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REVIEW ARTICLE

Review on Carbon-Graphene Nanocomposite Based Conductive-Ink in Printed Electronics

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Abstract

Energy is the divesting need of human being to make the life easy going and comfortable. But according to the recent scenario, there will be insufficient source of generating energy. Printed electronics is a new concept of printing technology. PE is safest printing ink technology for securing documentation, for making circuits on different subtracts, less time consuming for making and easily detect if counterfeit. Nano print technology with semiconductor materials is in improvising and it has been future trend in energy sector with enhancing various properties of nanomaterials. It has been developed in the area of the digital printing technology by using and combining different nanomaterials. With ever-increasing demand for light-weight, small and transportable devices, the speed of production of electronic and optoelectronic devices is consistently increasing and alternatives to the current vital, voluminous, fragile, semi semiconducting and clear materials will inevitably be needed at intervals the long run. This review article explains about the carbon-Graphene nanocomposite based conductive ink, which can be a source in digital printing technology to draw various types of circuits and to make different surface to conductive surfaces. It also describes brief information about carbon and Graphene material individually. It also concludes carbon-graphene nanocomposite based conductive ink in printed electronics technology with several literature surveys.

Key Words: *Carbon-Graphene nanocomposite; Conductive ink; Printed electronics; Advantages of Cg based conductive ink in printed electronics; Application sectors of printed electronics*

Nomenclature: -

PE-Printed Electronics	V-Volt	CCI-Carbon Conductive Ink
CG-Carbon Graphene	LED-Light Emitting Diode	HECG-High temperature Edge Carboxylated Graphene
AFM-Atomic Force Microscopy	S/m-Siemens per meter	CHF-Carbon Heating Film
CVD-Chemical Vapor Deposition	kDa-Kilodalton	MOC-Metal-Organic Complexes
nm- Nanometer	MCP-Micro Channel Plates	RFID-Radio Frequency Identification Data

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Introduction of carbon and graphene

Carbon is one of the most versatile elements used in graphic printing and in PE applications. It happens in many chemical phenomenon forms, as well as diamond and C. There are two forms of carbon; graphite, which is a gray black platelet form and carbon black, a jet-black amorphous form. The most important advantage offered by carbon is that it can be formulated into inks of different resistivity which are crucial in PE applications. Carbons inks that are commercially available are categorized based on the type of resin used type of carbon used, and resistive properties. However, they will even be categorized supported their use: as a written electrical device, as a conductor or as a protecting coating for different conductors. A number of the famed applications for carbon-based inks area unit membrane switch, written circuits and electrodes for sensors. Many of the commercial inks available have been formulated for use as screen and inkjet inks. The biggest advantage of carbon over silver is the inert nature of carbon. In most applications, more than one printed layer is deposited. The overprinting of layers will be problematic if the solvents or chemicals employed in the inks aren't compatible. Since carbon is proof against just about any gas or liquid, compatibility problems are of less concern compared to silver or different metals. Since carbon is resistant to virtually any gas or liquid, compatibility issues are of less concern in comparison to silver or other metals. Another disadvantage with using silver inks is Electromigration. Electromigration is the gradual displacement of metal atoms in a semiconductor. It occurs when the current density is high enough to cause the drift of metal ions in the direction of the electron flow and is characterized by the ion flux density. Carbon does not have a tendency for electromigration. This means a conductor printed with carbon is more stable over time and chemically more resistant [1-3].

"The attributes of Graphene-transparency, density, electrical and thermal physical phenomenon, elasticity, flexibility, hardness resistance and capability to get chemical reactions with different substances-harbor the potential to unleash a brand-new industrial revolution of additional brilliant proportions than that ushered in by electricity within the nineteenth century and also the rise of the net within the Nineteen Nineties." - LarrainVial. This statement says it all for the wonder material "Graphene". Single layers of carbon *i.e.,* "Graphene", from which graphite is built, have attracted broad interest in the scientific community because of recent exciting experimental results. Graphite is a versatile material and a naturally occurring, most stable form of carbon. The word "Graphite" (writing stone) is derived from the Greek word "Graphene". Graphene is a two-dimensional hexagonal carbon structure arranged from sp^2 hybridized carbon atoms. It has many interesting properties such as high mechanical strength and electrical conductivity. Intensive research is being done to utilize these excellent properties of Graphene to create enhanced technologies. Examples of such Graphene based enhanced technologies include transistors, transducers, chemical sensors, DNA sequencing, solar cells, batteries, and capacitors. A single layer of Graphene without defects possesses an optical transmittance of 97.7% and a sheet resistance of $\sim 100\ \Omega\ sq^{-1}$[4,5]. Graphite consists of hexagonal carbon sheets that are stacked on the top of each other. Figure1 shows the variety of structures offered by Graphene. Graphene is an isolated atomic plane of graphite and P. R. Wallace theoretically studied it in 1947. He predicted the electronic structure and noted the linear dispersion relation. In October 2004, Konstantin Novoselov and Andre Geim from University of Manchester (UK) successfully isolated the single layer Graphene with a mechanical exfoliation method. In July 2005, they published a paper describing the fabrication, identification and Atomic Force Microscopy (AFM) characterization of Graphene. An AFM picture of one such sample is shown in (Figure 1) [6,7].

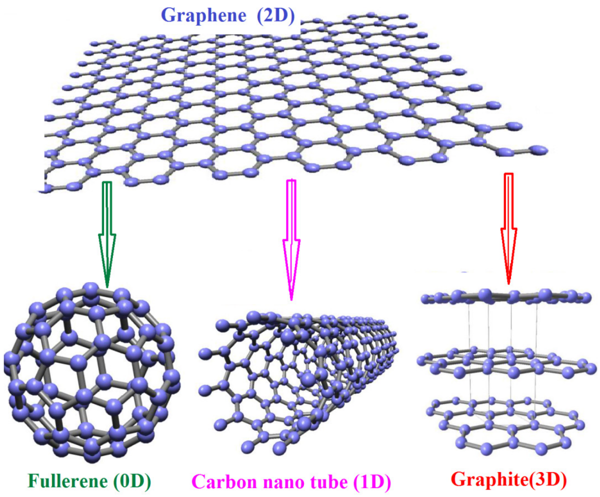


Figure 1) *Variety of structures offered by Graphene [8].*

Synthesis process of graphene

Depending upon the source, graphite is classified as being either natural or synthetic. Natural graphite is subdivided into three primary types; amorphous, flake and crystalline. Synthetic graphite is subdivided into many types depending upon the properties of the carbon precursor used during the manufacturing process and the heat treatment used during processing. In 1800s, Edward Goodrich statesman 1st introduced artificial carbon by process carbon at hot temperature. Relying upon the temperature and also the properties of the carbon precursor used, differing kinds of carbon will be fashioned by graphitizing the carbon. Graphitization is that the method during which restricted movement and arrangement of carbon atoms takes place throughout the warmth treatment method. The amorphous carbon used for making graphite can be derived from petroleum, coal and natural or synthetic organic materials. In some cases, graphite can also be manufactured by the direct precipitation of graphite carbon from pyrolysis of a carbonaceous gas such as acetylene and it is called as pyrolytic graphite.

