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Review on Recent Advances on Touch Sensor for Flexible Displays

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ABSTRACT

One essential element that makes human-machine interaction possible is a touch screen, which combines a display and a touch sensor array. The development and use of flexible electronics in a variety of industries are also being strongly influenced by advancements in flexible touch screen technologies. Significant research and development has been conducted in the last ten years on novel materials and structures for touch sensors in flexible displays, particularly for flexible organic light-emitting diode (OLED) displays The potential and challenges of these technologies are also examined, along with the latest developments in electrode materials and structures such as ITO, graphene, metal mesh, silver nanowires, carbon nanotubes, and conductive polymers.

KEYWORDS: *Touch sensor, silver nanowires (AgNWs), flexible display, integrated touch*

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I. INTRODUCTION

Flexible electronics are expanding quickly in the field of medical, energy, information technology, and the defense application. They may enable to create smart textile in future.

They process sensors, actuators, circuits and other electronic devices on substrates that are stretchable and flexible. Optimization of the size and performance has been the trend of electronic devices. Flexible devices must adapt to different surfaces, be it rigid, soft, curved, flat, fixed, or movable.

The display, which serves as the visual output device for many electronic devices, has also been made more flexible to allow for the creation of new intelligent products, such as wearables and folding smartphones [2], [3]. Flexible displays are superior to their rigid counterparts in several ways, including being lightweight, durable, and having a thin, bending form factor [4]. For instance, a gadget with a flexible screen can be rolled up or folded up to make it smaller. Touch technology, is essential to meeting the requirements of the human-machine interaction experience on these devices. For flexible displays, transparent and flexible touch sensors are crucial input devices. Usually, a display can have a touch panel made up of touch sensors piled on top of it. By tapping the panel with one or more fingers and/or a certain stylus, users can enter data [5]. The touch screen allows the user to interact directly with the displayed content without the need for a mouse, touchpad, or other comparable input devices. Mobile phones, tablets, computers, game consoles, and mall information kiosks are just a few of the gadgets that employ touch screens extensively to give consumers precise, quick, and easy interactions. Although there are several ways to achieve touch sensing, Capacitive, resistive, infrared, and surface acoustic wave technologies are frequently used [6].Two electrode layers and one dielectric layer are sandwiched inside the well-known capacitive touch sensors for rigid electronics. Nowadays, the majority of flexible touch panels are capacitive as well. There are new specifications for flexible touch sensors' composition and construction. Conventional touch screens use an Out-Cell construction, which integrates distinct touch and display modules through lamination. This method is not appropriate for flexible displays since it makes the display thicker and heavier, which decreases flexibility. In order to reduce the thickness of the entire device, integrated touch sensors, where a portion or the entirety of the touch sensor is built into the display module, have been proposed.

Hybrid-Cell, In-Cell, and On-Cell architectures are methods for integrated touch. In addition to lowering the module's thickness, integrating a touch sensor inside the display unit enhances the display's optical performance and permits greater touch accuracy[7]. The optical properties, lifetime, stability, and cost of touch sensors are dominated by flexible transparent conductive electrodes, which are important components of flexible touch displays [8]. The most common electrode material is flexible substrates coated with indium tin oxide (ITO). However, ITO's broad use in next-generation flexible electronic devices is severely limited by its drawbacks, which include brittleness, high temperature deposition, and indium shortage [9].As a result, substitute materials, such as conductive polymers [14], metal nanowires [12], metal meshes [13], graphene [10], carbon nanotubes [10], and others, have been employed as flexible transparent electrodes. These materials' superior optical transmittance, low electrical resistance, and high flexibility make them suitable.

II. TOUCH SENSING MECHANISMS

Because of high sensitivity and multi-touch capability [15],capacitive touch sensing technology is widely used in phones, watches, and PCs.

