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Nanowires Properties and Applications: A Review Study

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ABSTRACT

One-dimensional nanostructures are generally cited as nanowires, nanofibers, nanotubes, and so on. The foremost prominent feature of these materials is their electrical conductivity, which, unlike classical physics, doesn't increase their resistance because the diameter decreases. Numerous properties of these materials like electrical conductivity, optical, magnetic, biological, and environmental their sensory have created many applications for them altogether industries. nanowires (NWs) propose potential impact on electronics, computing, memory, data storage, communications, manufacturing, health, medicine, national security, and other economic sectors as well. NWs offer excellent surface-to-volume ratio (interface phenomena), low defect density, high optical output, and controllable n-type conductivity, making them more appropriate and sensitive for sensing applications. NWs with their ultra-sensitive and real-time detection capabilities lend their applications in nano biosensors, chemical sensors, gas sensors, and electrochemical sensors. NWs have been used in improving the optical absorption as well as for the collection efficacy in photovoltaic devices. NWs having small size, low weight, low cost for mass production, and are also compatible with commercial planar processes for large-scale circuitry. In the paper, the authors are focusing to summarize the recent advances in NWs with their potential applications in various fields such as research, health, security, education, entertainment, and power generation.

1. Introduction

Due to the existence of varied paths for the interaction of electrons in three-dimensional (3D), two-dimensional (2D), and one-dimensional (1D) structures (Zhang et al., 2015, Matthews and Blakeslee, 1974, Ye et al., 2009, Biermanns et al., 2012). Carbon nanotubes have many

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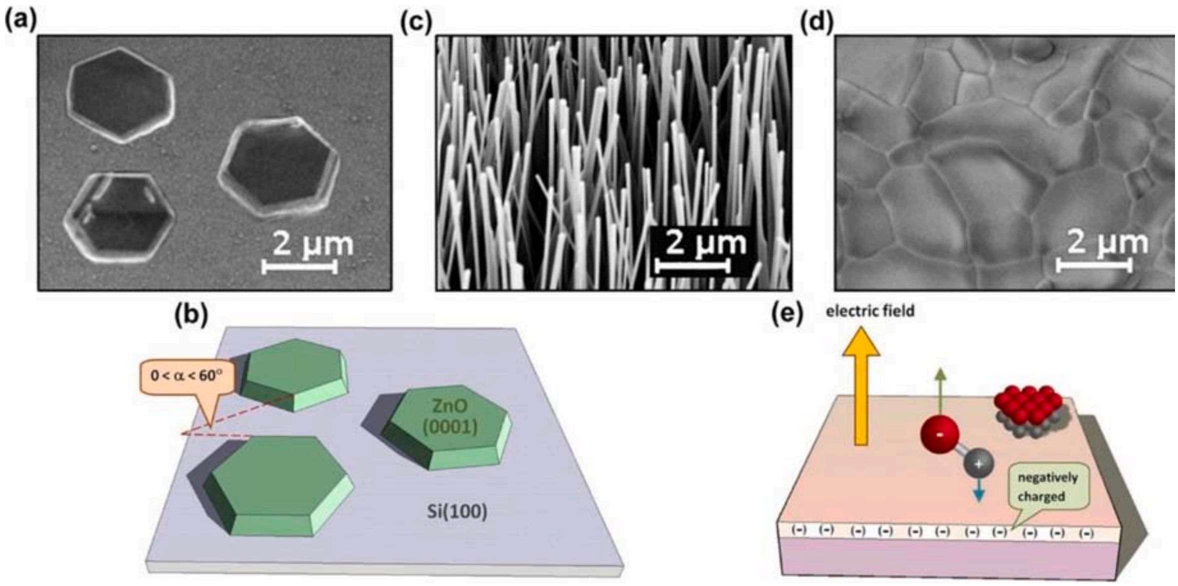

Fig. 1. (a) SEM image acquired at sample-tilt of 30° of hexagonally shaped mesas grown on Si(100) substrate, and (b) schematic cartoon showing the rotational angle difference, which confirms the lack of epitaxial relations with the substrate, despite the alignment of the c-axis perpendicular to the substrate. (c) SEM image of c-oriented ZnO nanowires grown on Si(100) substrate. (d) Polycrystalline ZnO film grown on a Si(100) substrate. Each individual grain is c-aligned but is rotated on the c-axis in a random angle. When they expand, they meet each other forming grain boundaries. (e) Schematic of Si substrate with negatively charged surface oxide, which exerts an electric field that aligns the polar axis of the deposited molecule along electric field lines. For ZnO, the zinc (oxygen) face is positively (negatively) charged; thus, the oxygen face points up (Wang, 2006, Volosskiy et al., 2015).

applications within the sphere of Optoelectronics furthermore as Nano computers (Raychaudhuri and Yu, 2006, Kavanagh, 2010, Trammell et al., 2008, Glas, 2006, Cirlin et al., 2009, Geisz et al., 2006). Numerous applications of nanotubes are often used as insulation, conductor, and semiconductor or semiconductor (Cirlin et al., 2010, Glas et al., 2007, Uccelli et al., 2011, Qian et al., 2015). One of the goals of nanotechnology advances in electronics and branches of knowledge is to form memory and chips with greater capability and lower cost (Shimamura et al., 2013, Vainorius et al., 2014, Belabbes et al., 2012, Heiss et al., 2011, Wallentin et al., 2012, Pemasiri et al., 2009). Optoelectronics might be a branch of nanotechnology that has emerged from the impact of nanotechnology on electronics science and industry (Qian et al., 2015, Bechstedt and Belabbes, 2013, Senichev et al., 2018, Azulay et al., 2020). The history of this data dates back to about 50 years ago once we tried to create transistors as small as possible (Wang, 2006, Volosskiy et al., 2015, He et al., 2013, Zhang et al., 2020). Optoelectronics plays an awfully important role in global technology in terms of making smaller, faster, and fewer energy-consuming electrical devices (Zhang et al., 2020, Zhang et al., 2020, Zhang et al., 2020, Zhang et al., 2020). Increased data storage, smaller computer calculators, logic circuit design, nanowires, and other applications of Optoelectronics (Chen et al., 2020, Wang and Chen, 2020, Koenigsmann et al., 2012, Liu et al., 2014). Today, in various fields, including nanotechnology, the link between different disciplines of science is undeniable (Scofield et al., 2015, Lan et al., 2007, Ju and Kim, 2015, Yang et al., 2015, Hui et al., 2012). One amongst all the results of this collaboration is the design of Nano-calculators. Aromatic hydrocarbons from benzene root are a good transfer medium for electrons due to the presence of p orbitals and electron clouds above and below them, also due to the resonance phenomenon, and in contrast, chain hydrocarbons act as conductors (Huang et al., 2015, Qian et al., 2006, Lu et al., 2004, Liu et al., 2010, Wang et al., 2014). with combining these hydrocarbons, diodes, logic gates, and electronic circuits are going to be designed (Wang et al., 2015, Heywood and Mann, 1994, Schneider and Kelly, 1995, Bělohradský et al., 1996, Liu et al., 2013, Zhang et al., 2014). One-dimensional nanostructures are generally called nanowires, nanofibers, nanotubes, Nanorods whiskers, and so on. In many materials, Nano cables and nanotubes represent the identical category. Although whiskers and Nanorods are usually relatively shorter in length, there are not any precise definitions (Liu et al., 2016, Qian et al., 2006, Liang et al., 2012, Wang et al., 2016, Song et al., 2016). One-dimensional structures have a diameter of several nanometers to several hundred microns (whiskers and fibers); in the end, the diameter of nanowires Nanorods rarely reaches over some hundred nanometers. Nanowires typically have an extended length to diameter ratio than Nano rods (Song et al., 2016, Lan et al., 2007, Liang et al., 2013, Sun et al., 2016, Chen et al., 2012). One of the foremost prominent features of metal nanowires is their electrical conductivity parallel to the wire axis. As you recognize, the electrical resistance of a conductive wire in physics is expressed as Equation 1 (Liang et al., 2013, Zhang et al., 2013, Zhou et al., 2016, Qian et al., 2007, Zhou et al., 2014, Gong et al., 2009, Jacobsson et al., 2016, Yao et al., 2016):

$$R = \rho L/A \tag{1}$$

The energy structure of nanowires is continuous along the axis of the wire and discrete along the cross-section, so because the diameter changes, the space between the energy levels changes. Therefore, the material and length to diameter ratio of nanowires are two factors affecting their properties (Fig. 1). Nanowires are going to be crystalline or amorphous or, wishing on their constituent elements, another classification is also made for nanowires (Yuan et al., 2015, Zhou et al., 2015, Lehmann et al., 2015, Russo-Averchi et al., 2012, Kang et al., 2012). Nanowires may additionally be accustomed stimulate mammalian cells specifically through electrical and optical stimulation. The arena of nanowire photonics grew at a similar rate thereto of nanowire electronics. Since the invention of the first room-temperature ultraviolet nanowire laser, many other optical processes are studied for these semiconductor nanowires building blocks including, for example, subwavelength waveguiding and nonlinear optical mixing (Algra et al., 2011, Krogstrup et al., 2011, Krogstrup et al., 2010, Joyce et al., 2010, Johansson et al., 2009, Salimi et al., 2017, Kianfar, 2018). These studies laid the muse for nanowire-based subwavelength photonic integration, novel nanowire scanning probe imaging, and spectroscopy further as energy conversion. It is also contributed to a replacement field of

Table 1
Various types of nanowires with their diverse applications (Azam and Singh, Inpress).

Types of Nanowires	Applications of Nanowires
Silicon	Electronics, biosensors, Electroluminescence
Germanium	Electronics, IR detectors
GaAs	High speed electronics, Photoconductive roles
InAs	Photodetector, Solar cell, NWFET, Tunnel diode, TFET, SET
InP	NWFET, Single-photodetectors, Single-photon detector, Tunnel diode
GaP	Single-photonsource, Photodetector, Solar cell
Ag NWs	Wearable devices
CuO NWs	Electronic-conductor
Zn NWs	Optoelectronics, light emitters and lasers
DNWs	Radiation particle detectors, UV-light detectors and emitters, high-speed and high-power field effect transistors, field emission sources, position-sensitive biochemical substrates, and room temperature-stabilized high-efficiency single-photon emitters.
Cadmium telluride	IR detectors for various wavelengths

scientific study in nanowire photonics, which is fascinating (Zhao et al., 2019, Li et al., 2018, Wang et al., 2017, Xia et al., 2017, Shen et al., 2016). The flex idleness to control pulses of sunshine within submicron volumes is very important for highly integrated light-based devices, like optical computers, to be realized (Chen et al., 2016, Hu et al., 2015, Kianfar, 2019, Liu and Kianfar, 2020, Kianfar et al., 2018, Kianfar et al., 2018, Kianfar et al., 2018, kianfar, 2019).

Carbon nanowires are nanostructure that exhibits many excellent applications. The nanowires are fabricated by heating the powder form of graphite with nickel at approximately 1200°C temperature inside quartz tube (Kianfar and Mahmoud, 2020, Kianfar and Razavi, 2020, Kianfar, 2020, Kianfar et al., 2020, Kianfar et al., 2015, kianfar, 2020, Kianfar et al., 2017, Kianfar and Viet, 2021, Faravar et al., 2020). Density and capacitance can be enhanced by adding polyaniline in direct carbonization. Besides, normal, hollow nanowires can be obtained by polyaniline in hydrolyzation. In spite of carbon atom, graphene, fullerene, graphite, and diamond can also be incorporated into nanowires. 3D printing strategy is used to make graphene oxide (GO) nanowires (Yang et al., 2020, Gao et al., 2020, Kianfar et al., 2020, Kianfar, 2020, Kianfar, 2020, Kianfar, 2020, Kianfar, 2020). It is interesting that porous nanowires can maintain their increased reversible capacity even at high current density, so they act as useful anodes in storage batteries (Kianfar and Mazaheri, 2020, Kianfar, 2020, Kianfar et al., 2020, Kianfar, 2020, Kianfar and Mafi, 2020). Nanowires of graphite can be used as radar having adsorption properties. Electrospinning and annealing of carbon nanowires can result in the synthesis of graphite nanowires (Shan et al., 2020, Yu et al., 2021, Hu et al., 2020, Zhao et al., 2014, Yu et al., 2020, Chu et al., 2016, Kianfar, 2020). Graphite helps in the growth of nanowires. Graphite and diamond can form hybrid nanowires which are applied in electromechanical nano switches. Fullerenes can be introduced in nanowires and are used in electronics but only a little literature is available on fabrication of nanowires with fullerene after 2014 (Kianfar, 2020, Kianfar et al., 2016, Kianfar, 2016, Kianfar, 2015, Kianfar, 2015, Kianfar, 2015, Kianfar, 2019). The silicon–carbon nanowires and nanotubes as fabricated by simulation methodology possessed the single-crystalline hexagonal geometry and higher tensile strength (Hajimirzaee et al., 2020, Kianfar, 2021, Kianfar, Inpress, Tomita et al., 2018). However, nanowires synthesis in a very reproducible way remains a challenging task. In fact, most of the nanowires are successfully synthesized with chemical vapor deposition (CVD) and reactive-ion etching (RIE) techniques. against this, solution-based nanowires synthesis has also emerged recently. a close study on nanowires structures may help the emerging researchers to direct toward diverse applications (Koukharenko et al., 2013, Weisse et al., 2012, Abramson et al., 2004, Zhang et al., 2013, Pei et al., 2012, Chen et al., 2018). in Fig. 1a, the presence of 3 ZnO hexagonally-shaped mesas on a Si(100) substrate confrms that the mesas are indeed c-oriented. Te sides of the hexagonal mesas are not mutually parallel, as shown schematically in Fig. 1b, thus confrming the lack of epitaxial relations with the substrate. Growth of c-oriented nanowires on Si substrate, as shown in Fig. 1c, has been reported in several papers. For example, c-oriented ZnO nanowire arrays have been grown on silicon or glass substrates without the use of a preexisting textured thin flm. Tese were synthesized at temperatures ranging from 400 to 600°C using metal organic vapor phase epitaxy, chemical vapor deposition (CVD), atomic layer deposition, chemical vapor transport, or a hydrothermal approach. In many cases, the upright alignment was explained by the formation of a ZnO wetting layer template for ZnO nanowire alignment; however, an explanation for the c-axis orientation of the wetting layer was not given. Similarly, zinc acetate was spin-coated on the growth substrate. In that case, it was suggested that thermal decomposition of the zinc acetate produced ZnO colloids and nanocrystals with their (0002) planes parallel to the substrate surface. However, the question why these nuclei prefer a specifc orientation has remained open.

