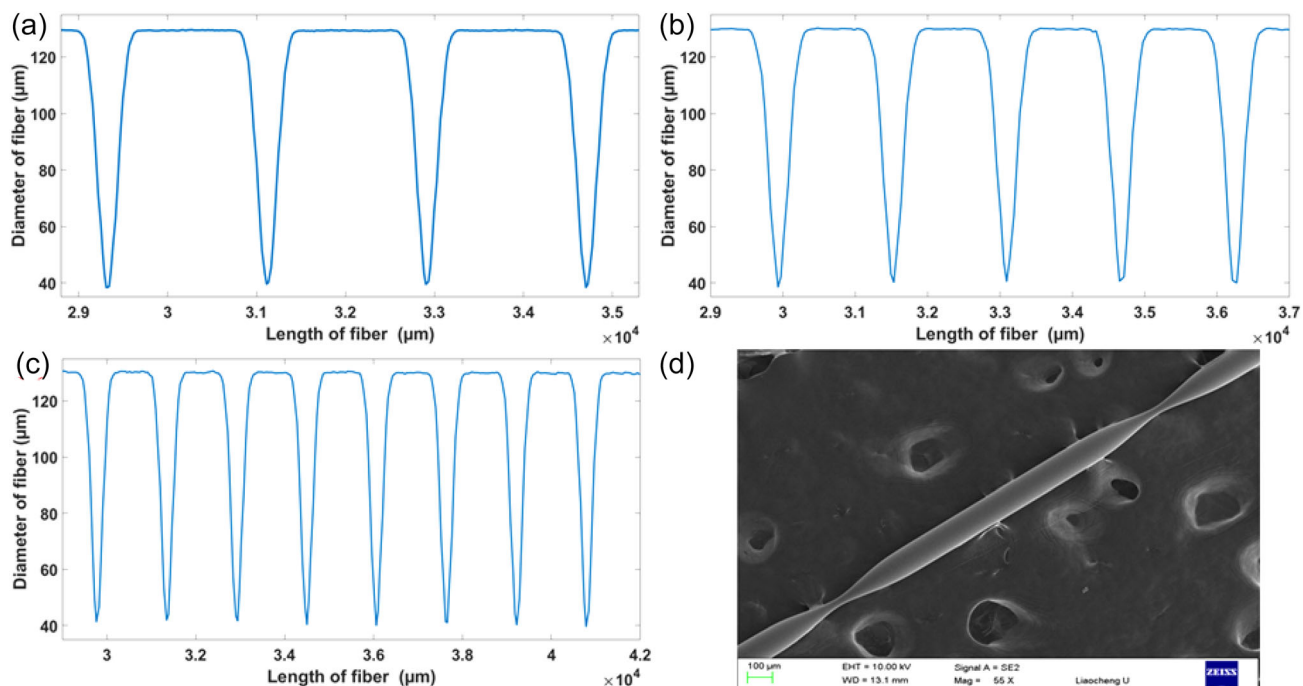


Fig. 7 Multi-tapered ( four, five, and eight) structure of FOS for detection AA (Zhu et al. 2020b)

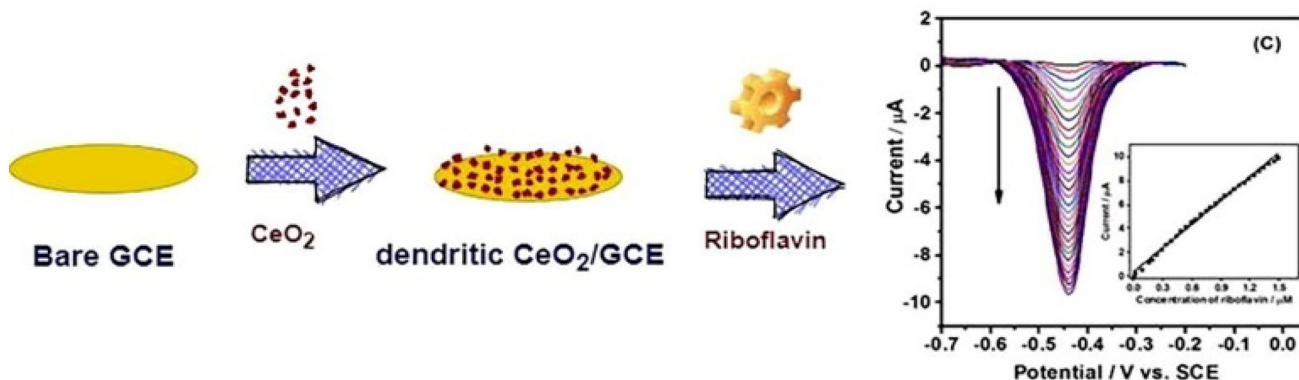


Fig. 8 Schematic illustration of modified GCE electrode dendritic CeO<sub>2</sub>/GCE and its response to Vit B<sub>2</sub> (Manoj et al. 2021)

CDs decreases as Vit B<sub>12</sub> concentration rises, giving a linear relationship in the region of 0 to 60 μM. This technique was successfully used to detect B<sub>12</sub> in injections, and the IFE platform may be used to detect other proteins using different fluorescent nanomaterials (Ding et al. 2018).

## Remarks

Over the years, a lot of research has gone into detecting vitamins, which proved to be vital for a healthy human body. Sensors based on different techniques like electrochemical and optical have been current in research. Most of the recent study for vitamin detection was based on the electrochemical process. Even though optical sensors have

shown promising results in other detection like cholesterol, glucose, and uric acid, vitamins are one such biomolecule where optical sensing is not much explored (Singh et al. 2020a, 2020b; Kumar et al. 2019; Agrawal et al. 2020; Chaudhary et al. 2021).