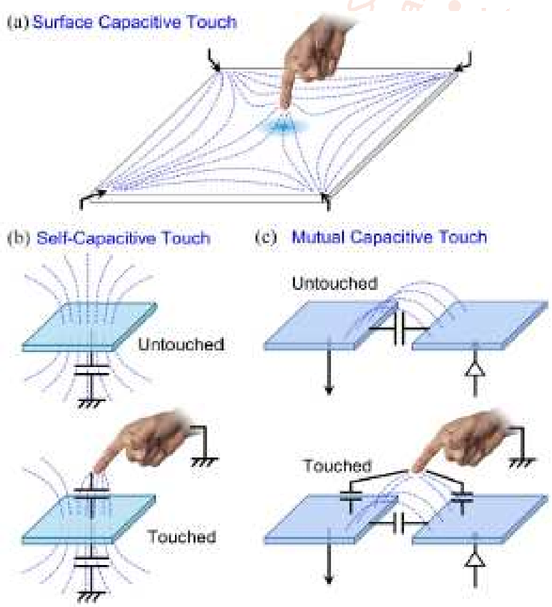

Fig1. Capacitive touch screen mechanisms

A capacitive touch sensor is made up of one or more layers of transparent conductors placed on a glass substrate using sputtering or evaporation and patterning (lithography and etching). When the conducting electrode receives alternating current (AC), the capacitor becomes conductive. When a human finger or stylus comes into contact with the sensor, the electric field is disrupted, resulting in a change in capacitance. The indices of the electrodes, which vary capacitance, can be used to establish where the contact occurred.

A controller IC further processes the data. Surface capacitive touch sensing technology [15] and projected capacitive touch sensing technology are two specific subcategories of capacitive sensing technologies. Moreover, self-capacitive and mutual capacitive touch are the two subcategories of projected capacitive touch sensing.

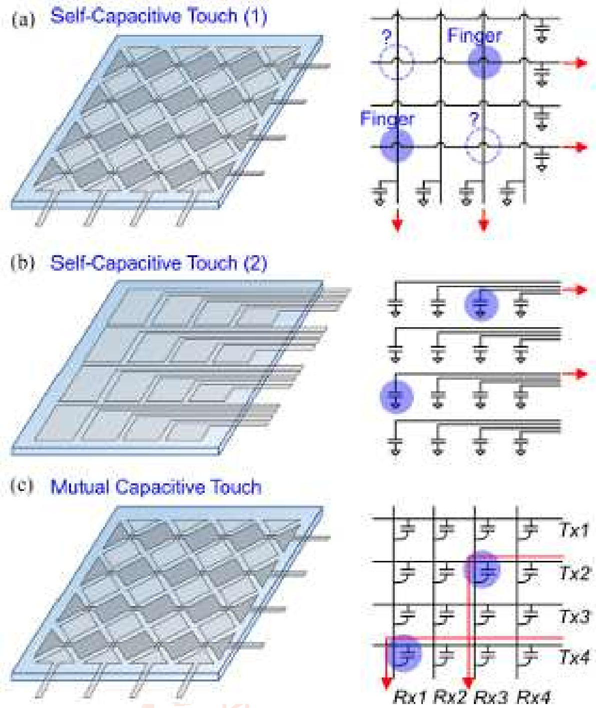

Fig 2 Electrode structures and equivalent circuit diagram

A. SURFACE CAPACITIVE TOUCH SENSING TECHNOLOGY

Only one side of the insulating layer of the surface capacitive sensor [17] has a conducting layer. Four synchronized AC voltage signals are connected to each of the four corners.

As seen in Fig. 1(a), the AC creates an electric field on the touch panel surface across the four corners. The touch's location can be ascertained by monitoring the capacitance change at each corner.

Compared to conventional resistive touch sensors, surface capacitive touch sensors offer a number of benefits, such as hard surface, high sensitivity, longer lifespan, and excellent optical transmittance. They have a number of shortcomings, including limited resolution and multi-touch incompatibility. Now it is mostly used in interactive systems like touch screen kiosks.

B. PROJECTED CAPACITIVE TOUCH SENSING TECHNOLOGY

Unlike surface capacitive technology, which uses a single conductor electrode, projected capacitive technology [19] typically uses one or more layers of designed electrode arrays. The projected capacitive touch technology [20] consists of patterned electrodes, as illustrated in Fig. 1(b), (c).Touching the sensor modifies the electric field, which in turn modifies the electrode's capacitance or the capacitance between neighboring electrodes[1]. The indices of the electrodes where capacitances change can be used to locate the touchpoint. Multi-touch, or two-point touch or pinch, is supported by the projected capacitive touch sensing technology, which improves human-computer interaction. Based on their methods of detection, projected capacitive touch technologies can be divided into self-capacitive touch sensing and mutual capacitive touch sensing technologies.