Figures 2(a) and Figures 2(b) show the structure of natural graphite and Figures 2(c) and Figures 2(d) show the structure of synthetic graphite with different diameters [9].

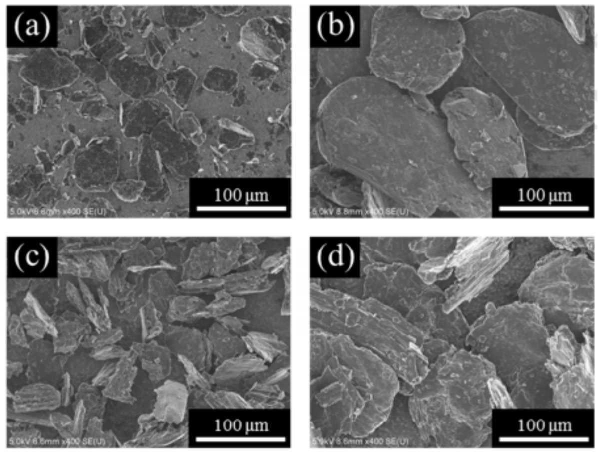


Figure 2) *(a) Natural graphite with 50μm diameter size, (b) Natural graphite with 150μm diameter size, (c) Synthetic graphite with 50μm diameter size, (d) Synthetic graphite with 150μm diameter size [10].*

There are a number of ways in which scientists are able to produce Graphene. The first successful way of producing monolayer and few layers Graphene was by mechanical exfoliation which is also known as "the adhesive tape technique". However, several analysis establishments round the world are attempting to search out the simplest, best and effective approach of manufacturing prime quality Graphene on an oversized scale that is additionally value economical and ascendible. The most common way for scientists to create monolayer or few layers Graphene is by a method known as Chemical Vapor Deposition (CVD). This can be a way that extracts carbon atoms from a carbon wealthy supply by reduction. The most downside with this technique is finding the foremost appropriate substrate to grow Graphene layers on and conjointly developing an efficient approach of removing the Graphene layers from the substrate while not damaging or modifying the atomic structure of the Graphene [9]. Other methods for creating Graphene includes, growth from a solid carbon source using thermo-engineering, sonication, cutting open carbon nanotubes, carbon dioxide reduction, and also graphite oxide reduction. This latter method of using heat, either by atomic force microscope or laser, to reduce graphite oxide to Graphene has received a lot of publicity of late due to the minimal cost of production. However, the quality of Graphene produced currently falls short of theoretical potential and will inevitably take some time to perfect. Many commercially available carbon inks contain some graphite and amorphous carbon. Graphite is obtained from the pure form of carbon or carbon containing substances. Graphite is composed of a number of layers of Graphene sheets whereas Graphene is a single sheet made of carbon atoms. The conductivity for graphite is higher in the in-plane direction as compared to the perpendicular direction because the bonding forces between atoms of the same layer are greater than forces between atoms of different layers [11,12].

Properties of graphene

Electronic properties

Graphene differs from most conventional 3-dimensional materials. One of the most interesting properties of intrinsic Graphene is that it is a semi-metal or zero-gap semiconductor (with both holes and electrons as charge carriers) with very high electrical conductivity. Carbon atoms have a complete of half dozen electrons; two within the inner shell and four within the outer shell. The four outer shell electrons in personal atoms are accessible for chemical bonding, however in Graphene; every atom is connected to three alternative carbon atoms on the 2-dimensional planes, going one negatron freely accessible within the dimension for electronic conductivity. These highly-mobile electrons are called pi (π) electrons and are located above and below of the Graphene sheet. These pi orbitals overlap and facilitate to reinforce the carbon-to-carbon bonds in Graphene. Fundamentally, the electronic properties of Graphene are dictated by the bonding and anti-bonding (the valance and conduction bands) of these pi orbitals. In 1947, P. R. Wallace stated that at Dirac point in Graphene, electrons and holes have zero effective mass. This occurs because the energy-movement relation (E-k relation) is linear for low energies near the 6 individual corners of the Brillouin zone. These electrons and holes are known as Dirac fermions or Graphinos, and the 6 corners of the Brillouin zone are known as the Dirac points. Due to the zero density of states at the Dirac points, electronic conductivity is actually quite low. However, the Fermi level can be changed by doping (with electrons or holes) to create a material that is potentially better at conducting electricity than at room temperature. The equations describing the E-k relation is: [13,14]

$$E = \hbar v_F \sqrt{\kappa_x^2 + \kappa_y^2} \quad (1)$$

Mechanical properties

One of the stand-out properties of Graphene is its inherent strength. Due to the strength of its 0.142 nm long carbon bonds, Graphene is the strongest material ever discovered, with an ultimate tensile strength of 130 GPa, as compared to 0.4 GPa for A36 structural steel, or 0.3757 GPa for Kevlar. Not only is Graphene extraordinarily strong, it is also very light at 0.77 milligrams per square meter. What makes this particularly special is that Graphene also has elastic properties, being able to retain its initial size after strain. In 2007, Atomic Force Microscopic (AFM) tests were carried out on Graphene sheets that were suspended over silicone dioxide cavities. These tests showed that Graphene sheets with thicknesses of between 2 nm and 8 nm had spring constants in the region of 1-5 N/m and a Young's modulus of 0.5 TPa [15].

Applications of graphene

Polymer masterbatches

Graphene can be incorporated into polymeric materials to form Graphene-polymer composite materials. As many polymeric materials suffer from strength-related problems, the incorporation of Graphene can help to increase the tensile strength of the polymers, increasing the shelf life of the polymeric material in commercial applications. Incorporating Graphene into polymers can also give polymers electrical conductivity properties [16].

Sensor

The ideal detector is ready to find minute changes in its encompassing surroundings. Because of the placoid and consistent arrangement of atoms in an exceedingly Graphene sheet, each atom inside the sheet is exposed to the encircling surroundings. This allows Graphene to effectively find changes in its surroundings at micrometer dimensions, providing a high degree of sensitivity. Graphene is additionally ready to find individual events on a molecular level. Several of graphemes properties square measure useful in detector applications; intrinsically, Graphene may well be utilized in sensors in varied fields as well as bio-sensors, medicine, field impact transistors, desoxyribonucleic acid sensors and gas sensors [16].

Structural composites

Graphene is incorporated into varied composites for applications wherever strength and weight square measure limiting factors, as an example within the part business. Graphene is being incorporated into several materials to form the present material stronger and additional light-weight. For the aviation business, a stuff that is far lighter than steel however still offer the mandatory strength can save tons of cash on fuel consumption, that is why Graphene has began to be incorporated into such materials. Graphene-based structural composites have a large potential to become a wide used different to several materials used these days [17].