2. Types of nanowires

So far, we are at home with various nanostructures, including carbon nanotubes, nanoparticles, and nanocomposites; another nanostructure that has been the topic of much study and research today is nanowires. The wire is usually a structure that extends in one direction (longitudinal direction) and is extremely limited within the other two directions. a vital feature of those structures, which has two outputs, is electrical conductivity (Chen et al., 2020, Wang et al., 2021, Zhu et al., 2020, Chen et al., 2019, Lu et al., 2021, Pei et al., 2012). Electrical charge transfer occurs with applying an electrical potential drop at both ends of those structures and along their length. Making wires in nanometer dimensions is extremely interesting both technologically and scientifically, because, in nanometer dimensions, they need unusual properties (Pei et al., 2012, Chen et al., 2018, Schmidt et al., 2014, Zhang et al., 2020, Zhang et al., 2019, Sun et al., 2019, Zhang et al., 2019). The length to diameter ratio of nanowires is incredibly high (L >> D). samples of the utilization of nanowires include magnetic devices, chemical and biological sensors, biological markers, and internal connections in Nano electronics, like the connection of two pieces of aluminum superconductor made with silver nanowires (Zhang et al., 2020, Duan et al., 2021, Swinkels et al., 2015, Wu et al., 2013, Yazji et al., 2015, Soini et al., 2010, Zou et al., 2015, Rojo et al., 2013). Nanowires have very interesting properties that don't seem to be found in bulk or 3-D materials. There are different types of nanowires in terms of fabric, including metal nanowires (such as nickel, platinum, gold, or various metal-base alloys), semiconductors (such as GaN, InP, Si, etc.), nonconductors (such as TiO_2, SiO_2), polymer and nanowires. Molecular (such as organic or inorganic DNA) (Zhang et al., 2020, Liu et al., 2021, Gao et al., 2020). the kinds of nanowires may be divided into the subsequent groups (Wang et al., 2020, Sui et al., 2021, Duan et al., 2020, Gao et al., 2019, Zhang et al., 2015, Walia et al., 2016, Walia et al., 2014, Mauser et al., 2017, Zai-Jun et al., 2011):

ü Types of metals and semiconductors

which contain a good range of materials from noble metals (such as gold, silver, copper), single-element semiconductors (such as silicon and germanium), composite semiconductors (such as InP, CdS, and GaAs, similarly as heterogeneous structures) Nitrides (such as GaN and Si3N4) to carbides (such as SiC) (Liu et al., 2009, Gadeken et al., 2007, Hyder et al., 2000, Lagashetty et al., 2020, Yang et al., 2010, Wagner and Ellis, 1964, Huang et al., 2001, Law et al., 2004).

ü Functional types

A wide range of materials from functional oxides (such as ZnO, SnO_2

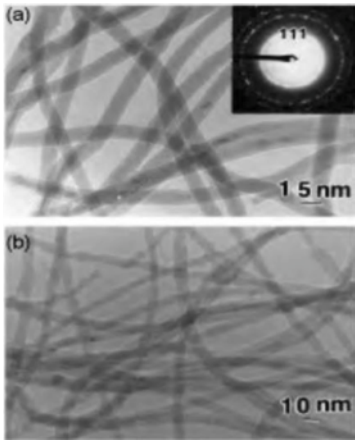

Fig. 2. (a) TEM image of silicon nanowires with an average diameter of about 15 nm. (b) TEM image of silicon nanowires after engraving of the outer oxide layer in dilute HF (Wang, 2006, Volosskiy et al., 2015).

and In_2O_3), structural ceramics (such as MgO, SiO_2, and Al_2O_3), composite materials (such as Si-Ge, SiC- SiO2) to incorporate polymers (Nakayama et al., 2007, Duan et al., 2003, Eaton et al., 2016). Most nanowires are structurally controlled for growth directions and lateral surfaces, which ends in controllable electrical and optical properties that have many advantages in nanotechnology (Yan et al., 2009, Azam and Singh, Inpress, Narayanan et al., 2015, Zhang et al., 2014, Zhang et al., 2021, Zhang et al., 2020, Zhang et al., 2020). Table 1 shows the kinds of Nanowires with Applications of Nanowires.

2.1. Elemental (metal) nanowires

These nanostructures promise great performance in electronic components thanks to their special properties. the event of electronics and gaining power during this field depends on continuous progress in shrinking electronic components (Zhang et al., 2020, Zhang et al., 2020, Zhang et al., 2019, Zhang and Zhang, 2013, Li and Gan, 2014). However, the laws of quantum physics, the limitation of producing techniques, and therefore the increase in production costs will limit researchers in downsizing conventional technologies. Extensive research in recent years on alternative technologies has focused a good deal of interest on nanoscale materials (Ruan et al., 2013, Zhao et al., 2014, Li et al., 2017, Du et al., 2012, Xu et al., 2019, Kianfar, 2019). the foremost important of those kinds of nanowires are nanowires such as: silicon, germanium, boron, tin, lead, indium, bismuth, selenium, tellurium, gold (Kianfar et al., 2019, Kianfar, 2019, Kianfar et al., 2018),

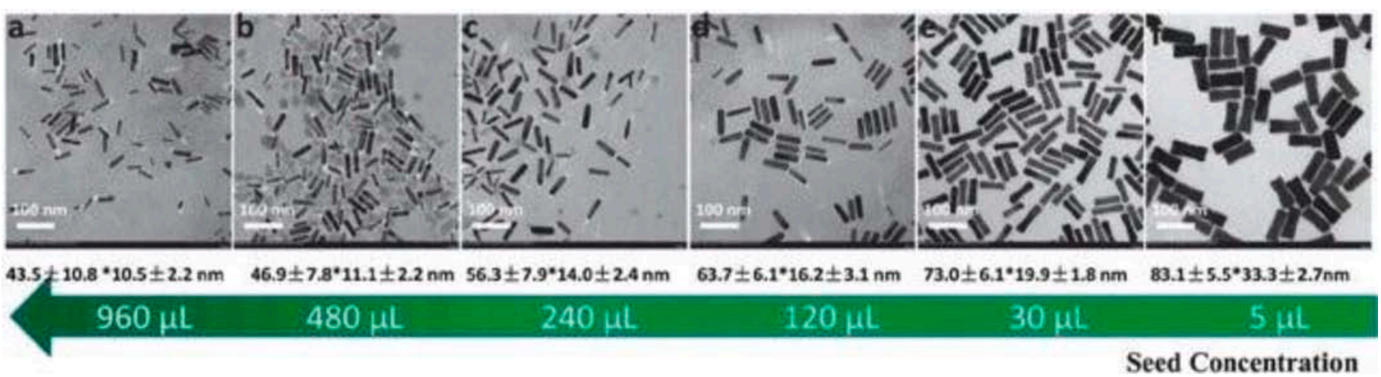

Fig. 3. TEM images of gold nanorods synthesized with different seed concentrations. In all cases, [AA] 1⁄4 1.6 [HAuCl 4], volumes of AgNO 3 (10 mM), HAuCl 4 (25.4 mM), CTAB (0.1 M) and H 2 SO 4 (0.5 M) added were 120 m L, 196.8 m L, 9.65 mL and 200 m L respectively, with seed solution (a) 960 m L[25-26].

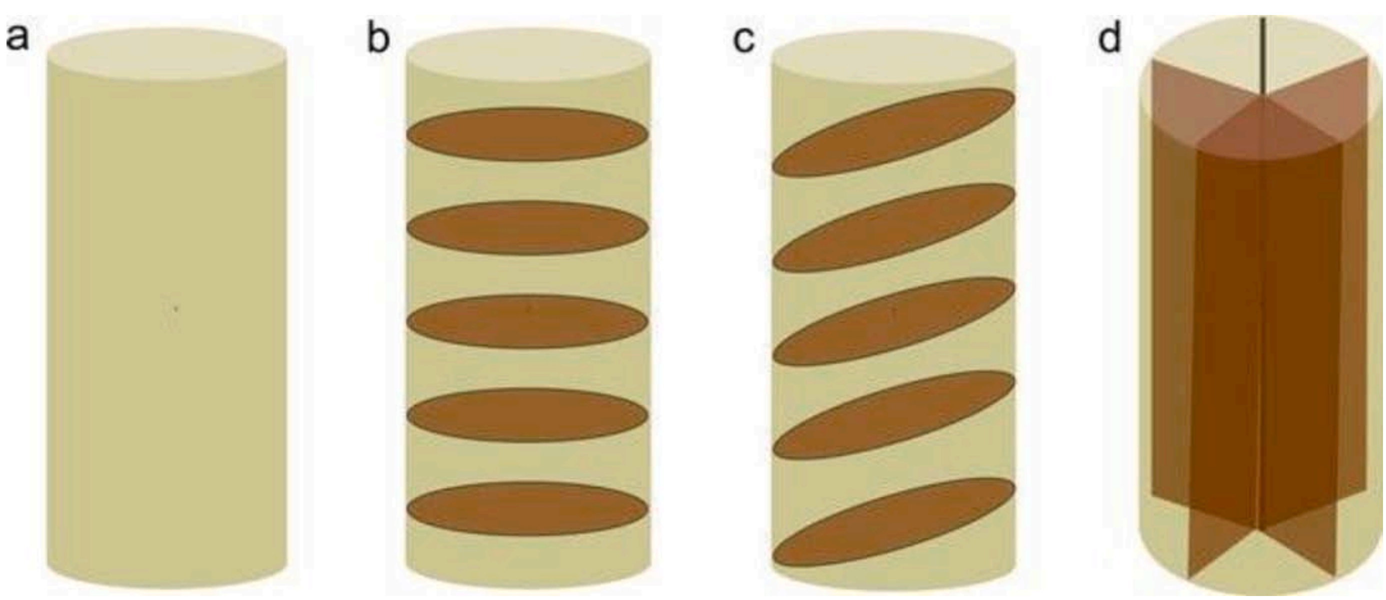

Fig. 4. Schematics of metal nanowires with different types of ordered arrangement of TBs, colored in brown. (a) Single crystal nanowire without TBs. (b) Nanowire with horizontal TBs. (c) Nanowire with inclined TBs. (d) Nanowire with five-fold vertical TBs (Narayanan et al., 2015).

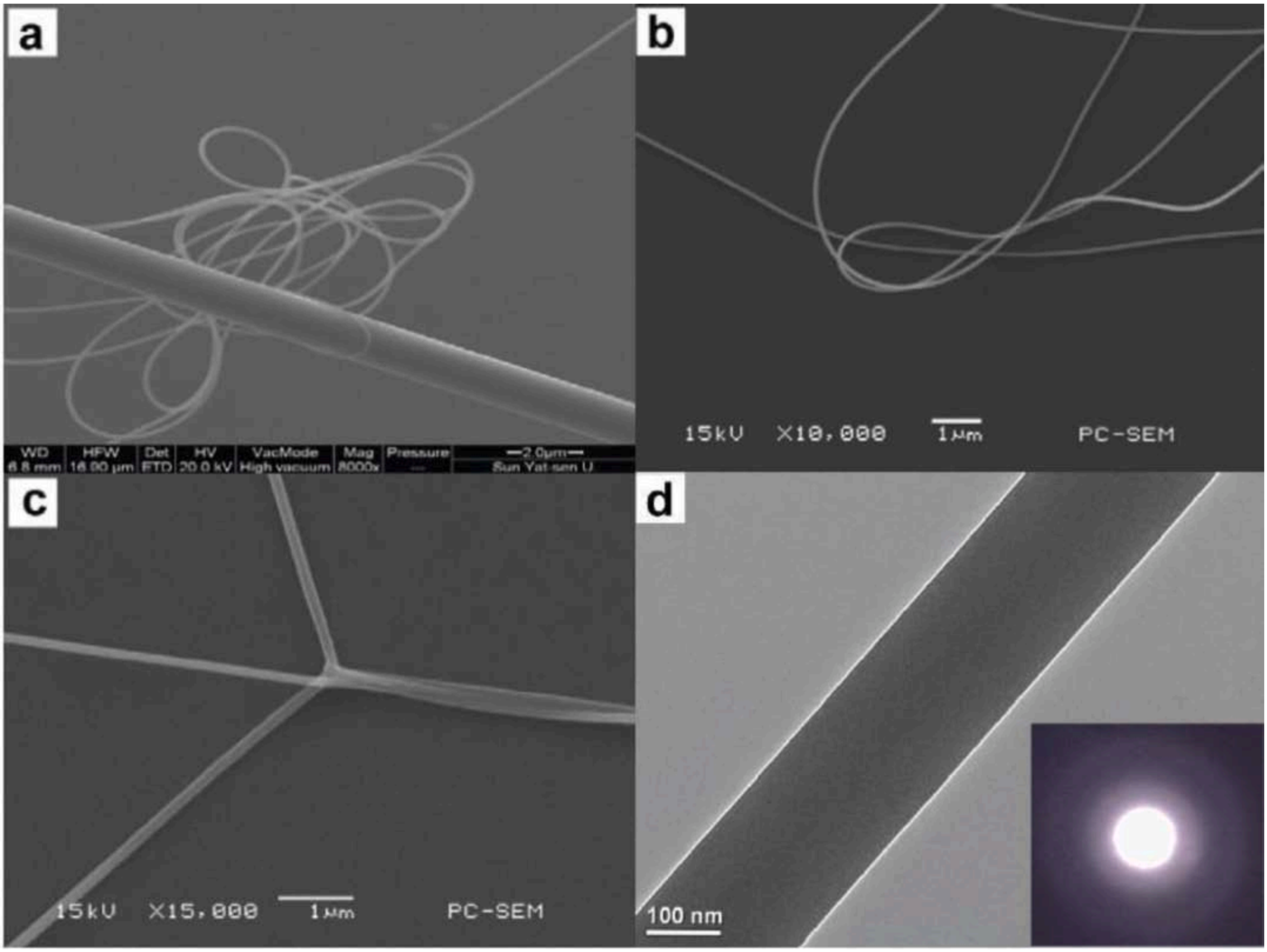

Fig. 5. (a), (b) and (c) scanning electron microscope images and (d) electron microscope images passing through the nanowire with a diameter of 190 nm (Wang, 2006, Volosskiy et al., 2015).

silver (Salimi et al., 2017, Kianfar and Kianfar, 2019, Kianfar et al., 2020), iron (Xu and Chen, 2014, Zhang et al., 2020, Zhang et al., 2020, Zhao et al., 2020), cobalt (Tu et al., 2021, Faghih and Kianfar, 2018, Kianfar and Mazaheri, 2020), nickel (Kianfar 2020, Kianfar et al., 2020, Kianfar, 2020, Kianfar, 2020), copper (Kianfar, 2021, Syah et al., 2021, Kianfar, 2021), zinc (Huo et al., 2021, Dai et al., 2021, Zhang et al., 2021), cadmium and cobalt (Liu et al., 2016, Numanoğlu et al., 2021, Thai et al., 2021). as an example, for the preparation of nanowires with silica compounds, for instance, SiOx and other precursors are used as sources of silicon (Fig. 2). Fig. 3 shows a transmission microscope (TEM) image of gold nanowires after purification. Fig. 4 shows the Schematics of metal nanowires with differing kinds of the ordered arrangement of TBs, colored in brown (Liu et al., 2016, Numanoğlu et al., 2021, Thai et al., 2021, Phung-Van et al., 2021, Moleiro et al., 2021, Tran et al., 2021).