1. SELF-CAPACITIVE TOUCH SENSING TECHNOLOGY

The capacitance between the electrodes and the ground is referred to as self-capacitance or absolute capacitance. [1] Fig. 2(a) depicts one kind of self-capacitance structure. An X-Y grid made up of row and column traces makes up the sensor. A self-capacitance is formed by each column or row trace. The indices of the row and column traces with changed self-capacitances indicate where the touch occurred. The self-capacitive sensing method [21] is noise-immune and has a high scanning frequency. It is unable to facilitate precise multi-touch sensing, though, which results in "ghosting," or unclear position sensing. Fig. 2(b) shows an example of another kind of self-capacitive sensing technology [22].

By connecting each electrode in the array to the driving IC with a separate wire, this technology allows for the detection of numerous contact points independently, resolving the ghost point problem with just single electrode layer[1]. Separate electrodes, on the other hand, need a lot of wires to connect, which takes up a lot of space and leaves less room for the electrodes. Therefore, it is frequently required to use a separate conductive layer for wires beneath the electrode layer in order to eliminate such blind spots. The other problem is that the driving IC requires an excessive number of input/out ports, particularly as the panel size increases[1].

2. MUTUAL CAPACITIVE TOUCH SENSING TECHNOLOGY

Mutual capacitive touch differs from self-capacitive touch sensing technology in that two neighboring electrodes are connected by a fringing electric field. The capacitance between the two electrodes is decreased when the finger makes contact with the panel surface because it affects the coupling between them. The indices of the two nearby electrodes define the touch location [23]. The longitudinal row electrodes are configured as transmitter electrodes (Tx), and the latitudinal electrodes are utilized as receiver electrodes (Rx), as illustrated in Fig. 2(c). The controller IC applies an AC signal to each Tx sequentially, and the IC records each Rx's response.

A layer of transparent electrodes is usually used, acting as the electrode Rx for receiving calls and the electrode Tx for sending touch signals. It is necessary to insert a set of isolated signals in between many Tx/Rx signal groupings. Nowadays, capacitive touch panels predominate on flexible displays. Additional methods for flexible display touch panels are under development.

A very sensitive near-infrared a-Si:H phototransistor was proposed by Lee et al. [24] in 2015 for use in touch sensor applications. The infrared sensor is simply situated on the narrow border of the gadget, which does not cover the display. Its structure is straightforward and quick to install. The complex touch detection causes an inevitable delay but has less impact on the visual effect. Additionally, the method needs a steady working environment and is susceptible to ambient light. Additionally, the separate circuit board adds to the high cost[1].

STRUCTURES

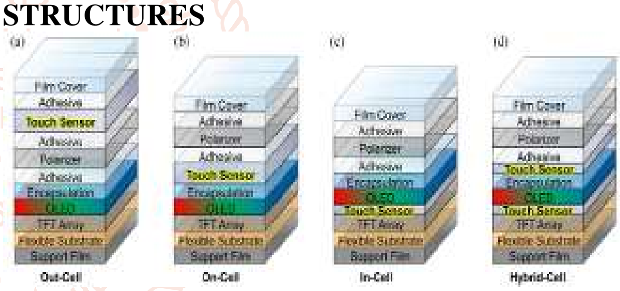

Fig 3. Structures of touch sensors for flexible display

OUT-CELL STRUCTURE

According to Fig. 3, a flexible touch screen (also known as an active-matrix organic light-emitting diode, or AMOLED) is made up of a display module assembled by adhesive lamination, a polarizer film, an independent touch sensor panel, and a film cover. Out-cell sensing is often accomplished using a number of structures, including Film-Film, Film2, Double-side ITO, and Single-side ITO/bridge touch structure [25]. The Out-Cell screen now has a straightforward design and advanced technology [26], but more is required to meet the demands for thickness and bendability[1].