Catalyst supports

Even though the surface of Graphene is placoid and uniform, like all different material breathing it's subject to intrinsic defects. Catalysts within the variety of metal ions will sit in these cavities and be supported. Additionally, to providing mechanical support, the wonderful charge carrier ability of Graphene assists the charge transfer reactions involving the catalyst. Graphene is additionally inert and doesn't interfere (in a negative way) with the interaction between the catalyst and therefore the substrate materials. Graphene additionally provides a fair dispersion of catalyst particles; therefore, the catalyst-substrate reaction is consistent across the total support [18].

Slot antenna

Graphene is simply atom thick layer of carbon atoms. Thus, being ultrathin, Graphene will be used for planning of antennas, additional specifically, small patch antennas or slot antennas. Because of ultra-small size the losses square measure terribly less compared to a luminous antenna however at a similar time the radiation efficiency is being compromised. The radiation potency of Graphene primarily based patch antenna is simply 6%. Bearing on, it is necessary to own a gain of a minimum of radiation efficiency of four-hundredth at low power. It had been shown in that if IDC (inter-digitated capacitor) was used with skinny Graphene films matched with slot antenna, the IDC matches antenna at around center frequency of 3.5 gigacycle with information measure of (100:1). With decrease in size of a luminous antenna typically the radiation potency is compromised [19].

OLEDs

In some recent years we tend to all have determined a forceful modification in show technologies. Smart show means that high distinction ratio, considerable color quality, high luminosity, adequate brightness, giant in size and pure black back. To the current demands the OLEDs had evidenced to be awfully smart different. But still there remains an additional scope of advancements in OLEDs by making them versatile victimization Graphene. Until date the bit panels primarily use ITO (Indium Tin Oxide) for planning. It also needs refined nanowires and nanoribbons for connections. However, once we use Graphene rather than ITO this problem is eliminated. Graphene here ought to be thought-about as a low sheet resistance layer that has terribly high transmittance (97.4% at 550 nm wavelength). Because of high mechanical strength and chemical skillfulness the utilization of Graphene for clear conducting conductor will be seen as the future of show devices [20]. Whereas scrutiny Graphene to other clear conducting electrodes, the simplest half is that the transparency of Graphene alongside it being ultrathin to avoid light being trapped. Good phones that we tend to square measure victimization these days' uses bit screen having clear electrodes manufactured from indium tin compound. However, as ITO has some major limitations they are 1) metal could be a material that's hardly on the market and already costly, and as demand can increase its worth will rise. 2) A rigid substrate like glass is needed for ITO as a result of ITO is brittle and hence it can't be used as an organic junction rectifier or as in flexible displays [21].

Batteries

Graphene because of its wonderful flexibility, high thermal conductivity and quality has become first alternative for victimization it as electrode in batteries. By adding atomic number 5, metallic element ions will stick to Graphene anode nicely. This analysis of victimization of Graphene is along with atomic number 5 was done by automobile company- Honda. Also, many automobile corporations like Hyundai and Kia motors have shown interest in victimization Graphene in their batteries [22].

Supercapacitors

Super-capacitors square measure devices that may interference an oversized amount of charge for awfully while. Additionally, their charging time is very less. Graphene has come back as a key player during this domain due to high lepton quality. It's essentially a hierarchical nanostructure comprised of Graphene and carbon sphere. Graphene primarily based super-capacitors will store virtually same energy as that of Ni:MH batteries [23].

Printed electronics (Graphene over silver based conductive ink)

The most important element of all the electronic devices is the "electrical wiring", which is the conductive structure formed by depositing metal that connects various components in the circuit. The conventional electronic systems are fabricated using photolithography, a complex and time-consuming multiple step process, which requires expensive facilities and instruments, generating large volumes of hazardous waste, which damages the environment. A Vacuum deposition process is also used for fabrication of electronic devices. This process is not costly as photolithography, but it requires a large amount of energy to execute the process. Also, the process is hard to control over small areas;

hence it is not suitable for high resolution patterns. Metal deposition by electro-less plating is also one of the methods used for fabrication of electronic devices. The main disadvantages with this process are, it is time consuming, not suitable for high resolution patterns, and it generates a large amount of waste hazardous to the environment. Moreover, these manufacturing processes require an environment that is dust free and temperature controlled. Providing such environment leads to additional costs to be invested on infrastructure and maintenance of that infrastructure [24]. The global market demand high quality and low-cost fabrication methods for manufacturing of electronic devices that are both faster and cheaper compared to traditional production methods. Printed Electronics (PE) is an upcoming technology where conventional printing methods are employed to print electrically functional devices. There is a worldwide effort to make these processes available for commercial use, and some are already being successfully commercialized. PE brings together previously separate fields, printing and electronics. Using conventional printing processes along with inks based on metal nanoparticles (NPs), metallo-organic complexes (MOC) are used to produce building blocks of electronic products such as transistors and diodes. The advantage offered by PE in the manufacturing of these components is a drastic decrease in the cost of electronic devices. Applications of PE have been demonstrated previously in the manufacturing of batteries, LED's, displays, speakers, sensors and fully printed RFID labels. Conventional printing processes are additive in nature and offer great advantages over the traditional processing methods for electronic device manufacturing. Flexible electronic devices are manufactured by depositing a single or multiple layers of functional materials on polymer substrates. The important challenge for PE is the formulation of the functional inks. Formulation of functional inks is similar to graphic inks, but in addition they should provide good printability of the printed pattern, good compatibility with the substrate and low-temperature processing in order to be compatible with flexible substrates. (Table 1) shows the comparison of conventional processing and printed electronics [13,25].

TABLE 1
Comparison of Conventional Processing and Printed Electronics [26].

Conventional Processing	Printed Electronics
Subtractive processing (photolithography and wet/dry etching for layer definitions	Additive processing (printing) for layer definitions
Controlled / Vacuum environment	Ambient temperature and pressure conditions
Typically requires a high temperature for processing	Requires low temperature for processing thus allowing use of flexible and plastic substrates

Extensive research work is being carried out recently with all the focus on developing printing as a platform for high volume manufacturing of electronics. Advances in the field of ink technology such as particle and binder manufacturing have enhanced performance of inks in terms of conductivity, flexibility, line resolution and their compatibility with various substrates. Functional inks suitable for screen, gravure and flexographic printing processes have been developed recently and have demonstrated compatibility with thermal processing techniques such as photonic sintering or thermal curing. Various conductive metals are employed in formulations of inks that are conductive in nature. Silver (Ag) is the primary choice for PE due to its high conductivity ($\sigma=6.3^{*}10^{7}\ \Omega^{-1}\ m^{-1}$), stability and performance. Other highly conductive metals that have also gained popularity are copper ($\sigma=5.96^{*}10^{7}\ \Omega^{-1}\ m^{-1}$), gold ($\sigma=4.4^{*}10^{7}\ \Omega^{-1}\ m^{-1}$) and aluminum ($\sigma=3.78^{*}10^{7}\ \Omega^{-1}\ m^{-1}$). Silver, is a very expensive material, therefore extensive research is being carried out to replace silver by less expensive metals. Copper, aluminum, and zinc are less expensive as compared to silver, however, the main challenge is to avoid their oxidation at room temperature which requires sophisticated reaction conditions such as use of hydrocarbon solvents, low precursor concentration and inert atmosphere. Oxidation is a formation of dense, thin layer of metal oxide on the surface metal particles, which results in loss of electrical conductivity and limits the use of these materials in the formulations of conductive inks. For applications that do not require very high conductivity, resistive inks based on Graphene and carbon fillers can be used. Inks based on a blend of conductive carbon with grapheme, is one of the popular options that is being tested and researched. Pure Graphene-based inks offer exceptional electrical conductivity with high-speed and cost-effective printability on a variety of printing systems, including roll-to-roll. Introduction of carbon fillers can reduce the amount of Graphene required to create conductive network in ink film resulting in saving of material and being more cost effective. Blends of Graphene-carbon inks do not require high-temperature sintering, they create robust films that does not crack or delaminate with repeated flexing and creasing. This enables true, flexible applications where bending, folding, handling, and dropping do not disturb the printed circuitry. Also, these inks do not form an insulating oxide layer; they are non-toxic and can be readily dispersed in solution [26,27].

