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Nanoink properties for nanodevices fabrication with inkjet deposition system

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Abstract

Inkjet deposition system is a recent technology in fabrication electronic devices. Previous method such as screen printing, gravure and flexography were widely implemented. Flexible electronic devices and smart textile application are examples of fabrication using inkjet deposition system. The objective of this project is to focus on the study of nanoink properties for nanodevices fabrication using inkjet deposition system. Rheometer is used to investigate the suitable viscosity for the nanoink during printing. Meanwhile inkjet deposition system defines the velocity, testing frequency and volume for the inkdrop properties. This study observed that the viscosity ranging from 8-20 Centipoise (cP) is suitable for nanodevices fabrication using inkjet deposition system. This study helps to ease the complex processing for nanodevices fabrication such as prefabricated mask and gives a great outcome for the printing process.

Keywords: Inkjet deposition, nanodevices, flexible circuit, ink, carbon

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1. Introduction

Nanoink is advanced technology to fabricate nanodevices. It can be developed by researchers or the commercial grade in can be bought directly from the business market. The nanoink properties should match with inkjet deposition performances for nanodevices printing process. Some of the properties are particles sizes viscosity and robustness that are required to suite the inkjet deposition system to avoid damages for the printer's printhead nozzle.

There are many challenges before nanoink can be commercialized into the business industry as a product. A study was conducted to develop nanoink to fabricate electronic devices at an initial phase [1]. Another research found that inkjet deposition system can be used as an alternative technique to fabricate nanodevices in the field of flexible circuit [2]. Printed flexible circuit has advantages compared with conventional method. This technique is much simpler, time and cost saving and promotes green technology. This is because it used direct transfer of the ink onto the substrate which only consumed a very minimal volume of nanoink and avoid waste of sample. Besides, this technique allows any type of substrate to be used for printing. For instance, to design light conducting circuit paper, aplastic substrate can be used. Another example is, for smart textile application fabric can be used as a substrate for wearable application [3].

Conventional method such as screen printing, gravure and flexography need mask or pattern to perform the printing. They also consume very high cost at start up process [4]. Ink components are divided into two major classes that are precursor and organic solvent. Nanoink and particle free inks are two types of conductive ink. For nanoink, it utilizes nanoparticle as the base component. Meanwhile particle free-based ink utilizes metal salts or metals complex as precursor which is dissolved in solvents [5]. Printing on heated substrate via inkjet deposition system produced better output as compared to the normal room temperature printing. The small feature size can be printed and maintained with high jetting frequency. Another advantage is the solvent or nanoink will evaporate faster and many layer can be printed on the substrate. Major problem while using inkjet printing technique are the nozzle inside the system tends to easily be clogged. Due to this, the nozzle was designed with a very minimal rise in temperature by increasing the gap distance with substrate holder [6]. The size, shape, and purity of nanoink can be characterized with UV-Vis, Transmission Electron Microscope (TEM) and X-ray Diffraction (XRD). The surface modification and stability of nanoink can be characterized with Fourier-transform infra-red (FTIR) spectroscopy and thermogravimetric analysis (TGA) [7]. Inkjet deposition technique shows great potential in many applications such as display, solar cell, sensing, and paper electronics [8]. Printed electronic is an alternative to fabricate nanodevices rather than conventional silicon-based technology. The benefit of using printed electronic technique is high manufacturing speed, large area, low cost, environmentally friendliness and applicable to flexible nanodevices [9].

The important part for inkjet deposition technology is fabrication of the conductive ink. It comprises of conductive particles, solvents, surfactants, dispersion stabilizers and dispersed conductive particles [10]. Inkjet printed technique has developed many nanoink [11-14] based on nanoparticle and deposit on various type of substrate such as kapton polyimide [15], papers [16], polyethylene terephthalate (PET) [17].

In this paper the properties of nanoink are investigated based on inkdrop properties such as velocity of inkdrop, testing frequency, volume of inkdrop, shape of inkdrop and number of nozzles used.

2. Materials and methods

2.1. Materials

Nanoink used in this work was purchased from Hisense and Sigma Aldrich company. The ink properties are verified through the ink specification as shown in Table 1 and Table 2.