A. INTEGRATED TOUCH SENSORS

Integrated touch sensor technology has garnered increased research interest due to its potential to further reduce costs, reduce module weight and thickness, and improve flexibility [27]. According to their stacking orders, the integrated touch screen structure may be divided into the following architectures.

1. ON-CELL TOUCH

An active-matrix organic light-emitting diode (AMOLED) display can incorporate touch sensors using a specialized technique called on-cell touch [28]. The touch sensor is placed above the OLED encapsulating layer in the AMOLED. Longitude and latitude electrodes can be positioned on the same conductor layer, with another conductor layer bridging the intersection locations, or on two separate conductor layers sandwiched by a dielectric layer [29]. A 45% high transparency and 166-PPI high resolution were reported by Hsieh et al. [30] after integrating an on-cell touch sensor on an IGZO-driven AMOLED. In order to simulate floating ground and noise interference problems, Hu et al. [31] suggested a new circuit model of the On-Cell touch sensor for AMOLED. High display quality, a large display area, and ease of usage are characteristics of the On-Cell structure. However, its viewing angles are limited, and external signals may disturb them .

2. IN-CELL TOUCH

This touch technology incorporates touch sensors right into the pixels. The touch sensor is integrated into the liquid crystal panel of the LCD or beneath the encapsulation layer of the OLED. Typically, the emitting pixels are integrated with the touch sensor patterns. It is more difficult to integrate additional electrodes in OLED cells during manufacturing. Furthermore, in order to prevent interference, the touch and display require more intricate driving circuits. To cut down on the number of conductor layers, the common electrode VCOM is often separated into blocks and reused as touch electrodes for In-Cell. Each block is coupled to a touch detection signal line.

High transmittance and the thinnest projected capacitive touch screen are achieved by this high degree of integration design.[1] To lessen parasitic capacitance, noise interference, and other issues, research is required. In 2021, Su et al. [33] exhibited a 10.95-inch In-Cell touch panel with an enhanced frame rate of 120 Hz by using an organic double-layer construction to reduce the parasitic capacitance of the electrodes. To solve the voltage drift problem in the touch detection step, Shen [33] et al. proposed a gate drive circuit with a two-stage precharge design that same year. This circuit enhanced stability and greatly reduced threshold voltage drift. [1]

3. HYBRID-CELL TOUCH

A touch-sensing technique that blends On-Cell with In-Cell is called Hybrid-Cell. The Rx is deposited and patterned on the surface of the OLED encapsulation in the Hybrid-Cell structure, whilst the Tx electrodes are integrated into the display module. Rx electrodes are created using an extra transparent conductor layer, while Tx electrodes are typically constructed on the common electrode layer (VCOM). Additionally, because the Tx must be connected to the IC via extra fanout regions on the left and right borders, the hybrid-cell screen is not appropriate for designs with narrow borders.Although conventional out-cell touch sensing is more developed, its image quality and module thickness is limited. While the On-Cell is better balanced overall, In-Cell is of best performance integrated touch sensing method but is also the most challenging to manufacture[1].

TRANSPARENT ELECTRODE MATERIALS

Many flexible optoelectronic systems, such as touch screens and interactive electronics, require transparent conducting electrodes. For the display underneath to be visible, flexible touch sensors in particular must be very conductive and as transparent as possible [34]. For On-Cell, the touch sensor material must also be viable for low-temperature operations directly on the display panel [33]. Additionally, materials that can be manufactured cheaply and on a big scale are advantageous when it comes to manufacturability.

As of right now, flexible capacitive touch sensors have already been built using metal mesh [36] and silver nanowires (AgNWs) [35], two flexible transparent electrode materials. Carbon nanotubes [37], graphene [38], and conductive polymer [39] are other potential materials for capacitive touches.