2.2. Polymer nanowires

The development of nanotechnology in photonics offers significant technological and scientific potential (Moleiro et al., 2021, Numanoğlu et al., 2021, Kim et al., 2008 Apr 25, Hwang et al., 2015 May 13, Younus et al., 2023, Pour et al., 2023, Alkhawaldeh et al., 2023, Akbari et al., 2023, Avval et al., 2022, Mirzaee et al., 2021). This has led to significant efforts to get new materials, develop easy-to-manufacture technologies, reduce the scale of photonic components, improve Device Integration Density, and make low-cost nanometer devices. during this regard, we will mention the utilization of polymer nanowires to realize these purposes. as an example, since nanometer-scale photonic wires are highly desirable to be used in high-density and shrink photon integrated circuits, wires with a diameter but the wavelength are produced with the tactic of pulling and heating silica fibers and bulk glasses. Polyethylene terephthalate (PTT) nanowires are used for the primary time for nanophotonic applications (Andrei Bernevig et al., 2006, Yan et al., 2009, Won et al., 2019, Rogers and Huang, 2009, Liang et al., 2012, Xu et al., 2016, Song et al., 2016, Song et al., 2016, Behzadi pour et al., 2020, Pour et al., 2020, Aval, 2019, Ashourifar et al., 2019, Behzadi Pour et al., 2019, Fard et al., 2019). Fig. 5 shows microscope images of PTT nanowires.

2.3. Nanowires with two different materials (core/shell)

Silicon oxide nanowires enjoy different atomic ratios from silicon to oxygen, so the value of x in SiOx can be various within the range of 1 to 2 (Lan et al., 2007, Hu et al., 2008, Jianyu et al., 2016, Fang et al., 2018, Bari et al., 2016, Park et al., 2017). The amorphous shell during this sort of nanowire prevents mechanical or radiation damage and restricts the chemical reactivity which will cause oxidation and contamination of silicon nanowires. The application of Si / SiOx core-shell nanowires is analogous thereto of SiOx nanowires (Won et al., 2021, Kwon et al., 2018, Kim et al., 2018, Kim et al., 2020, Hong et al., 2015 Aug 26). The

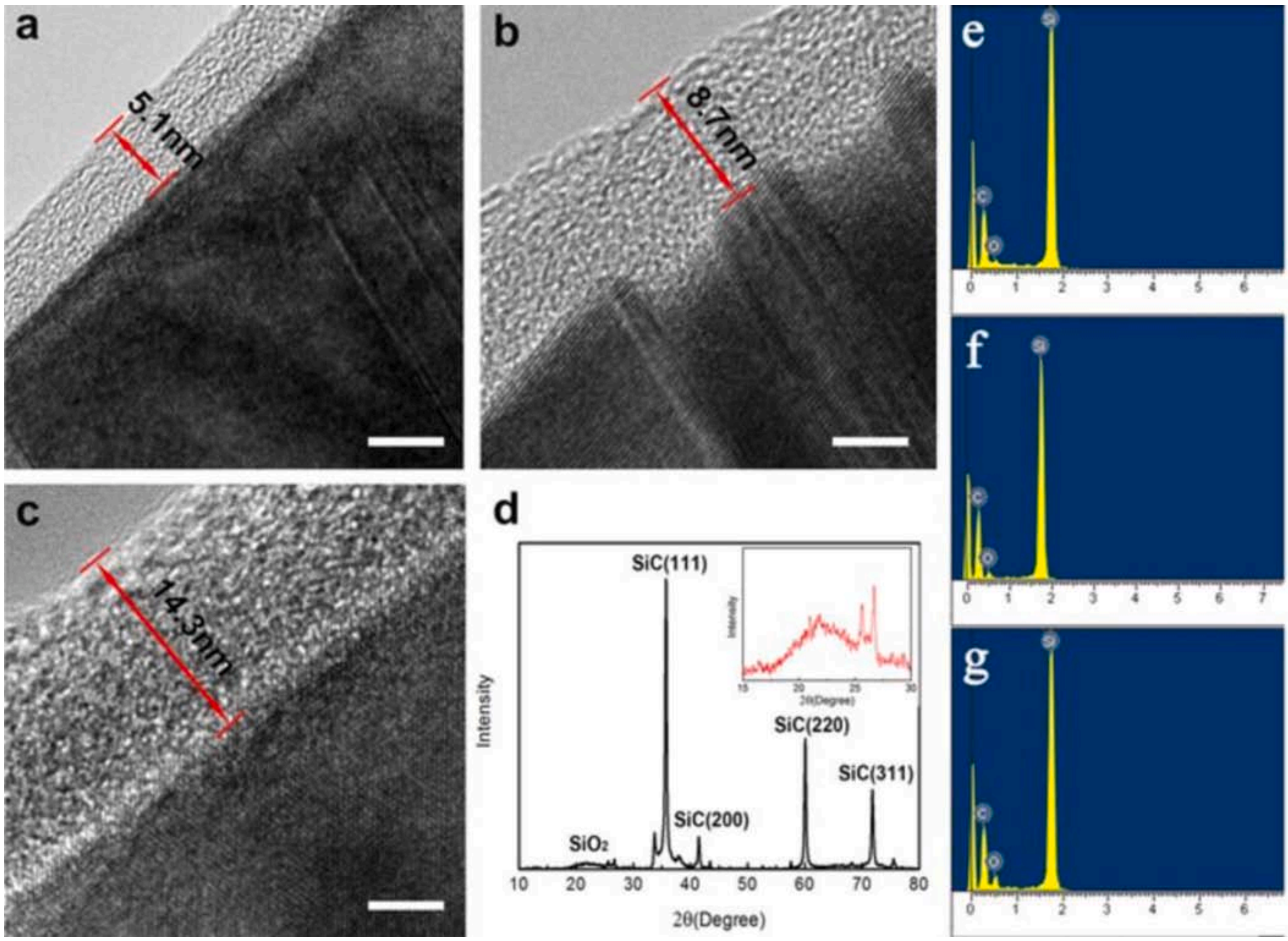

Fig. 6. Morphology and microstructure characterization of SiO_2@SiC nanowires. (a–c) TEM images of SiO_2@SiC nanowires with different shell thicknesses. The scale bar corresponds to 5 nm. (d) X-ray diffraction pattern recorded from SiO_2@SiC nanowires, and the top inset shows the enlarged image range from 15°–30°. EDS results (e–g) were obtained correspond to (a–c), respectively (Wang, 2006, Volosskiy et al., 2015).

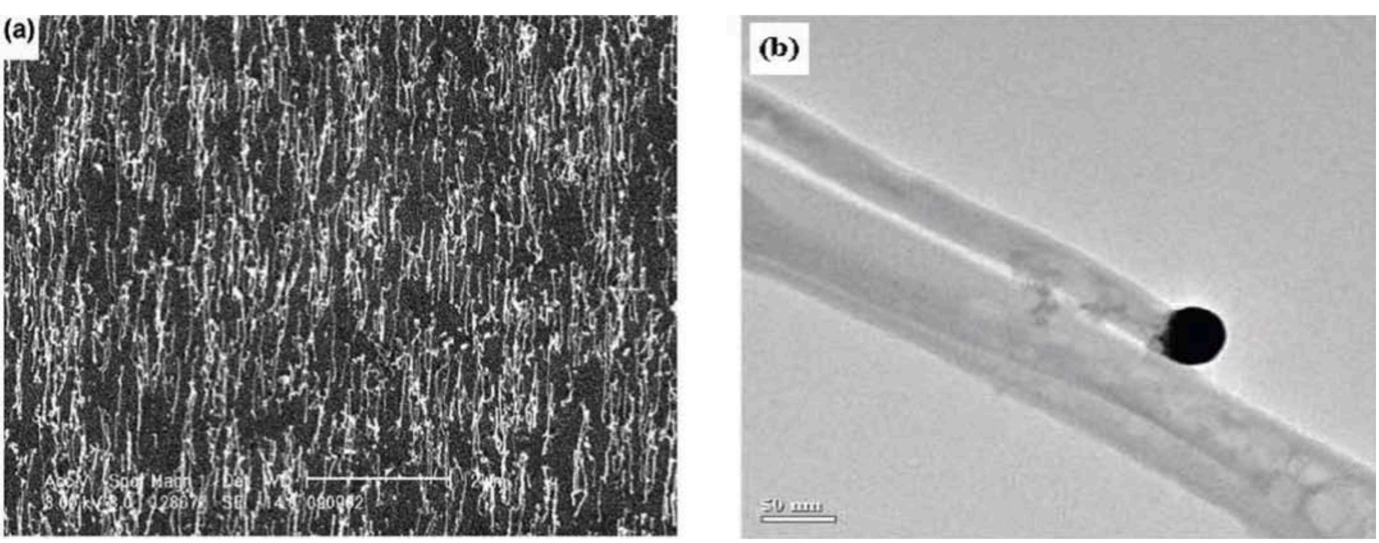

Fig. 7. (a) SEM image of Si / SiOx shell-core directional nanowires synthesized at 800°C and (b) TEM image of a nanowire with a metal particle on top (Wang, 2006, Volosskiy et al., 2015).

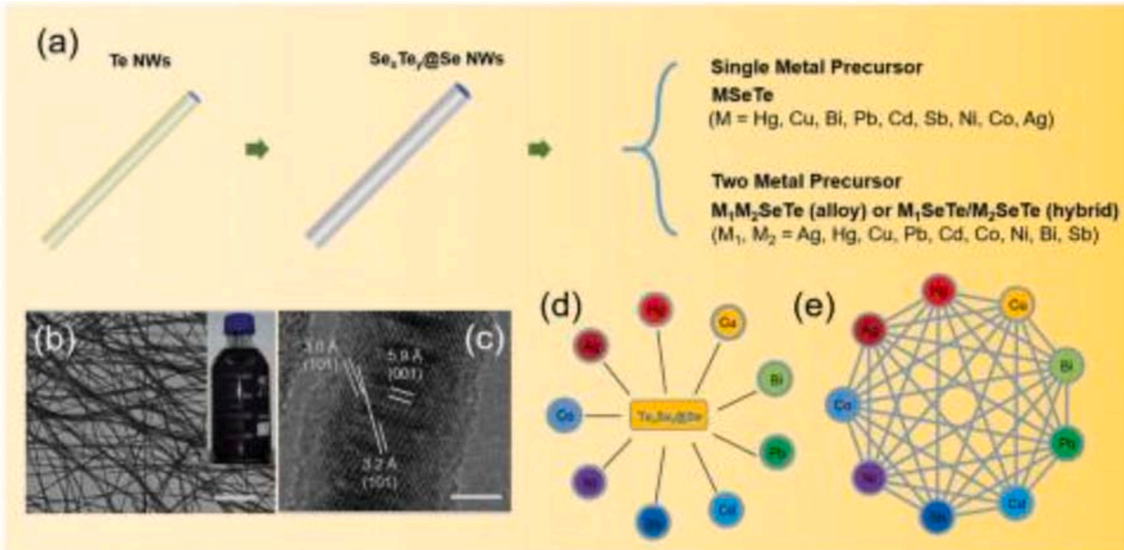

Fig. 8. Schematic illustration of core-shell NW evolution achieved with a chemical transformation synthesis (more than 45 kinds of NWs) (Narayanan et al., 2015).

Table 2
List of properties of gold nanowires and their potential applications.

Properties of Gold Nanowires	Potential application	Reference
Large surface area	Nanoelectrode Sensor, catalytic	(Glas, 2006)
Electron transport with organic OA layer	High resistivity, $10^6\Omega$, temperature-dependent non-linear behavior, lower catalytic ability	(Shimamura et al., 2013, Belabbes et al., 2012)
Electron transport without OA layer	Low resistivity, 10^3 Ω, high electron transport, electrochemical, nanoelectrode sensor, high catalytic ability	(Shimamura et al., 2013, Belabbes et al., 2012)
Mechanical properties	High engineering strength, interconnects	(Qian et al., 2015, Pemasiri et al., 2009)
LSP	SEF, SERS	(Qian et al., 2015, Bechstedt and Belabbes, 2013, Senichev et al., 2018, Azulay et al., 2020)
Chirality of gold cluster	Asymmetric drugs, sensors, and catalysts	(He et al., 2013)
Self-assembly	Active substrates for SERS	(Biermanns et al., 2012)

Table 3
List of the flowing resent researches on optical properties of Gold Nanowires sensing.