The highly specialized field of printed electronics demands highly specialized ink formulations. The end-use properties of the application and the desired printing processes govern the composition of the functional inks. The raw materials for the inks and their dry weight in the formulation are selected in a way that the final inks will fulfill all the requirements of the given printing process. The basic components of ink include filler, binder, solvent (s) and additives. Fillers are usually pigments which differentiate the graphic ink from the functional ink. To formulate the graphic inks, pigments capable of providing colors are selected whereas for functional inks, functional materials are selected. The function of the binder is to bind the pigments to the substrate or media on which it is printed and cohesive binding of the pigment particles. Conventional water based, conductive inks are comprised of a liquid vehicle (water or organic solvent). This vehicle determines the basic properties of the ink and they dissolved or dispersed components. Conductive inks can be formulated by blending either nanoparticles or precursors of metal particles that are highly conductive, such as silver, gold, copper, zinc, and carbon. The precursors usually reduce to the original metal compound by reaction with a reducing agent. Silver is most widely used con ductive material because of its high electrical conductivity, but carbon and copper can also be used for applications where cost is a concern. The conductivity of any ink formulation basically depends on the printing process, drying method, and substrate. The conductivity measurements are generally analyzed in terms of sheet resistivity (ρ_s) [28].

Properties of inks

The rheological properties of inks must be compatible with available inkjet printing technology. The surface tension and viscosity of the ink determine the velocity, size, and stability of the ejected droplet and the shape of the droplets impinging on the substrate. The impingement shape establishes trace resolution and thickness, which ultimately determine the trace mechanical and electronic properties [29].

Surface tension

Surface tension is the force acting on the surface of a liquid, tending to minimize the area of the surface; quantitatively, it is the force that appears to act across a line of unit length on the surface. Surface tension is also known as interfacial force or interfacial tension. The surface tension of water is 72 dyne/cm; some surfactants can reduce the surface tension value for water to a value in the range of 30-50 dyne/cm. A low surface tension liquid has the tendency to wet, or to spread across, a high surface tension surface. The phenomenon helps to determine whether or not the ink will remain where it is printed, and how wide it dries. The wetting characteristics of the functional ink strongly contribute to the electrical property variation, printed structure edge definition, and printing resolution. One of the general measurement methods of surface tension is the Du Nouy ring method, in which a platinum ring of precisely known dimensions is suspended from a counter-balanced lever-arm. The arm is held by torsion applied to a wire to which it is clamped. Increasing the torsion raises the arm and ring. The ring carries with it a film of the liquid in which it is immersed, and the force needed to pull the ring free is measured. The detachment force is related to the surface or interfacial tension by $\gamma = BF/4\pi R$, where F is the force on the ring that causes it to break with the fluid measured; R the mean radius of the ring; and B the correction factor related to the geometry of the meniscus formed by the ring [29].

Viscosity

Viscosity is a measure of a fluid's resistance to flow. It describes the internal friction of a moving fluid. A fluid with a large viscosity resists motion because its molecular interrelation gives a high internal friction. A fluid with a low viscosity flows easily because its molecular interrelation results in very little friction when it is in motion. The viscometer makes use of the rate of flow of a certain volume fluid through a capillary tube of a given length. Researches were recorded for the flow of distilled water or any other solvent from the upper graduation mark to the lower mark and then used for calculation of the viscometer. The viscosity of the measured fluid was determined following the same procedures for the calibration: $\eta = ktd$, where t is the flow time in seconds and d is the density of the measured fluid [29,30].

Density

Density is defined as weight per unit volume of a certain conductive ink, which varies within the range of 0.8 ~ 2.0 gram/ml. Density is as significant as that of surface tension and viscosity on the generation and deflection control of the inkjet droplets [29].

Particle suspension

Most current commercial pastes or inks include metal particles or flakes as the main conductive component. In our preliminary experiments, it was found that even particles as small as several microns in diameter could clog the inkjet orifice and then the printing process would then be forced to stop for cleanup. There is a tendency to apply Nano silver or gold colloids as conductive inks, which have less clogging problems and can be cured at a relatively low temperature to form continuous thin films on various substrates. In the current research, however, the formulation of a particle-free solution for inks is preferred to reduce cost and elongate shelf life. Inks with a surface tension on the order of 25-70 mN/m and a Newtonian viscosity of 1-10 mPa have been found to be most suitable. Most commercially available inks possess viscosities and surface tensions that exceed permitted levels, and thus do not allow droplet formation in the range of 30-100 μm in size using inkjet technology [31,32].

Components of conductive inks

Pigments/Fillers

The function of pigments in a graphic printing ink is to provide color. For color inks there are several chemistries and parameters involved in using pigments. However as discussed before, pigments in conductive inks are replaced by micron or nano sized metal particles or precursors of metal particles. The main parameters in selecting the type of metal always depend on the conductive properties desired by the end product. Other parameters in selecting these metallic particles are application based, process used for deposition and method of curing of the conductive inks. For this study, conductive carbon and Graphene is selected as a primary pigment for the formulation of the ink [33].

Resin

The primary function of resins in ink formulation is to provide adhesion of filler material to the substrate along with cohesive adhesion of filler material. Resins can be a naturally occurring substances or man-made materials produced in non-crystalline solid or liquid form. Along with adhesion, the resins also provide crucial properties such as hardness and flexibility of ink film. Resins can be classified by various ways; by source, solubility or by molecular weight. By source resins can be classified as natural or synthetic resins. Rosin based, cellulose or cyclized rubber are examples of natural resins. Synthetic resins are prepared by polymerization of a single monomer or a combination of two or more monomers such as epoxides, acrylic, polyamides and vinyls. Based on the solubility, resins can be classified as water-based or solvent-based. Solvent-based resins are soluble in solvents such as alcohol or acetates. Water-based resins, as the name indicates, are soluble in water. Usually, in water-based ink formulation, solution and emulsion resins have its own function and both should be present in the finished ink. Solution resins are low molecular weight acrylic resins, which are good for dispersing the pigments, while grinding on a three-roll mill or a bead mill. These solution resins are not very good film formers but they do provide hardness to the ink film; hence they are only used for grinding purpose. Emulsion resins are high molecular weight resins, which have very good film forming properties, are typically added to the ink formation after the grinding stage. Depending on the application and end-user requirements, various combinations of these resins can be used. In graphic inks, all the properties except color depend upon the properties of the resin mixture. Commonly used resins are acrylics, alkyds, cellulosic derivatives, rubber resins, ketones, maleics, formaldehydes, phenolics, epoxies, fumarics, hydrocarbons, isocyanate free polyurethanes, poly vinyl butyral, polyamides and shellac. Choice of resin for conductive ink is a very critical as is its compatibility with the solvent, fillers, and substrate should be taken into consideration [34,35].