A. INDIUM TIN OXIDE

A highly degenerated and highly doped n-type semiconductor, indium tin oxide (ITO) has a wide energy gap (3.5–4.3 eV), high transmittance, low resistivity, superior abrasion resistance, and chemical resistance [40]. ITO is now the most widely used transparent conductive electrode material. Vapor phase deposition is usually used to coat it on substrates composed of flexible plastic or stiff glass. We need to address some issues of ITO. Firstly, Indium is expensive due to its limited supply. Secondly the deposition process using vacuum deposition equipment is costly. Thirdly it is brittle as a metal oxide and hence unsuitable for wearable and flexible technology. Many studies are now being conducted to enhance the functionality of ITO electrodes for flexible touch screens. An epoxy-copper-ITO (ECI) sandwich-structure transparent electrode was proposed by Song et al. [43], significantly enhancing the mechanical characteristics of ITO electrodes. At 50 nm ITO thickness, the film sheet resistance is 50 Ω/sq, and it balances well with the transmittance, which is 90% at 600 nm. This kind of work opens up new possibilities for ITO's use in flexible electronics[1]. According to Park et al. [43], ITO's mechanical properties are greatly influenced by its crystallinity. They deposited ITO films at 250 °C (sheet resistance of 36Ω/sq, light transmittance of 88%) and then transferred them to cyclic olefin polymer films, which showed better stability in repeated bending test in demonstration.[1]

A high-performance flexible ITO film made by in-line vertical plasma arc ion plating was reported by Kim et al. [45]. The films have a short bending radius of 5 mm, a high average optical transmittance of 85.88%, and a low sheet resistance of 15.75 Ω/sq. This is because the ionized ITO is forced by the system energy to the substrate, which results in increased adhesion and crystallinity.

B. SILVER NANOWIRES

Because of their exceptional conductivity, high transmittance, and flexibility, silver nanowires (AgNWs) have garnered a lot of attention [46]. Silver is exhibits strong mechanical properties and excellent chemical stability. These AgNWs have optical transmittance and electrical conductivity that are on par with or superior to those of ITO films. The uniformity of the sheet resistance is the main obstacle to the practical use of AgNWs in transparent conductor films. Consequently, a lot of work has gone into making AgNW films more uniform[1].

Herein, Jia et al. [47] described a dynamic heating approach employing infrared light to make excellent uniform AgNWs. The coffee ring effect is lessened after drying because AgNWs are kept from sticking to the surfaces of the as-prepared films. The film's sheet resistance non-uniformity is a mere 6.7%. The wavelength transmittance of 95% at 550 nm and the average sheet resistance of 35 Ω/sq are similar to those of high-quality ITO films that are sold commercially. With little change in resistance, the material has withstood more than 5000 bending cycles in a mechanical bending test.

On a polydimethylsiloxane (PDMS) substrate, Choi et al. [48] embedded electrode wires composed of reduced graphene oxide (AgNWs/rGO) and silver nanowires into an a polyurethane (PU) dielectric layer. Using patterned AgNWs/rGO wires embedded in PU dielectrics on PDMS substrates, a set of 5×5 stretchy transparent capacitive touch sensors was demonstrated. The device operates steadily even when stretched, as seen by the fact that neither capacitance changes. There are numerous opportunities for transparent, flexible capacitive touch sensors when thin film electrodes are directly fabricated on elastic substrates. Avoiding material waste during the preparation process is also essential to maximize the use of silver nanowires.

An effective and universal transferring technique is offered by Liu et al. [49] to create incredibly stable and high-performing AgNW transparent electrodes on any substrate. Yang et al. [50] created a large-scale AgNW-poly(34-ethylene dioxythiophene): poly (styrene sulfonate) composite film with a transmittance of 96% at 550 nm and a sheet resistance of 12 Ω/sq using the Mayer rod coating technique. They also created a transparent 7 × $7cm^2$ touch screen that has outstanding touch sensitivity and consistency over the whole surface. However, a number of disadvantages of AgNW transparent conductive films, such as rough surfaces, difficulty in mass production, and patentability, including precision printing, limit their commercialization [51].

C. METAL MESH

Because of its high optical transmittance, low resistance, and exceptional bending ability, metal mesh—a micrometer-scale grid structure composed of intersecting metal wires—can be used in flexible electronics. Since metal meshes are more flexible and their performance can be adjusted by changing the line thickness and width, they hold greater promise than silver nanowires for flexible screens[1]. Additionally, it is less expensive to make in large quantities and has previously been used in flexible touch panels that are sold commercially. But the application of metal meshes has certain restrictions. The adhesion between modules reduces because of mesh ‘s uneven surface .The visual effect of display is affected due to mesh’s excessive density of moiré patterns[1].