Materials	Methods and Properties	Results (Factor)	Reference
Gold Nanowires arrays	Optical Diffraction methods	Used for surface molecule adsorption process	(Azulay et al., 2020)
Gold Nanowires arrays with DNA	ssDNA hybridizing, optical diffraction measurements	Detect sequence of unlabeled ssDNA	(Kianfar, 2020)
Gold Nanowires with different cross section	Scattering loss and joule heating with cross section	Scattering loss dependent on plasmon mode rather than cross section	(Kianfar, 2020)
Gold nanoantenna dimmers	Scattering loss and joule heating with cross section	Bonding and antibonding combination show	(Kianfar, 2020)
Bowtie gold nanoantenna	Surface enhance fluorescence	Factor of 1340	(Kianfar and Mazaheri, 2020, Chu et al., 2016)

photoluminescence characteristics of SiOx nanowires emit blue-red light, making them fit for the fabrication of photoluminescence materials like strong blue light transmitters, integrated optical Nano-instruments, and high-resolution optical tip near-field scanning light microscopes (Kim et al., 2015, Han et al., 2014, Lee et al., 2012, Hong et al., 2019, Song et al., 2022, Kim et al., 2020). Also, the superb biocompatibility of those nanostructures prepares them to be employed in biomedical applications. The foremost important centering methods of those nanostructures are laser ablation, chemical vapor deposition (CVD), sol-gel, rapid thermal annealing (RTA), ion implantation and carbon-assisted growth. (Won et al., 2019, Jeong et al., 2015, Chang et al., 2013, Jung et al., 2019). An example of shell-core Si / SiOx nanowires is seen in Figs. 6 and 7 which show MSeTe-Based NW Evolution with a Chemical Transformation (Olea et al., 2005, Law et al., 2006, Chang et al., 2017, Bang et al., 2021).

Nanostructures of alloys or hybrids integrated from two or more chemically distinct materials are hugely attractive thanks to their improved functionalities and novel properties (Moon et al., 2017, Lee et al., 2016, Majdi et al., 2021, Bokov et al., 2021). Se and Te are both elements of the sixth main group and possess six outer electrons within the $5s^2$ $5p^4$ configuration. Both Se/Te alloyed and heterogeneous nanostructures are reported later (Fig. 8) (Narayanan et al., 2015).

2.4. Gold Nanowires

As the Gold Nanowires do not appear to be thermally stable, mild heating could push them to disintegrate into nanoparticles. Therefore, Gold Nanowires become stable with the assistance of an organic molecule layer, like oleylamine (OA) (Jasim et al., 2022, Mikhailov and Chachkov, 2020, Chachkov and Mikhailov, 2020, Chachkov and Mikhailov, 2020, Mikhailov and Chachkov, 2020, Mikhailov and Chachkov, 2020, Bakhtadze et al., 2020). Thus, the pure Gold Nanowires without protective layers have spectacular conductivity and catalytic ability, and they may be severely involved in sensing and catalytic fields. Table 2 gives a list of features of gold nanowires and their potential applications (Miraoui and Didi, 2020, Gözükızıl, 2020, Chupradit et al., 2021, Yang et al., 2021, Shang et al., 2021). GNWs exhibit interesting optical properties with numerous applications in sensing like their surface plasmon resonances (Table 3). They want to confine radiation to a volume of subwavelength dimensions. For instance, vibrational spectroscopy of molecules is achieved with surface enhanced scattering technique, like SERS and surface enhanced IR absorption (Zeng et al.,

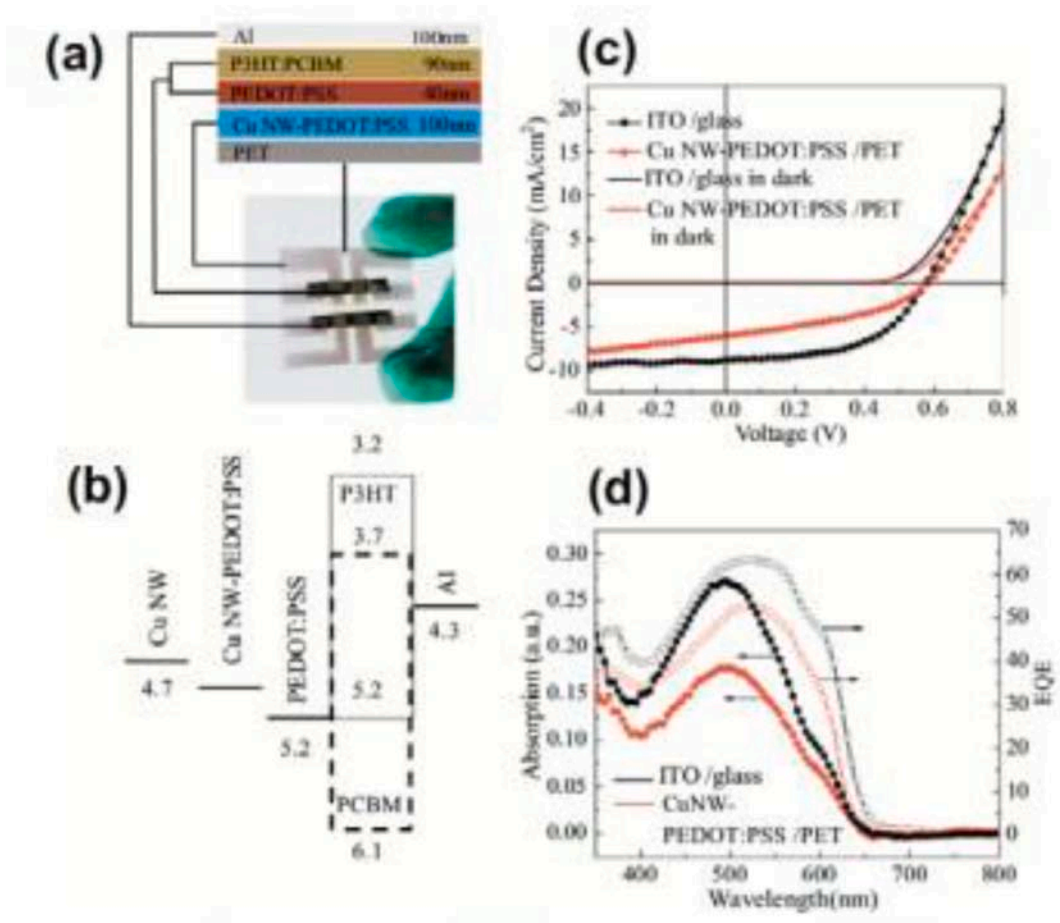

Fig. 9. (a) Photograph and schematic illustration of the fabricated Cu NW-based solar cell device, (b) Energy-level diagram, (c) J-V curves of the cells in the dark and under simulated AM 1.5 solar for devices on ITO/glass and Cu NW-PEDOT: PSS/PET electrodes, (d) IPCE and adsorption curves (Chen et al., 2015).

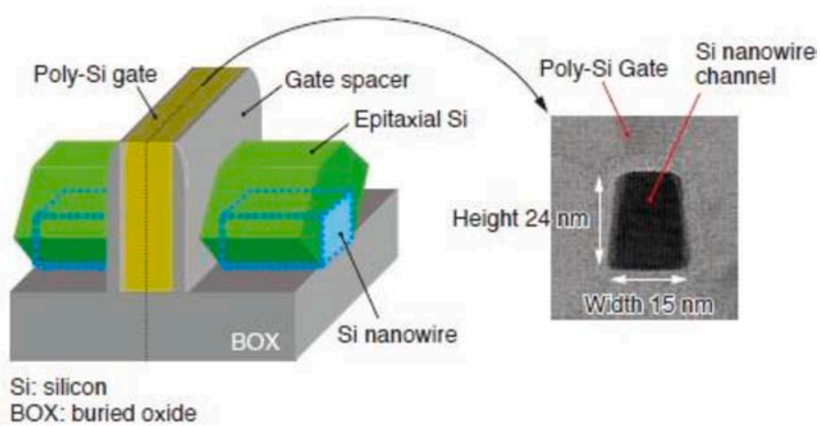

Fig. 10. Construction of transistors using metal nanowires (Wang, 2006, Volosskiy et al., 2015).

2021, Chen et al., 2021, Fu et al., 2021, Radhy and Jasim, 2021, Suhad et al., 2021, Panchal et al., 2021, Al-Shawi et al., 2021). Gold Nanowires present great opportunities as waveguides, due to deep sub-wavelength confinement, coherence maintenance and low scattering losses. Moreover, surface enhanced optical diffraction and fluorescence also show great potential for chemical and biochemical sensors (Zhang et al., 2015, Zhang et al., 2015, Wang et al., 2016, Zhang et al., 2017, Yang et al., 2017).

2.5. Synthesis of metal nanowires

There are several routes to synthetize metal NWs, such as chemical vapors deposition, electro-spinning and solution processed approach. Among these methods, solution synthesis including hydrothermal reaction, polyol reduction, water-based synthesis, seed-mediated growth and catalytic growth, are widely used. Among all these solution syntheses, metal ions are transformed into metal atoms by reducing agent, and the capping agent play the dominant role in controlling anisotropic growth of metal nanocrystal into nanowires (Gao et al., 2019, Zhang

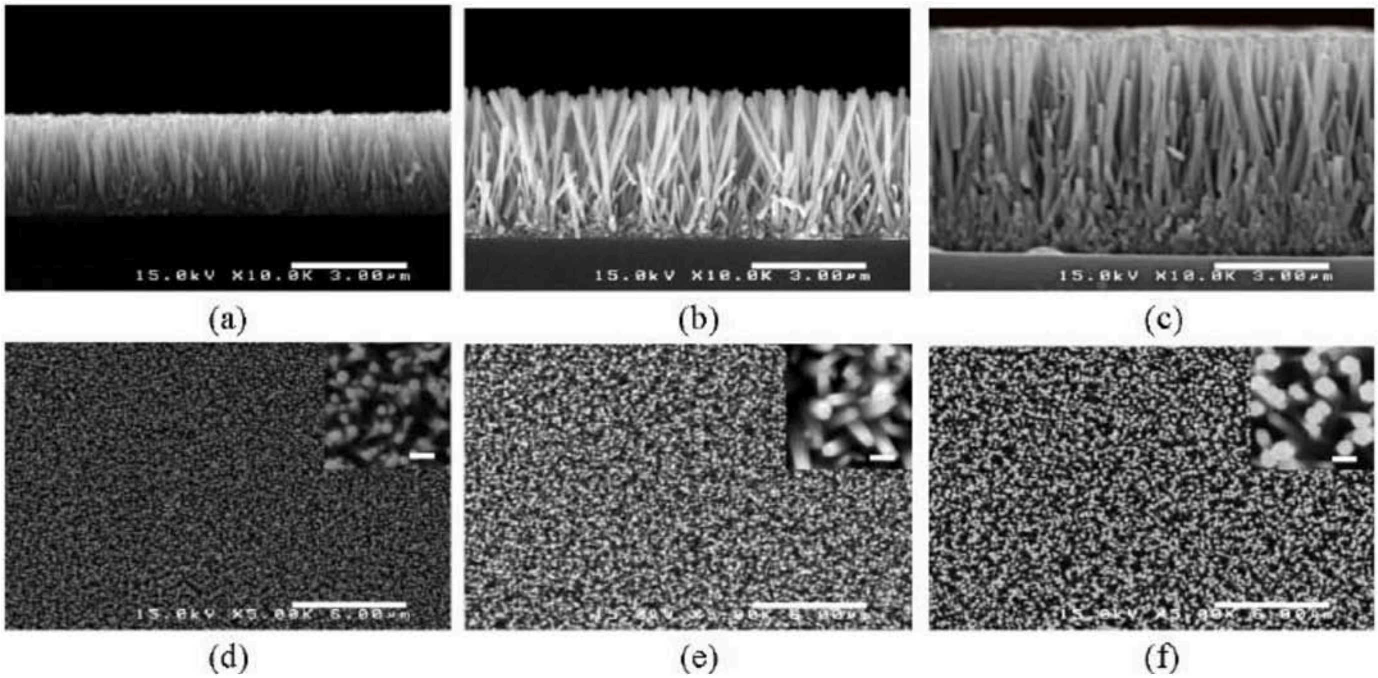

Fig. 11. Top view SEM images of ZnO nanowires grown using different substrate seeding methods: (a) without seeding, (b) drop-coating method, (c) spin-coating method and (d) twice-performed spin-coating method (Wang, 2006, Volosskiy et al., 2015).

et al., 2016, Du et al., 2022, Xu et al., 2021, Guo et al., 2021, Kalashgarani and Babapoor, 2022, Mohammed et al., 2023).

Roughness plays a critical role in optoelectronic devices applications. High surface roughness would lead to leakages or electrical shortcuts in the devices (Kianfar et al., 2020). Generally, ITO presents a smooth continuous surface with roughness of about 5nm. However, for the metal NW films, its glass or polymer substrate is not fully covered and leave roughness of at least double NWs diameter, approximate to 100-200nm. To overcome this problem, several methods have been explored to achieve a smooth NWs networks film, such as mechanical pressing, thermal annealing and polymer coating. Tokuno et al. (Tokuno et al., 2011) reported that mechanical pressing is essential for improving the electrical conductivity of Ag NWs transparent electrode. After the Ag NW electrodes were pressed for 5s under 25MPa at room temperature, a transparency of 80.0% and a low sheet resistance of 8.6/sq are obtained, which is equivalent to the performance of the Ag NW electrodes heated at 200°C. Recently, we reported a simple polymer coating method to decrease the roughness of Cu NWs FTCs (Kianfar et al., 2015). Cu NWs-based TCEs with low surface roughness (~70nm in height) were obtained by embedding Cu NWs into pre-coated smooth PEDOT: PSS PET substrates.