Table 1: Silver ink properties

Item	**Parameter**
Nanoink type	Silver
Printing method	Inkjet ink drop
Viscosity	8-20 cP
Surface tension	23–24 dyn cm^{-1}
Cleaning Agent	NMP, Ethanol
Substrate	PET,Plastic, Glass etc

Table 2: Graphene ink properties

Item	Parameter
Nanoink type	Graphene ink
Printing method	Inkjet ink drop
Viscosity	8-15 cP
Surface tension	25–30 dyn cm^{-1}
Cleaning Agent	NMP, Ethanol
Substrate	Plastic, rubber, paper etc

There are two types of nanoink used to fabricate nanodevices with inkjet deposition system which are silver and graphene ink. The silver nanoink in Table 1is suitable for inkjet ink drop printing method. The viscosity range is 8 to 20 Centipoise (cP). The surface retention is 23 to 24 dynes per centimetre (dyn cm^{-1}). The cleaning agents used in order to avoid clogging in printhead are NMP and ethanol. Nanodevices substrate used for this type of nanoink are plastic, rubber, glass, and paper.

The graphene nanoink in Table 2 also suitable for inkjet inkdrop printing method. The viscosity range is 8 to 15 Centipoise (cP). The surface tension range is 25 to 30 dynes per centimetre (dyn cm^{-1}). Also, NMP and Ethanol are used as the cleaning agent for printhead washing. Plastic, PET, rubber, and paper are type of substrate used to fabricate nanodevices for this type of nanoink.

Initially, before the printing begins, both nanoink were inserted into the small ink container which is located inside the inkjet deposition chamber. Both nanoink must be inserted carefully with a small syringe in order to avoid bubble development. The nanoink container inside the inkjet deposition system is connected with a small dark color tube. The tube is connected with a small filter and printhead cartridge inside the inject deposition system. After filling the ink container, the air pressure is setup via pneumatic system front interface which is integrated with inkjet deposition system. The value of air pressure should not greater than 1.0 kPa to rule out negative pressure that can damage the printer nozzle. Familiarization with the software system also needed before printing process start.

2.2. Nanoink characterization

Figure 1 show Anton Paar Rheometer used to verify viscosity and retention of nanoink properties suitable with the inkjet deposition requirement for printing process. The samples were fill up inside the valve at the center of the rheometer. Then, the ink viscosity and retention properties of the nanoink were analyzed and the output is displayed on the connected data acquisition system.

Fig. 1 Rheometer

2.3. Nanoink auto measurement

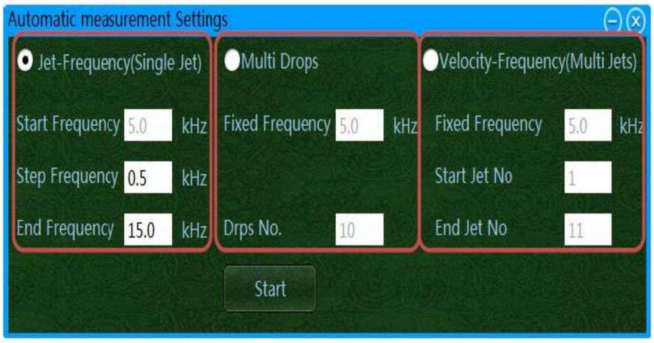

Fig. 2 Automatic measurement function

There are three options for automatic measurement function available in the inkjet deposition system interface as shown in Figure 2. The options are jet frequency (single jet), multi drop and velocity frequency. For jet frequency the ink drop parameter can be measured with different jetting frequency. However, only one nozzle can be measured with this mode selection. For multidrop mode option, the one ink drop can be measured several times. Meanwhile for velocity frequency (multi drops) multiple continuing nozzles can be measured. In this study, the jet frequency (single jet) option was selected as it is easy to compare performances of ink drop properties with different materials. All the automatic measurements module function is shown in Table 3.

Table 3: Measurement module

Module	Function
Start frequency	The frequency of starting measuring
Step frequency	The frequency space of measurement
End frequency	The frequency of ending measurement
Fixed frequency	The frequency depends on user setting
Drops Number	Number of repeating measurements in multidrop
Start Jet Number	The beginning nozzle which needs to measure
End Jet number	The ending nozzle which needs to measure

3. Results and discussion

3.2. Measurement results

Figure 3 shows the measurement results for nozzle number three via curve revealing mode measurement graphical user interface. After curved mode was selected parameter in horizontal axis such as value for testing frequency, number of nozzle and testing times will be displayed.