Wu et al. [52] created a novel transparent conductive electrode with higher performance (sheet resistance of ~2Ω/sq, at 90% transmission) using a procedure that involved electrospinning and metal deposition. By using electrospinning and a gold nano-groove grid on the PET substrate, the team was able to resolve the adhesion problem. On the basis of these films, a transparent touch screen device was later developed. The commonly used ITO in solar cells, touch sensors, and flat panel displays may be replaced by such metal nano-groove electrodes, expanding the range of possible applications to include skin-like sensors. To lessen the problem of metal surface roughness, Zou et al. [53] recommended applying a passivation layer to the metal mesh. For example, the inverted-structure polymer solar cell is made using a transparent electrode that is a hybrid of metal mesh / conductive polymer. Fig. 5 displays an optical microscope view of a metal mesh electrode that has been manufactured on a glass substrate. Furthermore, there is a 3.2% increase in the polymer solar cells' efficiency.

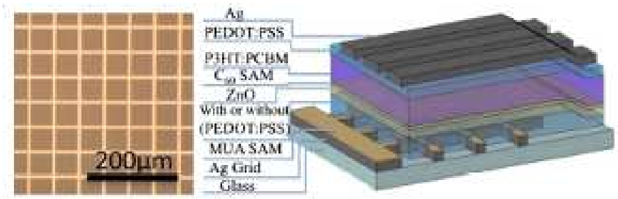

Fig. 5 Metal mesh and solar cell structure

Zhou et al. [54] created a flexible, translucent plastic conductor that has a silver network (PEAN) inserted in it. To increase the luminance of white and green OLEDs and decrease ohmic loss, they employed an improved optocoupler structure.

Flexible OLEDs with PEAN are expected to be utilized in large-area non-ITO flexible displays and lighting since their performance is on par with that of ITO devices. An 8.67-inch foldable OLED display with a touch sensor was created by Watanabe et al. [55]. As seen in Fig. 5, the touch sensor comprises an In-Cell structure with metal-mesh sensor electrodes generated in a counter substrate.

Fig.4 8.67 foldable organic light-emitting diode display with a touch sensor

The following drawbacks [56] limit the use of metal mesh in flexible touch display devices: (1) excessively dense metal mesh pitch will block the pixel cells, resulting in moiré patterns and reflection on a black image visible from a specific angle; (2) the costly vacuum metal deposition process; (3) minimal adhesion between the metal mesh and the modules on top, and uneven surface topography.

D. GRAPHENE

Carbon atoms with sp^2-hybridized orbitals form the hexagonal honeycomb lattice of graphene, a two-dimensional carbon nanomaterial. Graphene's massive specific surface area (2360 m^2/g), high electron mobility (200000 cm^2/Vs), strong conductivity, light weight, outstanding mechanical flexibility, and compatibility with large-area flexible solid supports make it an excellent choice for the creation of flexible sensors [57].

However, efforts to create transparent conducting films from graphene have been hampered by the lack of efficient techniques for synthesizing, transfering, and doping graphene at the scale and quality required for applications[1]. In order to achieve conductivity as high as 10^4S/cm and optical transmittance of 90%, Savchak et al. [58] encapsulated graphene oxide with polymers, which were then converted into highly conductive and transparent reduced graphene oxide films by dip-coating in water and thermal reduction. By combining two-step chemical vapor deposition-produced carbon nanotubes with 3D graphene foam, Cai et al. [59] created a stable, noise-free strain sensor with stretchability. It has a measurement factor of up to 35, a dependable sensing range of up to 85%, and good cycling stability (>5000 cycles). A 5 ×5 array of flexible touch sensors made with a 3DGF/CNT percolation network and encapsulated with elastic PDMS is shown in Fig.6