2.5.1. Silver and copper nanowire

Copper nanowire is a promising new filler for Nanofluids for cooling applications (Jianyu et al., 2016). Elongated one-dimensional nanostructures such as nanowires provide a percolated network for fast conduction of heat in the low conducting fluid (Fang et al., 2018, Bari et al., 2016, Park et al., 2017). There is an on-going drive to replace traditional transparent conducting electrode (TCE), indium tin oxide (ITO), as its brittleness and scarcity, and to meet the development of flexible and wearable electronics (Won et al., 2021, Kwon et al., 2018, Kim et al., 2018, Kim et al., 2020, Hong et al., 2015 Aug 26, Kim et al., 2015). Metal nanowires, typically Ag and Cu nanowires (NWs), are of particular interest for optoelectronic applications as the next-generation flexible, stretchable, and transparent conductive electrodes due to their excellent mechanical and electrical properties (Han et al., 2014, Lee et al., 2012, Hong et al., 2019, Song et al., 2022, Kim et al., 2020). It is necessary to develop a facile route to produce well-defined metal nanowires for their large-scale production and commercialization (Fang et al., 2018, Bari et al., 2016, Park et al., 2017). Among a variety of processes that were used to prepare Cu NWs and Ag NWs, solution synthesis was considered to be a promising approach due to the precursors being abundant and the morphology and structure of the product could be modulated with tuning reaction conditions. Herein, we highlight the review of latest developed strategies based on published patents and researches to prepare Ag NWs and Cu NWs with particular discussion on flexible and transparent conductors based on their percolating networks (Jianyu et al., 2016, Won et al., 2019, Jeong et al., 2015, Chang et al., 2013, Jung et al., 2019).

2.5.2. Applications of metal nanowires flexible transparent conductors

The advantages of metal NW FTCs, such as low sheet resistance, high optical transmittance and good mechanical flexibility, allow them having various promising applications in optoelectronic devices, e.g., photovoltaic cells, OLEDs, transparent heaters, touch panels, electronic circuits and so forth.

2.5.2.1. Photovoltaic Cells. Metal NW FTCs show equivalent performance to ITO when used as electrodes in photovoltaic cells. Brabec et al. (Shaheen et al., 2001) reported an organic solar cell with an efficiency of 2.5% based on high-quality Ag NW conductive electrode with transparency (T) up to 90% and a low RS of 9sq-1. Using their synthesized polymer as active layer, Wiley and co-workers (Kianfar et al., 2018) increased the efficiency from 1.1% of normal device to 2.8%, where the Ag NW electrodes used have a RS of 33sq-1 and a T of 84%. Their devices on Ag NW/PET demonstrated flexibility and retained an efficiency of 2.5% after large deformation to 120. The cell structure is depicted in Fig 9. Where PEDOT: PSS layer acts as hole-transporting layer (Fig. 9a). Besides, PEDOT: PSS also plays a role to tune the work function of the anodes and smooth the surface (Fig. 9b). The PCE is 1.4% with a short-circuit current density of 6.05mAcm–2, a fill factor of 40% and an open-circuit voltage of 0.58V (Fig. 9c). This efficiency is lower than the device on ITO, which is probably caused by the 11% decreased transparency of Cu NW-PEDOT: PSS/PET film with respect to ITO/glass. The

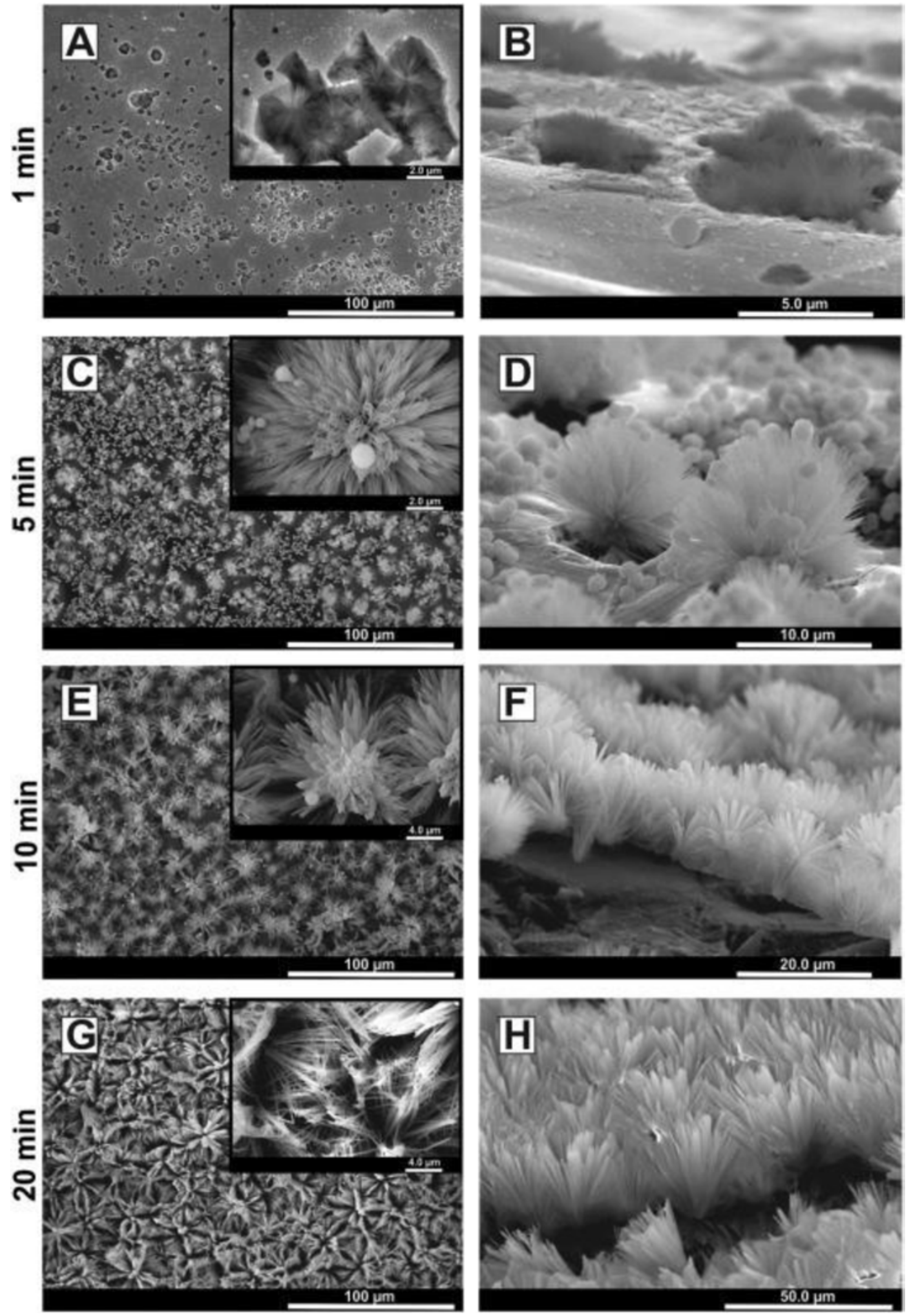

Fig. 12. FE-SEM images of Zn foil after different durations of anodization in 5 mM $NaHCO_3$ at the potential of 10 V. Top- (A, C, E, G) and cross-sectional (B, D, F, H) views (Wang, 2006, Volosskiy et al., 2015).

low transparency will reduce the amount of photon-generated carrier and thus increase the serial resistance. Fig. 9(d) displays the absorbance and IPCE of the Cu NW- and ITO-based devices. Apart from the absorption intensity on Cu NW-based device is much strong due to its low transparency, both devices feature similar absorption and IPCE curve fluctuation, indicating that our Cu NW hybrid electrodes match well with the whole device. Hence, the performance of the cells is expected to be significantly elevated by improving the quality of the Cu NWPEDOT: PSS/PET electrodes.

2.5.2.2. OLEDs. The rapid development of metal NW FTCs has inspirited researchers to fabricate flexible OLEDs. Especially the NWs take advantage of solution processibility including printing or roll-to-roll process, well matches the requirement for manufacturing large-area and low-price OLEDs (Mohammed et al., 2023, sabri Abbas et al., 2023, Abdul-Reda Hussein et al., 2023, Mahmoud et al., 2023, Smaisim et al., 2023, Smaisim et al., 2023). Several pioneer works have been reported to demonstrate flexible OLED devices using either small organics or polymer semiconductors as building blocks. As mentioned above, the electrodes used in OLEDs need flat surfaces, where the roughness is expected to be small as that of ITO (Fattah et al., 2023, Kadhim et al., 2023, Kianfar, 2023, Kianfar, 2022, Smaisim et al., 2022, Kianfar and Sayadi, 2022, AL-Salman et al., 2023, Alabada et al., 2023, Ahmed Mahdi et al., 2023). To this end, Pei et al. (Yu et al., 2011) fabricated smooth Ag NWs/polyacrylate electrodes with roughness lower than 10nm to assemble polymer light- emitting diodes (PLED).

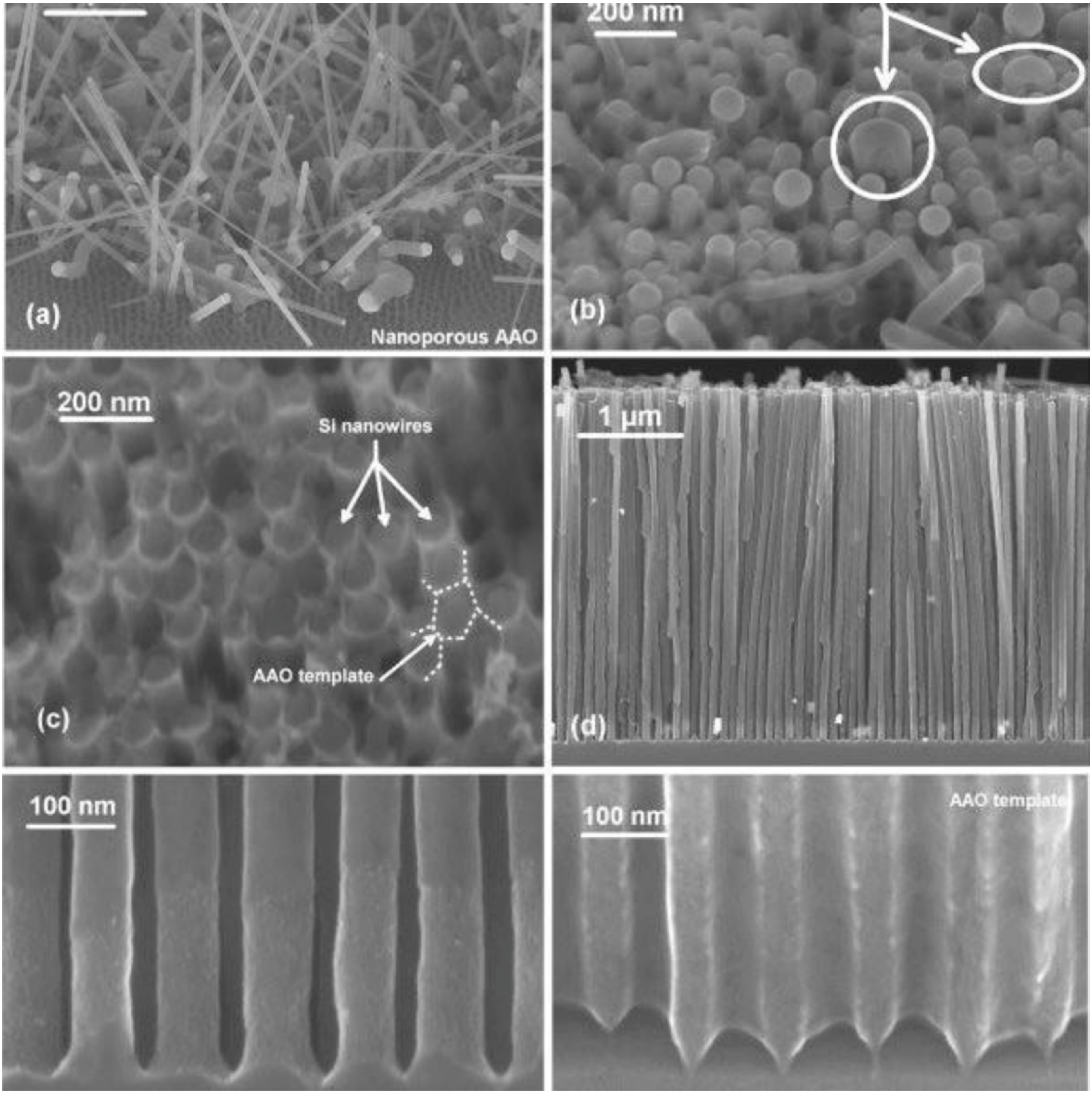

Fig. 13. Scanning electron microscope image of silicon nanowires (Wang, 2006, Volosskiy et al., 2015).

The fabricated PLEDs have a maximum efficacy value of 14.0cdA1, higher than that on ITO anode. The devices could be bent at different angles without loss of any electroluminescence.

2.5.2.3. Transparent Heaters. Transparent heaters are widely used in clearing automobile, microchips, defogging windows and displays. ITO film, a traditional fundamental material of transparent heater, not only requires a complicated manufacturing process and high roduction costs but also possess a related slow thermal response. Metal NWs is considered as a promising material for replacing ITO in transparent heaters (Hachem et al., 2022, Salahdin et al., 2022, Abdelbasset et al., 2022, Ansari et al., 2022, Isola et al., 2022, Hajimirzaee et al., 2022, Jasim et al., 2022). Hong et al. (Hong et al., 2015) developed a highly stretchable and transparent heater based on Ag NW /PDMS conductive films. Their flexible transparent heaters have high optical transmittance, excellent electrical conductivity, and superb mechanical and thermal stability.