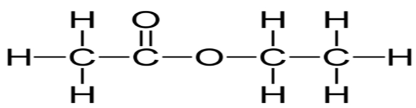
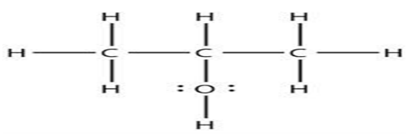
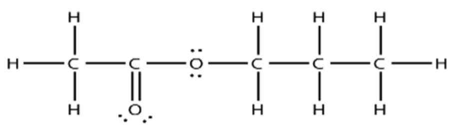
Solvents

Solvents form the major part of the ink and are responsible for controlling the rheological properties of the ink, such as viscosity, flow and leveling properties and evaporation rate of solvents from the inks. The basic function of the solvents is to keep the ink in liquid form when applied to the image carrier until transferred to the substrate. Solvents are classified as volatile solvents or slow drying solvents depending on the speed of evaporation. The selection of the solvent depends upon various factors such as the printing process, press speed, absorbency of the substrate, compatibility of other raw materials used in the process, toxicity, resin solubility and end use properties. Gravure and flexography printing processes run at high speed and the primary drying method is evaporation; hence require very highly volatile solvents such as ethyl acetate, isopropanol, or N-propyl acetate (Table 2). On the other hand, offset and screen printing requires a high boiling point solvent such as hydrocarbons, which should be viscous and hydrophobic [36,37].

Additives

Additives are the minor components (up to 5% by weight) of ink, but greatly alter the physical properties of the ink. Plasticizers, wetting compounds, anti-setoff compounds, waxes, shortening agents, anti-skinning agents, and anti-pin holing compounds are some of the few additives used in the ink formulations. Additives, when used correctly, can greatly benefit the runnability and functionality of ink. Waxes are used to improve the rub resistance, plasticizers make the ink softer and improve its flexibility, adhesion and, to some extent, gloss. Wetting agents are used to decrease the surface tension of the vehicle and increase the wettability of pigments. Dispersing agents are beneficial for dispersing the pigment in the vehicle to avoid agglomeration. Additives can vary depending upon the process; shorting compounds are used in paste inks for lithography and screen printing to minimize print defects such as misting of the ink. Defoamers are used in aqueous liquid inks to reduce foam. Driers are a special kind of additive used in sheet-fed offset inks to increase their drying speed by oxidative polymerization. Some commonly used drying agents are manganese and cobalt. For conductive inks it is not advisable to use very many additives

TABLE 2
Volatile solvents used in gravure printing [36].

Name	Structure or Composition	Boiling Point
Ethyl Acetate		77.1°C
Isopropanol		82.6°C
N-propyl acetate		101.6°C

since they can affect the final conductivity of the ink. However, depending on the printing conditions and formulation, plasticizers can be used to improve the flexibility and adhesion of inks. Wetting agents could be useful since they decrease the surface tension of the vehicle and increase wettability of the pigments/fillers. Dispersing agents can be beneficial in conductive inks, since they avoid agglomeration and metal particles being heavy can settle and agglomerate [38,39].

Substrates

Substrate is an important component in Printed Electronics. Different properties of the substrates are critical and hence important for various applications of PEs. Mechanical properties along with the surface properties of the substrate can affect the print quality and printability. (Table 3) summarizes the various properties for paper and polymer film. Paper being a biodegradable product, has attracted a lot of attention of researchers and investors over the years. Paper, depending on gram mage is used mostly for manufacturing bags, labels, cartons, or rigid packaging boards in graphic printing of packaging applications, while polymer films are widely used for manufacturing labels and flexible packaging, which require high barrier properties. Thus, paper is used where structural stability, absorbency and stiffness is desired while flexible substrates are used where high mechanical stability, smoothness and really good barrier properties are necessary. For PE applications, high purity polymer films meet most of the requirements. Polyethylene Terephthalate (PET) has been widely used substrates for PE applications. Even though polymer substrates meet most requirements of PE, they sometimes need surface treatment and modifications to improve ink wetting. PET films for PE applications are often required to be heat stabilized. Compared to polymeric substrates paper is thermally more stable and more economical to use. Also, with the application of coatings, paper surface can be modified in terms of the surface wetting properties of the paper and its smoothness and porosity [40,41].

TABLE 3
Comparison of Paper and Polymer film properties [39]

Property	Paper	Polymer Film
Stiffness	High	Low
Shrinkage	Low	High
Surface Smoothness	Low	Very High
Surface Modification	Possible	Possible
Absorbency	Very High	Low
Biodegradable	Yes	No
Mechanical Strength	Low	High
Chemical Stability	Low	High

Behavior of carbon-graphene inks

Stable and high-concentration Graphene inks with appropriate consistence and solvent composition area unit fascinating for printing. For this reason, each liquid section exfoliated Graphene and GO area unit normally won't to formulate Graphene inks. The preparation of Graphene by exfoliating C has been accomplished by many ways during a broad varies of solvents with or while not additives. But only a little half is appropriate for ink formulation. Another concern is that the indispensable additives that area unit utilized to stop Graphene flakes from aggregating and/or improve the ink printability [42]. Warmth (200-400°C) tempering is usually needed to get rid of the additives that make it not applicable to heat-sensitive substrates like papers and textiles. Therefore, careful choice of additives is extremely vital [43,44]. (Table 4)

TABLE 4
Comparison of Graphene like materials [45].

Graphene structures	Details
Graphene layers	A single-atom-thick sheet of hexagonally arranged, sp^2-bonded carbon atoms and known as monolayer Graphene.
Turbostatic Carbon	3D sp^2-bonded carbon atoms and known as rotationally faulted, no defined registry of the layers, prepared at low temperature and resist the development of 3D crystalline order upon very high temperature heat treatment.
Bilayer/Trilayer	2D (sheet-like) materials, consists 2 or 3 well-defined, countable and stacked Graphene layers of extended lateral dimension
Multilayer	2D (sheet-like) material, consists of a small number (between 2 to 10) of well defined, countable and stacked Graphene layers of extended lateral dimension
Nanoplates/Nanosheets/ Nanoflakes	2D graphite materials, thickness and/or lateral dimension less than 100 nm
Microsheet	A single-atom-thick sheet of hexagonal arranged, sp^2-bonded carbon atoms that is not an integral part of a carbon material but is freely suspended, lateral dimension between 100 nm to 100 µm

To date, most Graphene inks use alkyl radical polyose as stabilizer for inkjet printing, gravure printing and screen printing. Although shear and chemical science exfoliation ways show nice potentials for the economical production of high concentration Graphene dispersion, it had not been wont to build Graphene inks for inkjet printing before our work [16]. (Table 5)

TABLE 5
Performance of Carbon-Graphene inks synthesized by different methods [43].