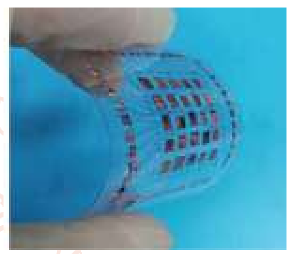

Fig.6 The 5 × 5 arrays of the 3DGF/CNT networked strain sensor

Ryu et al. [60] produced graphene sheets with an area of over 400 × 300mm^2 with a sheet resistance of 249 ±17 Ω/ sq using hydrogen free rapid chemical vapor deposition, roll-to-roll etching, and batch transfer techniques. A capacitive multi-touch screen was also created. Bae et al. [61] produced 30-in graphene films on flexible copper substrates by roll-to-roll fabrication and a wet chemical doping technique. They have a 90% optical transmittance and a 30 Ω/sq thin film sheet resistance. Additionally, it is integrated into a fully functional touch panel device. There hasn't been any hard proof of graphene's use in consumer electronics since the issues of size, consistency, and dependability haven't been addressed to meet industry standards.

E. CARBON NANOTUBES

The one-dimensional carbon allotropy known as a carbon nanotube (CNT) [62] has an aspect ratio (length-to-diameter ratio) greater than 1000. More than 100,000 cm^2/s of mobility and 10^9 A/cm^2 of current carrying capability are possessed by a single CNT. Despite the excellent electrical and optical characteristics of carbon nanotubes, it is still difficult to manufacture large quantities of high-purity and low cost CNTs. For the low-cost preparation of homogeneous CNT, the wet-pulling approach and solution-based spin-coating [63] are commonly employed. In order to create a CNT flexible transparent electrode film with an optical transmittance of 88% and a sheet resistance of 550 Ω/sq, Hecht et al. [64] used a spin coating technique with Unidym's CNT solution. This electrode film was then utilized to construct a four-wire resistive touch panel. The films were incorporated into a slightly smaller touch panel with a full-color LCD. A self-assembled silver nanoparticle/multi-walled CNT composite thin film with a low layer sheet resistance of 14.5 Ω/sq, an average visible transmittance (AVT) of approximately 67%, and a high color rendering index (CRI) of 97 was created by Zhang et al. [65] using a solution approach. This solution-processed transparent electrode gives the solar cell device a high CRI of 90 and an AVT of 36%. Choi et al. [66] created a five-wire resistive CNT touch sensor and made a flexible transparent electrode sheet by dispersing single-wall CNTs in sodium dodecyl benzene sulfonate and deionized water.

CNT is a transparent electrode material with great performance that may be used in a solution method, but its practical use is still hindered by its complicated separation procedure. To incorporate CNT materials in in flexible capacitive touch sensors, further research is required[1].

F. CONDUCTIVE POLYMERS

Poly (34-ethylene dioxythiophene): poly(styrene sulfonate) (PEDOT: PSS) is an appealing alternative among transparent conductive polymer materials due to its high transmittance, acceptable conductivity, outstanding flexibility, and enhanced work function [67]. Several optoelectronic devices based on PEDOT:PSS anodes, such as organic light-emitting diodes (OLEDs), organic solar cells, and supercapacitors, have shown promising photoelectric properties [68].The exceptional optoelectronic characteristics of OLEDs based on stretchy PEDOT:PSS grid anodes indicate that they have enormous promise as ITO-free anodes for flexible and wearable electronic applications.

Even though the excellent photoelectric properties have been achieved, the majority of current manufacturing techniques rely on spin coating. This usually results in severe processing losses, which greatly reduce overall mass output. As a result, investigating low-cost solution processing systems with high scalability, continuous production, big area, and minimal material waste is extremely desirable[1]. Zhou et al. [69] employed roll-to-roll compatible screen printing to produce PEDOT:PSS mesh-type transparent conductive electrodes on PET with an optical transparency of 80% and a square resistance of 450 Ω/sq.

Screen printed PEDOT:PSS mesh anodes enable the rapid and efficient production of anode clusters. Kim et al. [70] increased the conductivity of the PEDOT :PSS film to 3000 S/cm by treating the surface with sulfuric acid and performing a transfer process. This has allowed the integration of any flexible substrate or electronic component, as demonstrated by high-performance OLED displays based on this film in a practical way .So,PEDOT: PSS can be manufactured on a large scale at a moderate cost.