2.6. General methods of construction and application

There are two main approaches to creating nanowires: the top-down method and therefore the bottom-up method. within the top-down method, an oversized piece of fabric is reduced to smaller pieces with various methods like lithography and electrophoresis (movement of liquid suspended particles with means of an electrical current). within the bottom-up method, a nanowire is synthesized with combining or creating constituent atoms. Many methods of constructing nanowires today are supported a bottom-up approach (Hussein et al., 2022,

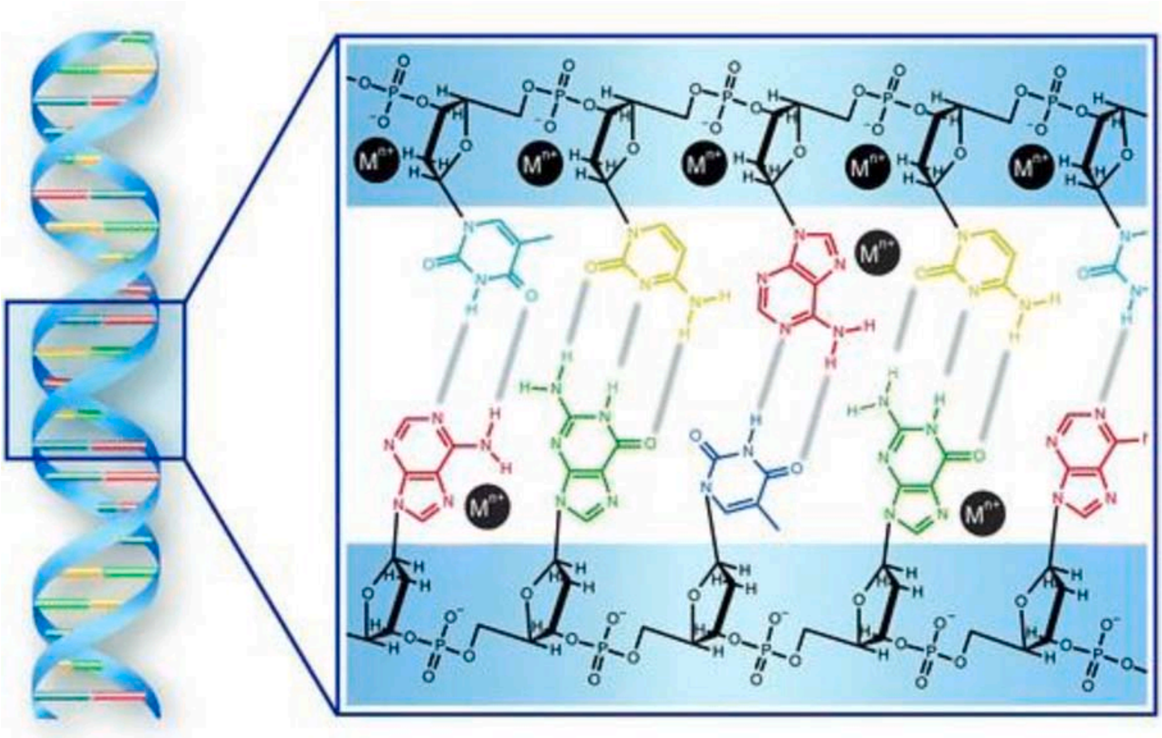

Fig. 14. The structure of a DNA molecule that intersects two strands of wire 2 nanometers in diameter (Wang, 2006, Volosskiy et al., 2015).

Abderrahmane et al., 2023, Wang et al., 2022, Xiao and Smaisim, 2022, Mourad et al., 2022). Liquid phase synthesis is vital thanks to advantages like the homogeneous nature of the reactions, the big selection of solvents, the chance of easy monitoring and therefore the low cost (Smaisim et al., 2022, Abderrahmane et al., 2022, Tan et al., 2022, Mir et al., 2022, Ruhani et al., 2022). because of the little size of the nanowire, the surface atoms are much larger in number than the inner atoms, and so the sting effects are more important. Nanowires are studied to be used in photon waveguides. Photons move inside the tube and electrons move within the outer shell (Cai et al., 2022, Moarrefzadeh et al., 2022, Hai et al., 2022, Smaisim et al., 2022, Smaisim et al., 2022). When two nanowires intersect as photon conductors, their junction acts as a quantum dot. Carbon nanotubes are a perfect choice for detecting sensitive gases because of their special hollow structure and enormous area. An electrically conductive nickel silicon nanowire has been shown to own high potential to be used as a microscope tip capable of reading nanometer structure and electrical information. Needle-shaped nanometer structures is utilized in field diffusers because they'll operate at a reduced voltage at the start of operation with an increased field of force within the tubes (Jiang et al., 2022, Tian et al., 2022, Alharbi et al., 2022, Wu et al., 2022, Tian et al., 2022, Brontowiyono et al., 2022). Today, the employment of nanowires within the diagnosis of diseases is well established. Nanowires will be used as accurate and extremely sensitive sensors that are located inside the body and just in case of problems or the presence of certain substances like toxins, it is reported to external warning devices and check out to eliminate or eliminate them. Scientists have succeeded in producing flexible, long nanowires that are a couple of thousand-fold thinner than human hair. The height, flexibility and strength of those nanowires give them special properties. as an example, their thinness and length increase their level. Therefore, these structures may be wont to design in no time and sensitive sensors (Tian et al., 2022, Smaisim et al., 2022, Smaisim et al., 2022, Smaisim et al., 2022, Smaisim et al., 2022, Mozafarifard et al., 2022, Sharba et al., 2022, Smaisim et al., 2022, AbdulHussein et al., 2022). These nanowires have the power to provide invisible ultraviolet rays, light enters the nanowire from one end and begins to shine from the opposite end. Nanowires pass this light efficiently with none loss. And in its path, if it encounters a pathogen or a toxic substance, the nanowire will start to shine, creating an awfully fast warning system, which might detect the disease sooner and faster than any test (Ahamad et al., 2022, Doss et al., 2022, Lefteh et al., 2022, Al-Madhhachi and Smaisim, 2021). Another application of nanowires in medicine is their use in blood vessels to stimulate the nerves of the brain. Researchers have developed platinum nanowires that are 100 times thinner and thinner than a human hair. They send these nanowires into blood vessels and direct them to the nerves of the brain through the tiny low camera. This method is incredibly useful to assist find various causes and therefore the emergence of neurological diseases like Parkinson's (Smaisim, 2018, Smaisim, 2017, Smaisim, 2017, Smaisim et al., 2016, Smaisim et al., 2016, Farahani et al., 2023).

3. Properties and applications

Metal nanowires have very good electrical conductivity. These nanowires are composed of metal atoms such as silver, gold, iron, etc., and they are widely used in the electronics industry. Nanowires can be used to make very small transistors (much smaller than today's transistors) and to use them to speed up computers and overcome the limitations of today's electronics industry, known as silicon electronics (Mir et al., 2023, Wang et al., 2023, Chen et al., 2023, Narayanasamy et al., 2023, Wang et al., 2023). In fact, the number of transistors on the CPU has increased, which leads to an increase in CPU speed and, consequently, computer speed. The speed of a CPU has a great impact on the speed of the computer and data processing. In today's technology (silicon) (Farahani et al., 2023, Mir et al., 2023, Abderrahmane et al., 2023, Wang et al., 2023, Chen et al., 2023), due to the constant size of the CPU, in order to increase the number of transistors, their dimensions must be smaller, and according to the laws of physics, the fall of the wire increases the electrical resistance and generates heat (Narayanasamy et al., 2023, Abdul-Reda Hussein et al., 2023, Mahmoud et al., 2023). The heat disrupts CPU operation and therefore the wires cannot be made smaller (Mahmoud et al., 2023, Mahdi et al., 2023, Hameed Mahmood

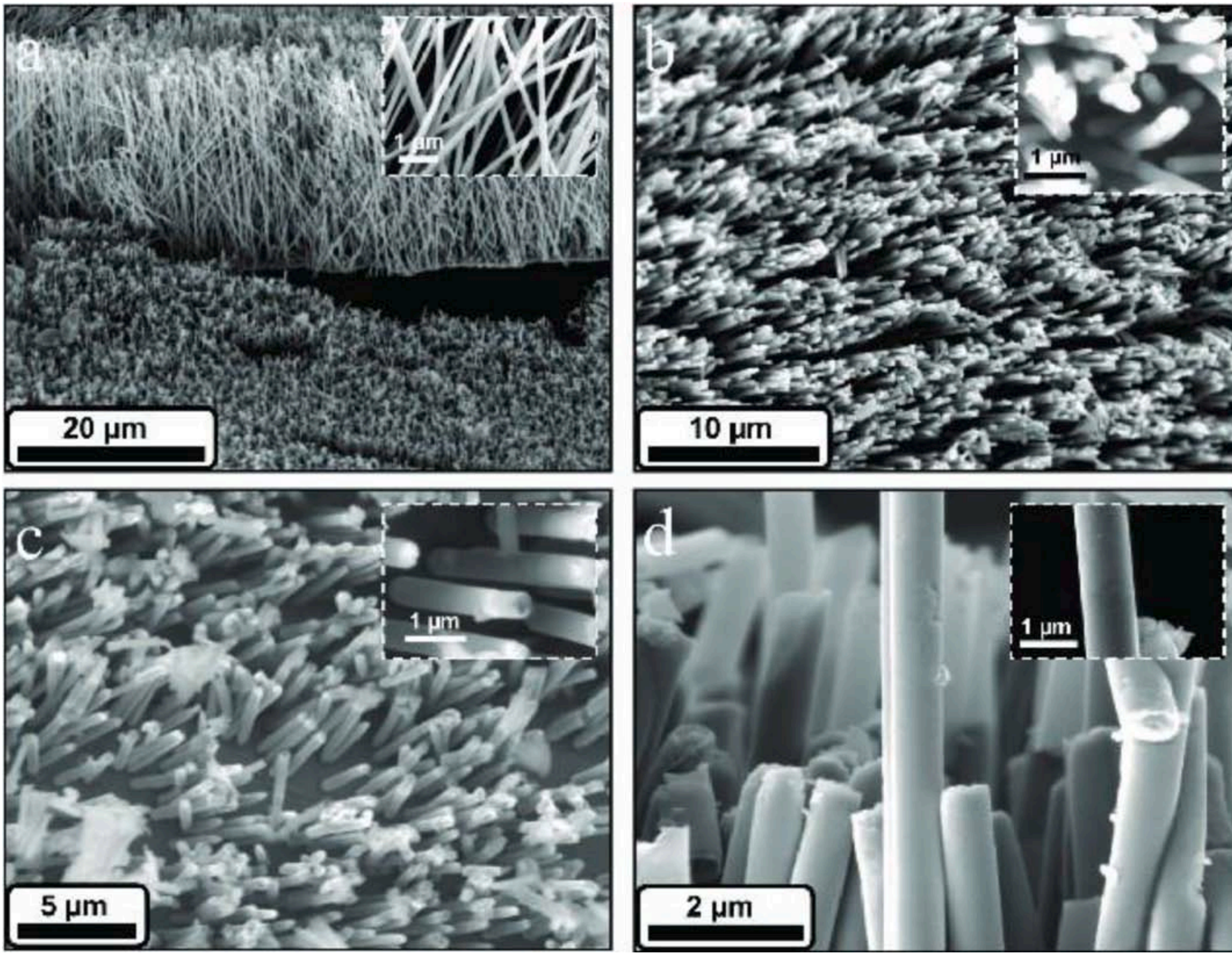

Fig. 15. An array of regular iron nanowires used to store information (Wang, 2006, Volosskiy et al., 2015).

et al., 2023). To solve this problem, metal nanowires are used. In fact, nanowires, due to their high electrical conductivity, do not generate heat due to the passage of current, and their dimensions can be very small and their number can be increased (Siswanto et al., 2023, Mahmoud et al., 2023, Mahmoud et al., 2023, Mahmoud et al., 2023, Jasim et al., 2023). An example of these transistors is shown in Fig. 10.

3.1. Optical properties

Semiconductor nanowires are commonly used in this part. The building blocks of these wires are atoms or semiconductor compounds (Al-Obaidi et al., 2023, Jasim et al., 2023, Jasim et al., 2022). Due to the discrete energy levels in the diameter direction, nanowires can exhibit interesting optical properties. Examples include the construction of very small lasers at the intersection of two ZnO nanowires or the construction of light-emitting diodes (LEDs) (Bokov et al., 2022, Jasim et al., 2022, Mansoor Al Sarraf et al., 2022). Fig. 11 shows the ZnO nanowires that are not oriented in the right part but are oriented in the left part with adopting special laboratory conditions. Fig. 12 shows the dimensions of a laser made of ZnO nanowires placed in a needle hole. Nanowires also have medical applications. Its applications include diagnosing the symptoms of various diseases such as cancer, targeting stem cell growth, stimulating nerves, and so on. Fig. 13 is a scanning electron microscope image of silicon nanowires that is most commonly used in this field.

3.2. Biological properties

The DNA molecule in an organism's body is actually made up of two strands of protein nanowires two nanometers in diameter (Mahmoud et al., 2022, Raya et al., 2022, Mahmood et al., 2022, Bahadoran et al., 2022). Today, in nanotechnology, this molecule has been widely used and is the model for making some nanostructured materials. The structure of the molecule is shown in Fig. 14.

3.3. Magnetic properties

Nanowires with magnetic properties such as Fe, Ni, Co-Cu and Co can be used to make magnetic memories with very small dimensions but very large data storage volumes (Kianfar, 2016, Kianfar, 2015, Kianfar, 2015). In fact, each of these nanowires is a bit of memory (Kianfar, 2015, Kianfar, 2019). In this application, it is necessary for the nanowires to be in a regular direction (Abramson et al., 2004, Zhang et al., 2013, Pei et al., 2012, Chen et al., 2018). The more orderly they are, the more desirable the storage of information. Fig. 15 shows an array of regular iron nanowires used to store information.