Method	Temp. (ºC)	Conductivity (S/m)
Sonication	250	250
Shear Exf.	350	400
Electrochemical	300	25
Supercritical (CO_2)	300	92
Nanoflakes	100	430

Alternatively, GO dispersions also are popularly utilised to form inks due to their wonderful process ability and dispersibility during a broad vary of solvents. There are unit reports on GO primarily based inks for inkjet printing, 3D printing and screen printing, however the electrical properties of written structures area unit determined by the reduction level of GO and therefore the restoration of graphitic lattice [46]. Carbon nanomaterials provide various possibilities for written and versatile physical science. Due to its promising and extraordinary properties, Graphene has been wide employed in the fabrication of written electronics. Graphene semi conductive inks have the potential to revolutionize the written conductor field by exchange metal like inks, semi conductive compound inks and different carbon material inks, whereas at identical time reducing biological hazards and production costs [47].

Applications of carbon-graphene inks in printed electronics

The photovoltaic industry is facing a depletion of the raw materials used in the production of solar panels. It is particularly true for indium, which is used in the form of indium tin oxide (ITO) as a transparent conductive oxide (TCO) in the production of solar panels. Worldwide scientists, universities and research centers have pounced upon Graphene and are studying the attributes of this amazing substance for possible future applications. Of all known elements none other besides carbon reacts chemically with so many other elements. A further astonishing property of Graphene is its tunability. When some of the carbon atoms in the crystalline lattice are replaced or doped with other elements it can be turned over a broad band from an excellent conductor to a semiconductor up to an insulator. No other material displays even remotely such qualities. The packaging density with semiconductor functions (diodes, transistors, ICs) of Graphene is much higher than on silicon. Some semiconductor materials are replaced by Graphene nanomaterial as its accurate and good electrical-optical properties. Graphene-based transistors can operate at much higher frequencies and more efficiently than the silicon transistors now in use. First transistor models have already established switching frequencies and efficiencies that can never be equalled from silicon types [48].

Acrylic resins

Acrylic resins are thermoplastics formed by derivatives of acrylic acids and meth acrylic acids. Highly reactive double bonds and miscibility with oil-soluble and water-soluble monomers enables easy polarization of these acids. There is range of the way to hold out the chemical action likes bulk, solution, suspension or emulsion techniques victimization type of catalysts. The chemical action of acrylic monomers is associate degree chemical reaction obtained either at temperature or by heating. Adding initiators, accelerators and catalysts usually speeds up the process. Ultraviolet (UV) lightweight, visible radiation or negatron beams (EB), that initiators aren’t necessary also can achieve chemical action or solidification. Polyacrylic acids and polymethacrylic acids are often considered together and they both are soluble in water. (Figure 3) shows the polymerization of both acrylic and methacrylic acids. The softening points of these polymers depend on the chemical structure and molecular weight. The outstanding characteristics of acrylic resins are their clarity, chemical inertness, excellent light fastness and resistance to yellowing on heating. The available range of acrylic resins and solubility with variety of solvents makes it the first choice of resin in the modern ink industry. Gravure, flexography, screen printing and high gloss lacquers use acrylic resins in the formulations. They impart good chemical resistance and improved print quality. With purging, odourless grades of acrylic resins are prepared that can be used in the food wrapping industry. Apart from ink formulation, acrylic polymers are used in a variety of applications, such as the automotive industry, medical devices, paper coatings, paints and adhesive industries [49-51].

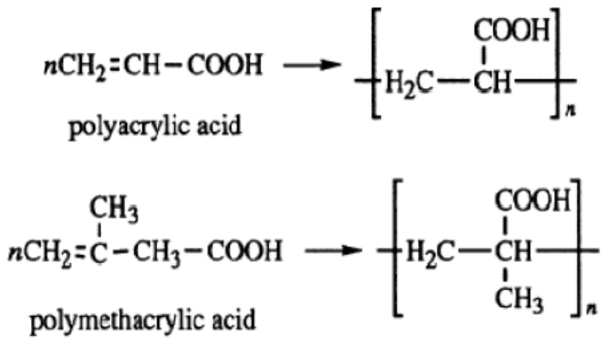


Figure 3) *Polymerization of acrylic acid and methacrylic acid [52].*

Soybean

Soybean is made up of 40% protein and 20% oil, and it has zero cholesterol and low saturated fat. It has been a major source of protein for the people all over the world. It is the only vegetable food that contains all the eight essential amino acids. It is also a good source of fiber, iron, calcium, zinc, and vitamins. Soybean and its derivatives have been used in the industry for a long time now. Especially use of soy oil in the printing ink industry is increasing rapidly as it has been a very effective substitute for petroleum-based vehicles in inks. Soy oil is used in Lithographic newspaper inks and commercial offset inks, which reduces the emission of VOCs and makes the printing process more environmentally friendly. Soy oil readily mixes with pigments, imparts deeper and brighter colors, which results in overall better litho print quality. The removal of soy-based inks is easier than petroleum-based ink in deinking processes. This results in less damage to the paper fibers, which can be recycled and reused. Moreover, soy oil-based inks are more stable during printing, which leads to less waste in comparison to conventional petroleum-based inks. As each printing process demands specific ink characteristics, researchers are working on formulating best soy oil-based ink which will be suitable to each printing process. Recently, eco-friendly pigment and soy oil were applied in formulating heat resistant soy inks [53,54]. Apart from soy oil, soy protein is also important and a potential raw material for the ink industry. The industrial merchandise that use soy supermolecule embrace adhesives, asphalts, and resins, clean-up materials, cosmetics, inks, paints, plastics, polyesters and textile fibers. The foremost favourable property of soy supermolecule for the paper trade is that, they kind additional large and open coating structures. The paper industry continues to use soy protein for paper coatings. Currently, soy protein is intensely researched for viability for green packaging applications alone or in blends with other green polymers. As this study will be focused on formulating the inks with soy protein, soy protein and its derivatives are explained below [55,56].

Soy protein

Proteins are built by condensation reaction where amino acid monomers are joined together *via* peptide bonds and water molecule is released. (Figure 4 (a)) shows the structure of amino acid and (Figure 4 (b)) condensation reaction of forming a peptide bond. Soy protein has a complex 3D structure and it contains 19 different amino acids, which are held together in a coiled structure by peptide bonds. The major functional groups present in soy protein are amino, carboxyl, hydroxyl, phenyl, and sulfhydryl. The principle soy protein is glycinin, which contains mainly acidic amino acids and their amides; and has a molecular weight around 320-360 kDa. Soy proteins can be obtained once the oil from the soybean legume is extracted. After the removal of hulls and oils, the leftover defatted flake of soybean contains about 50-60% of protein in it. An extraction reaction is carried out in alkaline conditions. As the water solubility of soy protein is closely related to pH, and it drops with decreasing pH reaching minimum at around pH 4.2-4.6. Hence it is required that the alkaline conditions are maintained during the extraction process [38,57].