The electrochemical process on a bare electrode used in the sensor tends to be lacking in performance. By depositing different materials over the electrode, the performance of the sensors is enhanced. In electrochemical, the major credit for improving the performance goes to the usage of modification in electrodes and the use of nanomaterials. Electrodes like GCE, SPCE, CC, and CFP have been modified with nanomaterials like CeO<sub>2</sub> nanodendrite bimetallic NPs (Au–Pd), NRs (Gd<sub>2</sub>O<sub>3</sub>), and Polyacrylonitrile NFs (PAN) (Chauhan et al. 2019) (Chauhan et al.

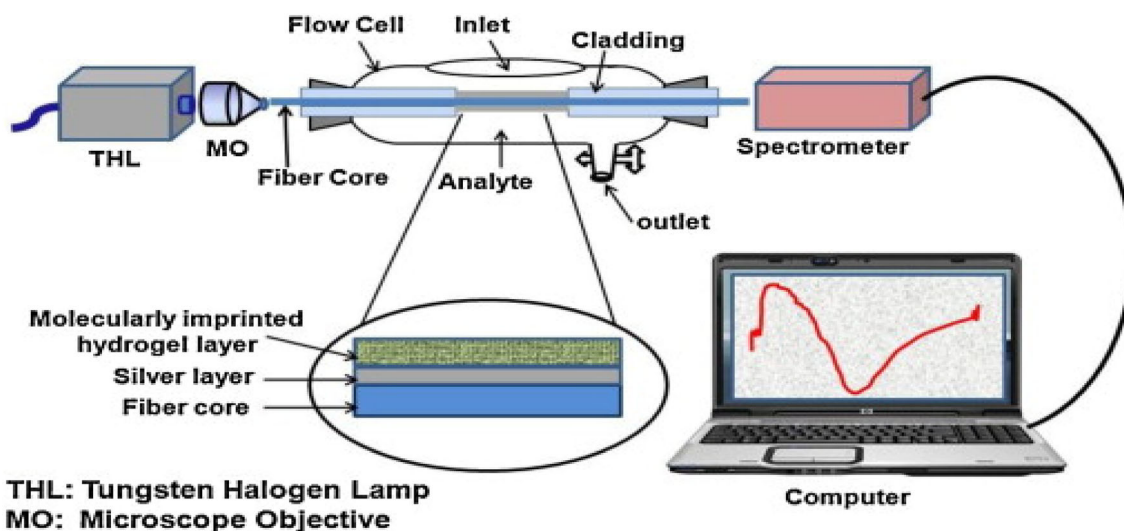


Fig. 9 The proposed FOS schematics for detection of Vit B<sub>3</sub> (Verma and Gupta 2013)

2018; Anusha et al. 2020). Several varieties of electrodes have also been explored, like ITO-coated glass, GCE, SPCE, and carbon cloth (CC) (Sarkar et al. 2018) (Chauhan et al. 2019; Kia et al. 2019) by various research groups across the globe.

Among the various biorecognition elements, aptamers have gained a lot of attention due to their potential to increase interaction between the analyte and aptamers. Aptamers are potential recognition elements for sensing vitamins and minerals (Heydari et al. Mar 2020). MIPs are also widely used in biological and chemical analytes due to their high affinity to its template molecule, making the sensor more selective (Zhang et al. 2017; Gupta et al. 2016) (Verma and Gupta 2013).

Various techniques can be used in optical sensing like fluorescence, colorimetry, and SPR/LSPR. In FOS, the structure and type of the fiber-like step or graded and single or multi-mode play a significant role. The nanomaterial used like AuNPs, ZnO-NPs, and composite nanomaterials helps improve the sensor.

## Future scope

The corona pandemic has drastically spiked the testing done for the vitamins and interest of people in the food they consume. So, quantification of vitamins has become suddenly very important, and this will consequently accelerate the research in the field of vitamin sensing. With the high demand for point-of-care testing, the need for easy-to-use, cost-effective, and simple testing kits has emerged. Electrochemical sensing and optical sensing would motivate researcher working in this area to design novel sensors which does not require much skill, can be easily handled,

and gives good performance at the same time. The use of aptamers, MIP, and nanomaterials has shared a new dimension to sensing and vitamin sensing.

## Conclusion

The performance of the sensors can be enhanced by the following points used individually or in combination depending on sample to be tested:

- Biorecognition elements (e.g., enzyme-based, antibody-based, and aptamers)
- Use of different nanomaterials to improve the transduction process (NR, bimetallic NPs, NT, and NFs).
- Use of the appropriate electrode (in the electrochemical process) or the use of optical technique (in optical sensing).

It is crucial to notice that electrochemical sensing has been used to quantify the vitamins and has also given good results. Optical sensing is still growing and is still to be explored in a few of the vitamins. There has been unequal research among the vitamins, with Vit D, Vit B<sub>12</sub> having more importance, but demand is growing for other vitamins too. Almost all vitamins are required to be tested in drugs and food, whereas in human blood, a few vitamins (like Vit D, B<sub>6</sub>, B<sub>12</sub>) are tested in general. For this reason, in many proposed methods, testing has been done specific target sample, and its efficacy is found. Vitamin detecting does have the potential to grow in the coming years due to its role in improving the immune systems and health of the human body. Fiber optic tends to detect the unexplored vitamins as they have done in sensing of other biological analyte.

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