3.4. Sensory properties

Nanowires are very sensitive due to their small size and lightweight and can be used as gas sensors. Fig. 16 shows an example of a ZnO

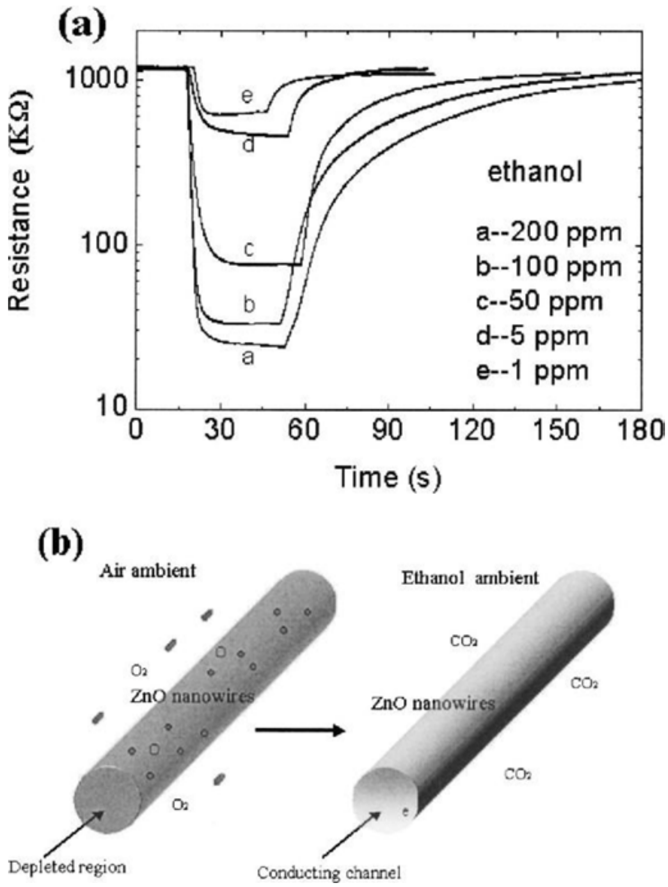

Fig. 16. a) Response and recovery characteristics of ZnO nanowires upon exposure to ethanol with a concentration of 1200 ppm at 300 C, and b) the sensing mechanism of ZnO nanowires to ethanol (Wang, 2006, Volosskiy et al., 2015).

nanowire sensor for detecting CO_2 molecules (Bahadoran et al., 2022, Mahmoud et al., 2022, Raya et al., 2022, Rheima and Al-Salman11, 2022, Mahmoud et al., 2022). Conventional gas sensors can detect the presence of a gas in the environment when its concentration is too high. But because nanowires are so small and light in weight, they can also detect a gas molecule (Chen et al., 2020, Wang et al., 2021, Zhu et al., 2020, Chen et al., 2019).

4. Method of making nanowires

There are different methods for processing and producing one-

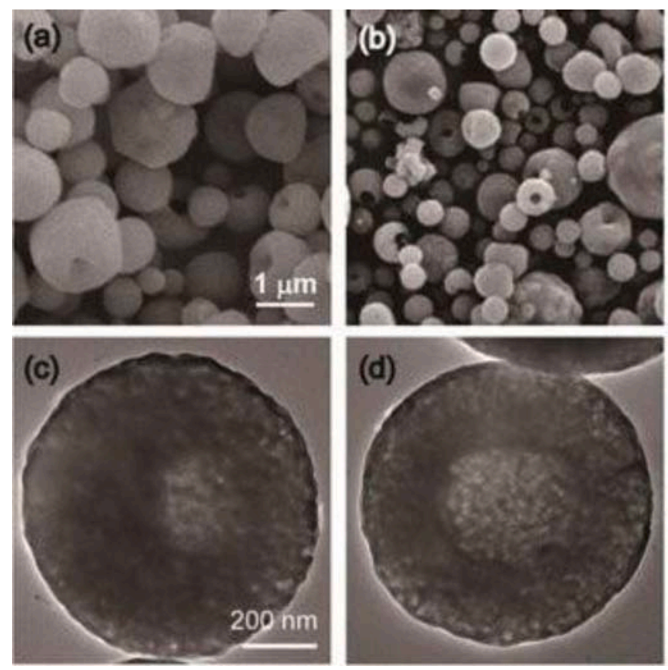

Fig. 18. TEM image of $SrFe_{12}O_{16}$ powder with different inorganic agents a) empty b) KCl c) KBr d) KI (Wang, 2006, Volosskiy et al., 2015).

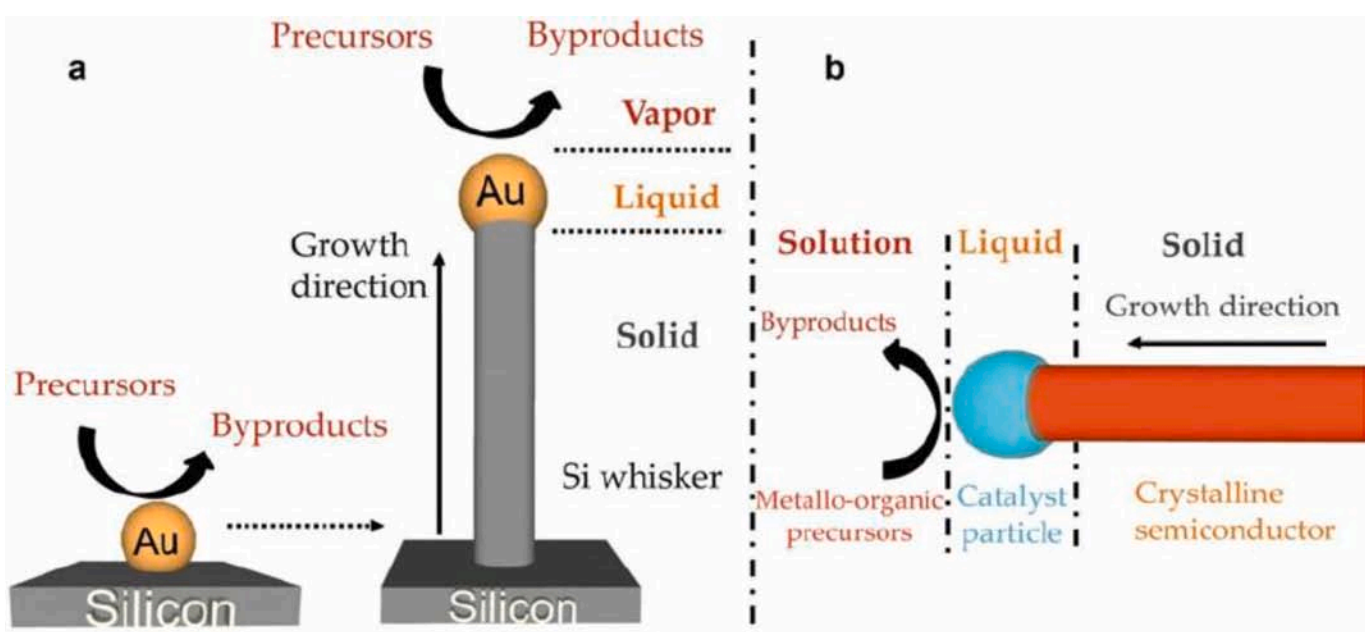

Fig. 17. Schematic illustration of the VLS and SLS mechanisms for the growth nanowires. (a) VLS mechanism for the growth under chemical vapor deposition conditions. (b) SLS mechanism for the analogous growth under solution (Wang, 2006, Volosskiy et al., 2015).

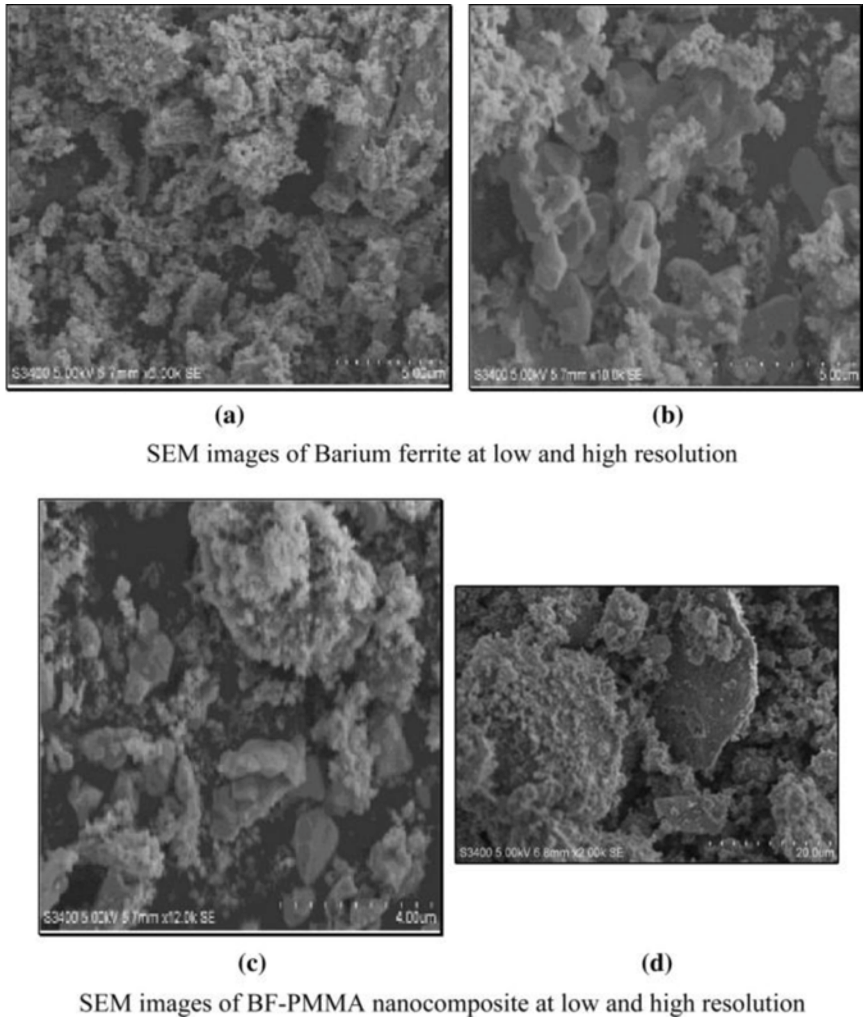

Fig. 19. (a, b) SEM images of barium ferrite at low and high resolution, (c, d) SEM images of BF–PMMA nanocomposite at low and high resolution (Lagashetty et al., 2020).

dimensional nanostructured materials. These methods generally fall into two categories (Lu et al., 2021, Pei et al., 2012, Chen et al., 2018, Schmidt et al., 2014, Zhang et al., 2020):

1 Spontaneous growth
   A) Evaporation (or dissolution) - condensate;
   B) Vapor growth (or solution) - liquid - solid (VLS or SLS);
   C) Recrystallization.
2 Methods based on template (Template, template)
   A) Electroplating
   B) Filling with melt or colloidal nanoparticles or solution
   C) Conversion with chemical reaction.

4.1. *spontaneous growth of one-dimensional nanoscale products*

Spontaneous growth is based on a decrease in energy level (Gibbs free energy) and this factor causes the growth of nanowires (as mentioned in the previous sections, all materials go in the direction to reduce their energy level) (Zhang et al., 2019, Sun et al., 2019, Zhang et al., 2019, Zhang et al., 2020). Decreased energy levels are usually caused with changing phase states (gas to liquid, liquid to solid, etc.), chemical reaction, or the release of stress in the structure. For nanowires or Nano rods to grow, the growth must be anisotropic. That is, the crystal grows faster in one direction than in others. In this case, one-dimensional nanostructures are formed with providing special laboratory conditions such as temperature and pressure (Duan et al., 2021, Swinkels et al., 2015, Wu et al., 2013, Yazji et al., 2015). When crystal growth occurs in only one direction, the nanowires have a constant diameter in the direction in which growth occurs. While there is no growth in other directions. Contamination and crystalline defects on growing surfaces play an important role in the shape (morphology) of the final product (Soini et al., 2010, Zou et al., 2015, Rojo et al., 2013). In this method, if specific catalysts are used, the growth of nanowires can be done with higher quality (Fig. 17).

4.2. *Sol- gel method*

There are two common methods for creating one-dimensional structures (rods or wires) using the sol-gel process (Zhang et al., 2020, Liu et al., 2021, Gao et al., 2020):

1 The use of surfactant molecules that increase the growth rate in certain crystal directions and the result of this directional growth is the formation of nanorods or nanowires.
2 Sedimentation of the final product obtained from sol-gel on nano-scale patterns.