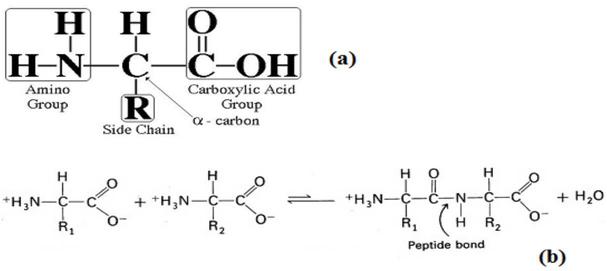


Figure 4) *(a) Structure of amino acid, (b) Condensation polymerization of amino acids forming peptide bonds [45].*

Depending on the supermolecule content, soy supermolecule are often categorised as-soybean flour, soy supermolecule concentrates, and soy supermolecule isolates. Soy flours area unit the smallest amount refined sort of soy supermolecule containing some fifty fifth of supermolecule in it. The practicality of the soybean flour supermolecule depends within the fat content, particles size and degree of warmth treatment. Generally, lower heat treatment and smaller particle size means that a lot of practicality. Fractionation of soy proteins can also be performed by ultracentrifugation based on sedimentation constants of protein to separate the large protein molecules. Soy protein concentrates are obtained by aqueous liquid extraction or acid leaching process and it contains about 70% protein. The major functionalities offered by soy protein concentrates are emulsification, water and fat absorption, viscosity and texture control. The majority of soy protein used in industry is obtained from concentrates [58,20]. Soy protein isolates are the most refined form of soy proteins and they contain about 90% protein. They are obtained by aqueous or mild alkali extraction followed by isoelectric precipitation. They possess both emulsifying and emulsion-stabilizing properties. These are water-soluble proteins, which have industrial applications for plastic films, adhesives, or composite materials. Soy proteins are amphoteric in nature, which means that they contain both cationic (positive) and anionic (negative) functional groups. And as most of the pigments used in industry are anionic in nature, soy protein strongly interacts with these pigments. Other advantages offered by soy proteins are high temperature resistance, high cross linking, excellent adhesion, and low cost [59-61].

Advantages of carbon-graphene inks

Graphene-based inks offer high conductivity, flexibility, high-speed printing and low-temperature curing. Advantages of Graphene-based inks over commercially available other conductive materials are listed below.

Silver-based inks are highly conductive and silver possesses a conductive oxide, hence the conductivity remains high over a long period of time. However, silver-based inks need extended amount of high-temperature solidification, that resists the type of substrates on that it are often written. Throughout sintering, binders and stabilizing agents are burned off which may result in cracking of the silver film because of shrinkage and hurt conduction. And also, silver is expensive and prices of silver can change over time, which leads to problems in cost estimation. Copper-based inks are low-cost alternatives to silver-inks. Its resistance is similar to silver-inks but copper oxide is insulating, which can result in lowering of conductivity over time.

Copper inks conjointly need sintering at warm temperature that limits their use with thermally sensitive substrates. Nickel and aluminium oxidize under ambient conditions to form non-conductive oxides. Various other metals have been used in inks, but their conductivity is much less than that of silver and they suffer the from same high-temperature restrictions on substrates [62,63].

Carbon nanotubes (CNT) are excellent conductors but exhibit poor dispersion stability and processibility. Presently, CNTs produced are a mixture of conducting and semi-conducting form. Apart from this, CNTs are carcinogenic and toxic in nature. Graphene-based inks alter new applications in written natural philosophy that would not be accomplished antecedently. The inks offer exceptional electrical conductivity with high-speed and cost-effective printability on variety of printing systems including roll-to-roll. With conductivity levels as much as 10 times higher than typical carbon inks, even Graphene-inks are available at about the quarter the price of expensive silver-inks. Graphene-inks require no high-temperature sintering. It creates robust films that do not crack or delaminate with repeated flexing and creasing. This allows true, versatile applications wherever bending, folding, handling, and dropping don't disturb the written electronic equipment. Also, Graphene doesn't kind and insulating compound layer, its non-toxic and it are often pronto spread in answer. High bond strength corresponding to that of forge silver-inks, low-temperature application and solidification, physical property that neither silver nor carbon inks will match permit the utilization of cheap, temperature-sensitive, thin, or versatile substrates like polythene, paper, paperboard and label stock on commonplace printing presses that use existing drying/curing instrumentation. These advanced capabilities save both capital investment and operating expenses [64,65].

Carbon-graphene material as conductive ink

In recent scenario, Graphene material has attracted many researchers due to its unique and diverse physiochemical properties. It has distinctive mechanical performance and advance electrical and thermal conductivities [43]. In present, Graphene material is being using in many electronic applications as it uses to fabricate flexible and low-cost electronic devices. More importantly, it has been used as conductive ink to coat or as directly using in different energy sectors [66]. Below are some literature surveys of Graphene materials.

D.S. Saidina et al. (2019) were synthesized Graphene material, which is the carbon nanomaterial. They fabricated conductive ink based on the Graphene nanoparticles. They also mentioned different material based conductive inks, which are used to print electronically. They described different printing methods like screening printing, gravure printing, flexographic printing, roll-on-roll printing etc. They concluded that how the Graphene nanoparticles are tremendously good and accurate in using as a flexible electronic source. Same as, L. Y. Xu et al. (2014) were fabricated hybrid conductive ink. They synthesized silver and Graphene nanoparticles and based on that they synthesized nanocomposite by using silver-Graphene nanoparticles. This hybrid ink is the combination of silver and Graphene material, which has unique and diverse electrical, thermal and opto-electrical properties [43,66]. Similarly, Youliang Cheng et al. (2018) and Rashedul Islam et al. (2019) were synthesized Graphene oxide based conductive ink. They used graphite flakes as a source of Graphene. They achieved high thermal stability with good mechanical property and conductivity. They used to coat the ink on textile fabrics for the various industrial applica tions. Panagiotis G. et al. (2017) were formed Graphene based conductive ink. They achieved $2x10^4$S/m conductivity with adjustable viscosity for the high throughput printing. Same as Bor Z. Jang and Aruna Zhamu (2008) were filed a patent on the Graphene platelets based conductive ink. They were used inkjet printing technique to print the conductive ink on sheet. They compared the resistivity of the sheet with coating and without coating. They proved that Graphene based conductive ink is very hard to print due to its large size structure as comparing with carbon black [67-70]. Ramiro Emerson C. Amon et al. (2020), Vasilios Georgakilas et al. (2015) and An Ji et al. (2018) were synthesized hydrophilic functionalized nanocomposite based conductive ink, which can be used in as battery material or in any energy sector. They used silver, carbon black, zinc and Graphene to make hybrid conductive ink. They used graphite flakes as a Graphene source. They described an easy, scalable, and surfactant free route for effective dispersion of pristine Graphene in water through the self-assembly with OH-functionalized hydrophilic nanotubes. Upon application of 3 V using a regulated power supply (MCP, M10-QD305), the LED illuminated and functioned well with very low circuit loss. This validates that the drawn electronic circuit using the as-prepared conductive ink has significantly low resistivity. They also mentioned to use sheet or paper-based drawing circuits to explain the conductivity. They also explained about the use of reduced Graphene oxide as a conductive material for future perspective [71-73].