However, the presence of acidic solid residues in the PEDOT: PSS matrix can cause performance degradation of PEDOT: PSS films on plastic substrates and hence flexible optoelectronic devices. To address the issue of solid acid residues Fan et al. [71] used acids gentler than sulfuric acid such as methane sulfonic acid and phosphoric acid. As a result, they achieved greatly higher conductivity (3500 S/cm), which was then applied to OLEDs, resulting in 84% optical transmission and better stability. Understanding additives can enhance the stability of flexible electronics used for medical, energy, and other applications.

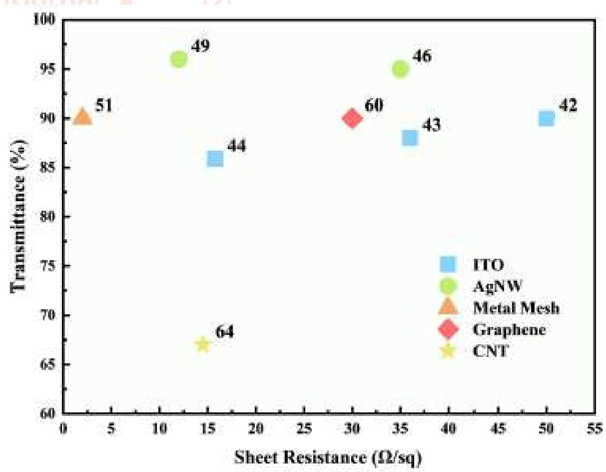

Fig .7 Comparison of the sheet resistance and transmittance of the transparent electrode materials

In Fig.7, the properties of AgNWs and metal meshes are already comparable, if not superior, to those of optimum ITO films, whereas graphene and carbon nanotube materials require further improvement[1].

CONCLUSION

The recent research on touch sensors for flexible screens, including their mechanisms, construction, and electrode materials are explained. The flexible displays, the constraints and potential of touch sensors in terms of structure and module thickness, cost and manufacturing feasibility, and display quality are investigated to guide future research.

A. STRUCTURE AND MODULE THICKNESS

The Out-Cell structure screen was traditionally incorporated as a separate touch module on top of the display module. These two modules are usually laminated with optically clear adhesive, resulting in a larger thickness. Integrated touch sensor technologies such as in-cell, on-cell, and hybrid-cell topologies, offer a solution to this issue. Because the touch module is partially or completely merged with the display module, the total module thickness is greatly reduced. In-Cell is the best solution regarding visual effects and module thickness. In-Cell must be integrated into the pixel circuit and needs a driving IC that coordinates the display and touch. Additionally, some designs reuse the OLED VCOM cathode as In-Cell touch electrodes, resulting in a more challenging evaporation process and poorer yield. On-Cell integrated touch for flexible AMOLEDs now dominates the industry[1].

B. COST AND MANUFACTURE FEASIBILITY

ITO, a and fragile substance, has historically been used as an electrode. New electrode materials have expanded the possibilities for flexible screens. The market share of AgNWs and metal mesh technologies is steadily increasing. However, new materials may not replace ITO in a short period of time. Because these transparent electrodes still have manufacturing flaws, such as surface roughness and adhesion difficulties.

Mass manufacturing of graphene and CNT is still a long way away. The electrical conductivity of these thin films is not comparable to that of conventional ITO thin films. AgNWs and metal meshes are thus the most promising materials for touch sensors in flexible displays, both in terms of technology readiness and market application[1].

C. DISPLAY QUALITY

To construct the metal mesh, silver, copper, oxides, and other raw materials of reasonable cost can be utilized. Technological limitations often result in touch patterns with metal mesh lines wider than 5 μm. Furthermore, with high pixel density, the moiré interference waves would be clearly visible. As a result, metal mesh may become unsuitable for exceptionally high-resolution displays unless the line width and resistance difficulties can be addressed. Laser-assisted printing [72]technology, AgNW patterns may be deposited on flexible substrates with line widths as small as 50 nm, allowing them to be used on screens of various sizes and pixel densities without exhibiting a moiré pattern. AgNWs also have a smaller bending radius than metal mesh films and exhibit minimal resistance variation when bent. However, due to the random distribution of AgNWs, their films exhibit severe diffuse reflection, resulting in a haze effect that must be rectified[1]

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