Fig. 18 shows the transmission electron microscope images related to the fabrication of $SrFe_{12}O_{16}$ nanowires with sol-gel method with the

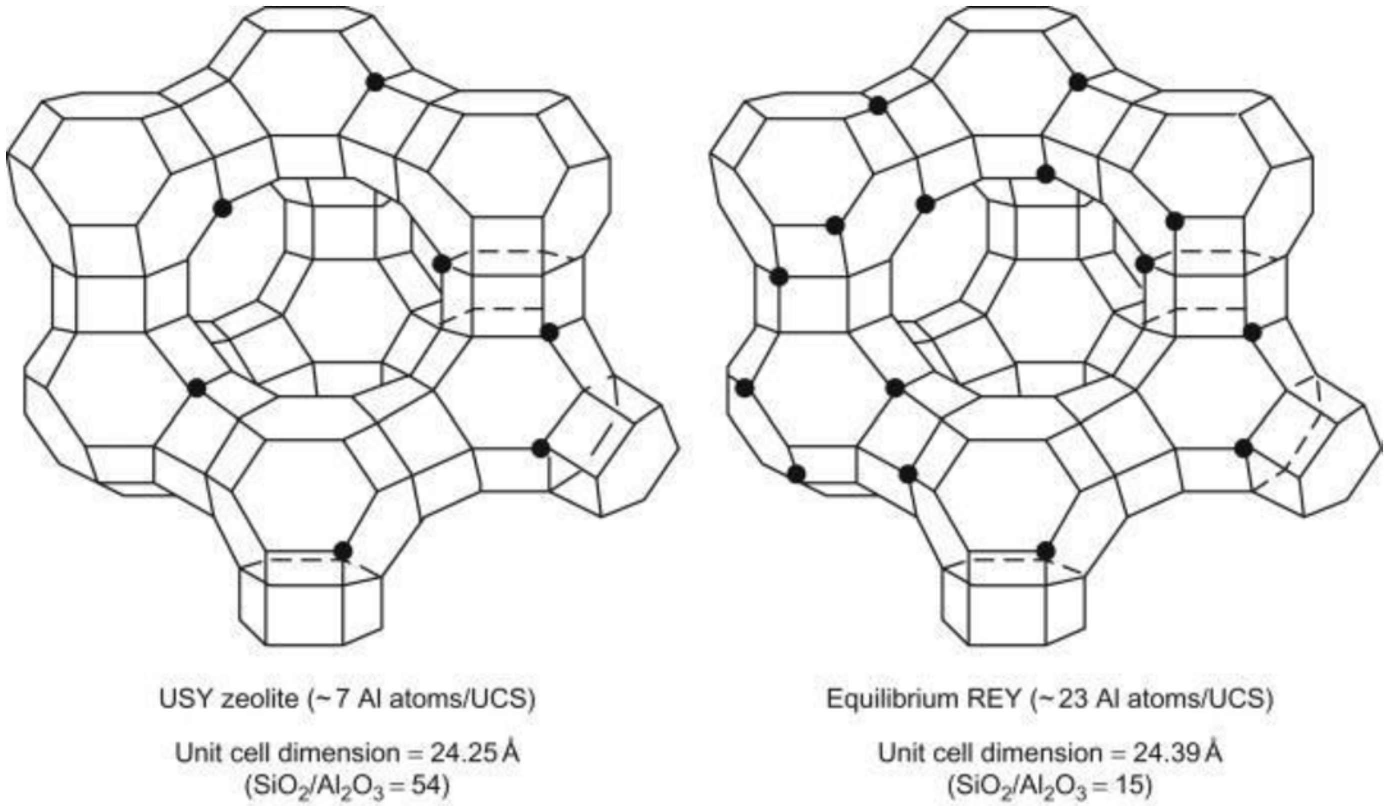

Fig. 20. Image of zeolite and cavities on its surface (Wang, 2006, Volosskiy et al., 2015).

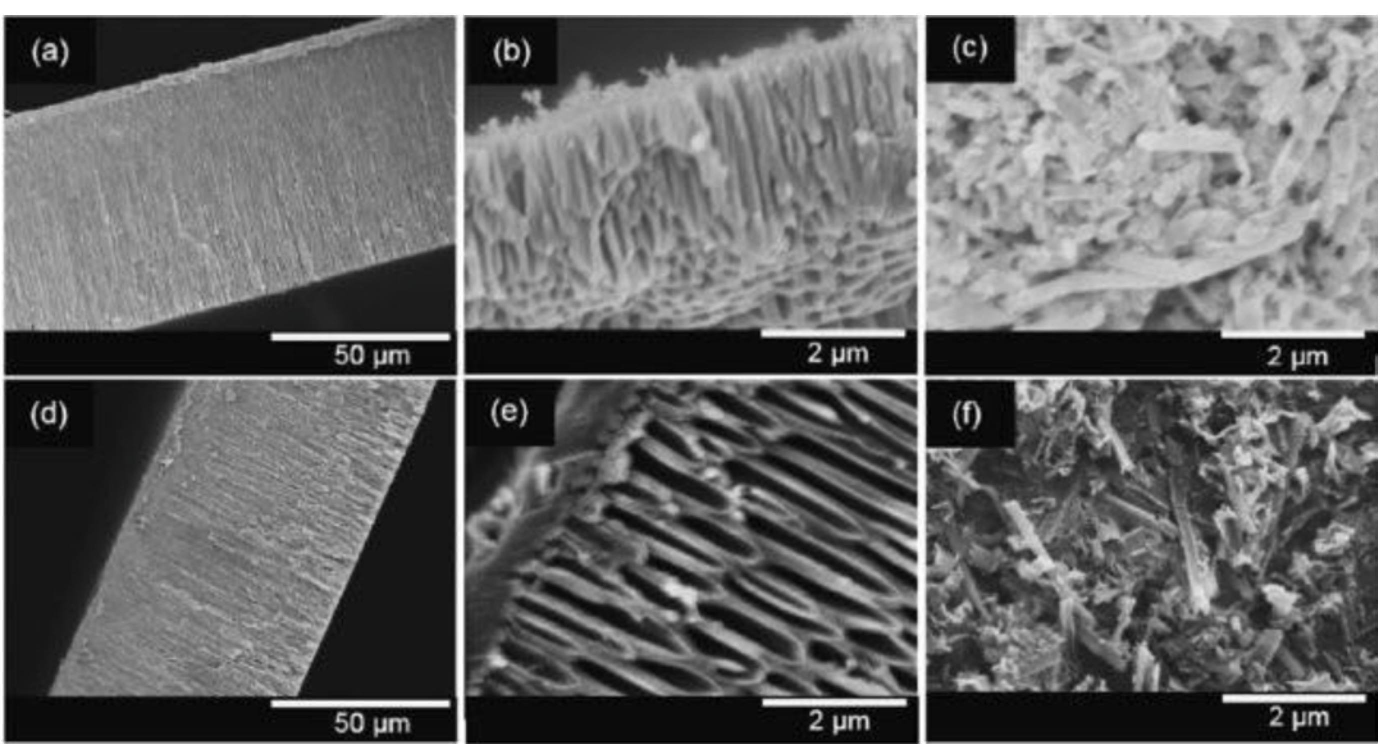

Fig. 21. SEM images of (a) vertical side of 100 nm-grade AAO template used in IS, (b) filter layer of 100 nm-grade AAO template, (c) synthesized nanorods via IS after AAO dissolution, (d) vertical side of 200 nm-grade AAO template used in VDS, (e) filter layer of 200 nm-grade AAO template, and (f) synthesized semi-nanotube structure via VDS after AAO dissolution (Wang, 2006, Volosskiy et al., 2015).

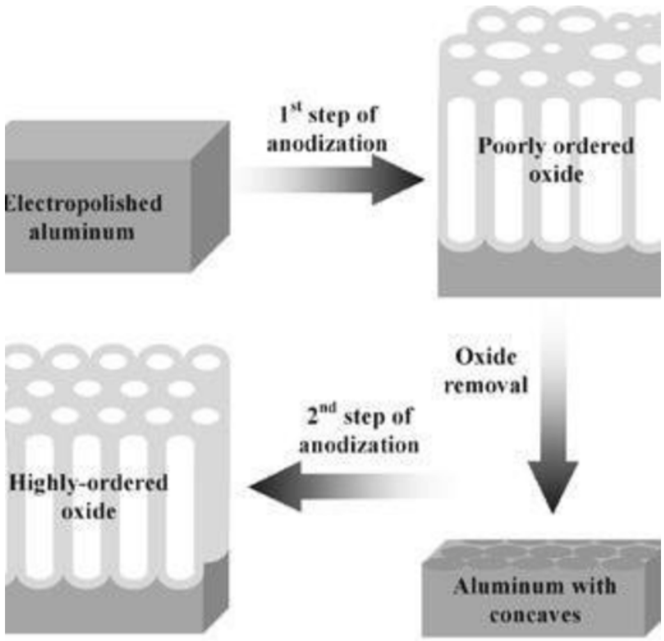

Fig. 22. Schematic of nanowire or pipe processing operation using AAO template processing: Preparation of AAO pattern with two-stage anodizing and Filling inside AAO cavities with sediments of the desired material (Wang, 2006, Volosskiy et al., 2015).

help of different surfactants. In this method, the initial gel is first prepared with sol-gel method. KBr, KI and KCl salts or dried gels are then mixed in different proportions. As shown in the figure, if these factors are not added, directional growth will not occur and nanoparticles will form. These salts and the like are the growth factor for some surfaces. The nanowires of this compound have magnetic properties and this property is used. PMMA (Polymethylmethacrylate) is also added to the tuber or gel as a chemical polymer inactivator and is involved in the directional growth of products (Wang et al., 2020, Sui et al., 2021, Duan et al., 2020, Gao et al., 2019). Figs. 19(a-b) show the FESEM image of barium hexaferite without PMMA and using PMMA and Fig. 19 (c, d) SEM images of BF–PMMA nanocomposite at low and high resolution, respectively.

4.3. Template processing

There are substances in nature that are called porous. Some materials, such as zeolites, are inherently porous, but others, such as aluminum oxide (alumina), silicon, etc., become porous when their surface is exfoliated in various ways (Zhang et al., 2015, Walia et al., 2016, Walia et al., 2014). Zeolite is a crystalline aluminosilicate network with a porous structure in which the porosity has a regular arrangement in space (Mauser et al., 2017). The pores can be filled with placing nanoparticles in them and used as a method for separating nanostructures in addition to the two methods mentioned above (Zai-Jun et al., 2011). Fig. 20 shows the structure of zeolite and its cavities. The cavities in alumina and silicon can be controlled with controlling conditions such as temperature. These porous materials can be used as a model for the production of nanostructured materials [(Raya et al., 2021, Tokuno et al., 2011, Shaheen et al., 2001, Chen et al., 2015, Yu et al., 2011, Hong et al., 2015). In fact, using different methods, these cavities are filled and nanostructures take the shape of cavities. Using this method, nanorods, nanowires, polymer, metal, oxide and semiconductor nanotubes can be produced. Different patterns with nanometer pores (channels) have been discovered for the growth of nanorods and nanotubes (Liu et al., 2009, Zhang et al., 2016, Du et al., 2022). The most important and commonly used pattern is anodized alumina (AAO) and porous silicon. Some polymers also become porous (silicon becomes porous using electrochemical peeling operations) (Gadeken et al., 2007, Hyder et al., 2000, Xu et al., 2021, Guo et al., 2021). The electron microscope image of alumina cavities is shown in Fig. 21. The obtained cavities have a hexagonal cross-section with a density of 1011 cavities per square centimeter. Electro preposition, chemical methods, gel gels, etc. can usually be used to fill cavities. Fig. 22 shows an example of the production of nanowires using the alumina template and its steps.

5. Future Perspectives

In this era of nanotechnology, Nanowires (NWs) propose potential impact on electronics, computing, memory, data storage, communications, manufacturing, health, medicine, national security and other economic sectors as well. NWs of all type viz. silicon, germanium, gallium arsenide, bismuth, tungsten, gold, cobalt, nickel, silver, boron, copper, ZnO, InO, SnO, ITO, CuO and inorganic nanowires offer excellent surface-to-volume ratio (interface phenomena), low defect density, high optical output and controllable n-type conductivity, making them more appropriate and sensitive for sensing applications. NWs are direct bandgap semiconductors and show excellent wavelength selectivity in the optical region of the solar spectrum. NWs in the ultra violet (ZnO, GaN, SiC) and infrared (Insb, GaSb) regimes are applied in detectors. NWs with their ultra sensitive and real-time detection capabilities lend their applications in nano biosensors, chemical sensor, gas sensor and electrochemical sensors. The incomparable properties of Nanowires are having their own importance in the manufacturing of future optoelectronic devices. Recently, Nanowires have been used in improving the optical absorption as well as for the collection efficacy in photovoltaic devices, by using less material than planar devices. In addition, they are having small size, low weight, low cost for mass production and also compatible with commercial planar processes for large-scale circuitry. Nanowires (NWs) are actually the nanoscale material that has applications in next generation devices to enrich their functionality, superior performance and also allowing high integrity and low cost. In the last two decades, a number of metallic, compound semiconducting and dielectric material have been used grown in two dimensional thin films via the cutting-edge techniques like Chemical vapor deposition (CVD), Metal organic chemical vapor deposition (MOCVD) and Molecular beam epitaxy (MBE). The wave length coverage of this material is from ultraviolet to infrared and its band gap ranges from 0.4 to 4.0 eV. High dimensional control has been gained as multiple quanta layering in III–V material as GaAs/AlGaAs with a layering thickness of 1 nm or fewer. The capacity of its growth as a thin epitaxial layer also in a controlled way that leads towards a number of its commercial applications in logic as well as in microelectromechanical systems, sensors, lasers, detectors, photovoltaics, memory, logic devices and others. NWs surfaces may be tailored from sensitive to chemical or biological species.

6. Conclusion

Processing and characterization of nanowires with desirable specifications can make significant changes in the development of nanotechnology in the fields of optical, electrical, magnetic and medical. The presence of high surface to volume ratio in nanowires has led to unique properties and novel applications for these materials. Methods of synthesis and processing of nanowires, like most nanostructured materials, are classified into two groups: top-down and bottom-up methods. The most important nanowires are metal, oxide, carbide, nitride, polymer and composite. The main applications of nanowires are electronic, mechanical, optoelectronic, and Nan electromechanical devices, chemical and biological sensors. The surface chemistry of Gold Nanowires must be infinitely understood which determines mutual interaction with other nanomaterial. In future research work, more attention should be paid to the reproducibility and robustness of Gold Nanowires assemblies, due to their weaker thermal properties and less stable mechanical properties, which are closely related to the performance of applications. Scientists have invested great efforts in developing methods to synthesize robust Gold Nanowires and develop Gold Nanowires sensors. There has recently been much progress in the preparation and performance of Gold Nanowires nanostructures, but development in the reproducibility and robustness of Gold Nanowires shall never end.

CRediT authorship contribution statement

Chou-Yi Hsu: Writing – review & editing. **Ahmed Mahdi Rheima:** Writing – review & editing. **Zainab sabri Abbas:** Writing – review & editing. **Muhammad Usman Faryad:** Writing – review & editing. **Mustafa M. Kadhim:** Writing – review & editing. **Usama S. Altimari:** Writing – review & editing. **Ashour H. Dawood:** Writing – review & editing. **Alaa dhari jawad al-bayati:** Writing – review & editing. **Zainab Talib Abed:** Writing – review & editing. **Rusul Saeed Radhi:** Writing – review & editing. **Asala Salam Jaber:** Writing – review & editing. **Safa K. Hachim:** Writing – review & editing. **Farah K. Ali:** Writing – review & editing. **Zaid H Mahmoud:** Writing – review & editing. **Ghobad Behzadi pour:** Investigation, Writing – original draft, Writing – review & editing. **Ehsan Kianfar:** Investigation, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The author declare that they have no competing interests.

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