Hartini Saad et al. (2020), Bich Ha Nguyen and Van Hieu Nguyen (2016) and Nazmul Karim et al. (2018) were fabricated Graphene and carbon-based de-icing nanostructure material to make conductive ink. They proposed good mechanical property and electrical property of the ink. Widespread applications of Graphene and Graphene-based nanostructures there exists also other less widespread, but perhaps not less important applications of Graphene and Graphene-based nanomaterials, such as: utilization of Graphene in anticorrosion technology. They proved that the Graphene-based glass roving demonstrates low resistance, 1.7 Ω cm^1 and efficient heating to a desired temperature at lower power consumption. They also demonstrated the use of this Graphene based glass rovings for manufacturing glass/epoxy composite for de-icing applications. They also mentioned mechanical performance of nanoscale Graphene nanoparticles was considered, suitable for electronic component production. Nanoindentation tests were performed to see how different parameters, such as different patterns (straight line, curve, square and zig-zag) and width of Graphene nanoparticles conductive ink influence the Young's Modulus and hardness of the substrate. According to the average value of indentation of Graphene, it was found that the smaller the width, the higher the Young's Modulus values and the biggest the width, the highest the values of hardness [74-76]. Similarly, Yun Zhao et al. (2019), Dawn M. Pedrotty et al. (2019) and Nazmul Karim et al. (2017) were fabricated metal material based conductive ink. They synthesized zinc, Graphene and carbon black material based conductive ink. They reported that inkjet-printed Graphene-based e-textiles for the first time and demonstrate two potential wearable electronics applications. All inkjet printing of surface pre-treatment enabled layer by layer deposition of an exact amount of materials at predefined locations. Moreover, inkjet printing of water-based and bio-compatible Graphene inks could potentially open up opportunities to manufacture environmentally friendly next generation e-textiles for sports, healthcare and military applications. There are several potential limitations of this study. First, this is an acute study, and chronic sustainability and biologic response from biopatch implantation was not evaluated. The mechanism of cell to material interaction is also unknown as outlined above and requires additional *ex vivo* and in vitro study to understand. They also mentioned the facile fabrication paves the way to massively prepare various patterned flexible heater for diverse applications. The conductivity and electro-thermal conversion performance of CCI is dramatically promoted by HECG for its superior electrical and thermal properties. The modified 35 CHF sample exhibits the fastest heating and cooling rate of 5.6°C/s and 15.6°C/s and a quite high steady-temperature of 83°C respect to its lowest resistance and huge heat exchange surface area [77-79].

Huang et al. were rumored that a series of inkjet printing processes victimization soluble single-layered GO and few-layered GO (FGO) are printed on numerous versatile substrates. Based on these findings, the electrical physical phenomenon of GO and FGO once twenty-five written layers on a polyimide (PI) substrate are 5.09 x 10^2 S/m and 9.09 x 10^2 S/m, respectively. In keeping with Huang et al., the low conductivity of GO written on PI compared to FGO could be attributed to the high variety of oxygen containing teams within the GO sample. In 2017, Ming Pei and Li were made-up GO ink by dispersing GO in mixed solvents of deionised water, ethanol and glycol within the quantitative relation of 1:1:1 victimization ultrasonication. The ready ink was inkjet printer onto a poly (ethylene terephthalate) (PET) substrate and therefore the electrical physical phenomenon once twenty printed layers was 0.497 S/m. They additionally investigated the electrical properties of treated and untreated PET victimisation oxygen–plasma treatment. The findings showed that electrical physical phenomenon of the treated PET was considerably improved over that of untreated PET at constant variety of printed layers [80]. Arapov et al. were conferred a comparison of 2 Graphene inks: one ready by the solubilisation of expanded atomic number 6 within the presence of a surface active compound, and therefore the different by valence Graphene fictionalization followed by redispersion during a solvent however while not a surface-active agent. Supported their findings, the physical phenomenon levels for dilated graphite-based inks and functionalised Graphene are about 1-2 kX/sq and a couple of MX/sq, respectively, for fifteen written layers. This method is simple and economical, and so includes a potential to be used for large-area printing of conductive films [81].

Meanwhile, Gao et al. were made-up extremely conductive pristine Graphene electrodes by inkjet printing victimization ethyl radical cellulose-stabilised ink prepared from pristine Graphene. No Graphene sheets were determined to settle at all-time low of the bottle even once nine months. This stability is rumored to be due to the robust hydrophobic interactions between ethyl polyose (as the helpful polymer) and therefore the Graphene sheets countering the van der Waals forces between the Graphene flakes, thereby inhibiting the aggregation of the Graphene. The written films have high physical phenomenon with the worth of 9.24 x 10^3 S/m once thirty written layers tempered at 300°C for 30 mints [82]. In 2016, Miao et al. were rumored a facile methodology of inkjet printing of Graphene nanoplatelets (GNPs) using chemical science method in inorganic salt-based solution while not victimization device. The electrical physical phenomenon of written pristine gross national product film improved from 44 S/m to about 2.5 x 10^3 S/m once twenty written layers once an easy thermal treatment of tempering at 300°C for 1hour [83]. Besides that, Majee et al. were rumored efficient inkjet printing of water-based pristine gross national product ink by a shear-exfoliation method with the help of bromine interval in liquid media employing a water-soluble polyose device, *i.e.,* (hydroxypropyl)methyl polyose. The DC (DC) conductivity was 1.4 x 10^3 S/m once the written GNP film was dried at 100°C, and increased to about 3 x 10^4 S/m once a further treatment of dipping the film in liquid iodine answer previous to drying. In distinction, a physical phenomenon of concerning 2.4 x 10^4 S/m was obtained once tempering the film at elevated temperature in air. The DC physical phenomenon of the doped gross national product films improved any to 1.5 S/m after tempering in air at 300°C. This shows a positive impact of the mixture of iodine doping and thermal tempering on physical phenomenon enhancement for written gross national product films [84]. In 2017, Secor et al. were incontestable Graphene inks with cellulose nitrate as a synergistic compound stabilizer. The written Graphene films on glass had electrical physical phenomenon values of 1.0 x 10^4 S/m and 4.1 x 10^4 S/m once tempered at 200°C and 350°C, respectively [85].

Conclusion

The alternative resistive inks for the gravure printing process, with lower cost, environment friendly, and potentially replacing expensive metal particles; using Carbon-Graphene in water-based gravure inks or inkjet printing technique will offer various advantages to the final product. Resistive inks, employed in style of resistive circuit applications, usually are needed to perform in heat conditions. High thermal resistance of soy protein will be an added advantage for the inks. Also, excellent adhesion will provide advantage to the required properties of the printed ink film.

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