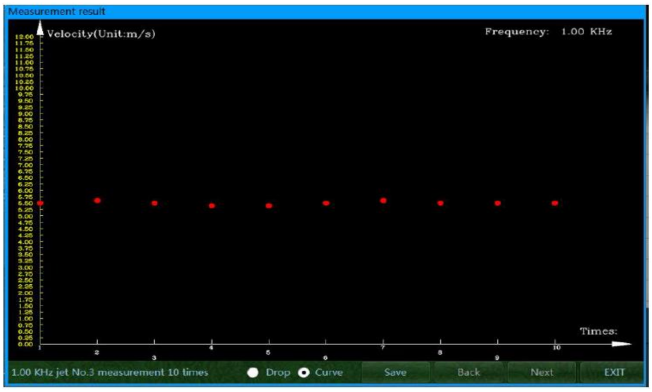

Fig. 3 Curve mode

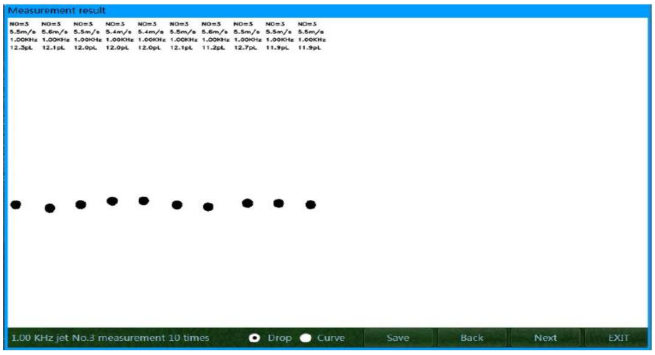

Fig. 4 Drop mode

Figure 4 shows the measurement results for nozzle number three via drop revealing mode graphical user interface. After drop mode was selected inkdrop properties such as velocity of inkdrop, testing frequency, volume of inkdrop, shape of inkdrop and number of nozzles is displayed.

3.1. Inkdrop properties

Each ink drop from the printer nozzle can be measured via the auto measurement function. Results parameter was number of nozzles (nozzle unit number), velocity in minutes per second (m/s), testing frequency in kilo hertz (KHz) and volume in pico liter (pL).

Table 4: Sample ink drop results for nozzle number 4 for silver ink

Number of Nozzles	Velocity (m/s)	Testing Frequency (KHz)	Volume (pL)
4	5.0	1.0	12.0
4	5.1	1.0	12.1
4	5.0	1.0	12.0
4	5.4	1.0	12.1
4	5.4	1.0	12.0
4	5.5	1.0	12.1
4	5.5	1.0	11.9
4	5.5	1.0	11.9
4	5.5	1.0	12.0
4	5.6	1.0	12.0

Table 4 shows the silver inkdrop measurement sampling from nozzle number 4 from 128 nozzle available in the inkjet printer. Data shows the inkdrop velocity is in the range 5.0 to 5.6 minutes per second (m/s). The testing frequency is selected at 1.0 Kilohertz (KHz). The range of inkdrop volume inserted is 11.9 to 12.0 pico liter (pL).

Table 5: Sample ink drop results for nozzle number 4 for graphene ink

Number of Nozzles	Velocity (m/s)	Testing Frequency (KHz)	Volume (pL)
4	6.5	1.0	12.3
4	6.6	1.0	12.1
4	6.5	1.0	12.0
4	6.4	1.0	12.0
4	6.4	1.0	12.0
4	6.5	1.0	12.1
4	6.6	1.0	11.2
4	6.5	1.0	12.7
4	6.5	1.0	11.9
4	6.5	1.0	11.9

Table 5 shows the graphene inkdrop measurement sampling from nozzle number 4 from 128 nozzle available in the inkjet printer. Data shows the inkdrop velocity is in the range 6.4 to 6.6 minutes per second (m/s). The testing frequency is selected at 1.0 Kilohertz (KHz). The range of inkdrop volume inserted is 11.2 to 12.7 pico liter (pL).

4. Conclusions

The ink properties such as inkdrop velocity, testing frequency, volume in pico liter can be measure automatically with inkjet deposition system. The performances of inkdrop properties can be compared via nozzle selected. It is observed that silver ink is better than graphene in terms of shape of inkdrop and velocity. Inkjet deposition system is a suitable method to fabricate nanodevices based on minimal time consuming, environmental friendliness and wide variety of substrate selection.

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