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Review on flexible Carbon Nanotube Based Strain Gage Sensors for biomedical applications

M Ravi Kumar, K Harika, Y Srinivasa Rao

Abstract- Aging brings dramatic changes in the skeleton and other organ systems. Major skeletal diseases associated with aging include osteoporosis, attendant fractures (hip, spine and wrist or Collies) and osteoarthritis and its resulting need for various joint replacements. The prosthetic joint market in the United Sates is between $4-5 billion annually and estimates have suggested that this number will increase by 10% annually as our population continues to age. The average life expectancy of hip and knee replacements is around 10 years, after which replacement of the prosthetic device becomes highly essential. A strain gage sensor that could be incorporated into the prosthetic implant represents a significant advance in terms of assessing the stability of the implant and potentially enables the surgeon to intervene preemptively before failure actually occurs. The proposed method outlines the fabrication of printable strain gage sensors for use in prosthetic implants and bone biology studies. The proposed strain gages are fabricated employing desktop inkjet printers and can be printed on flexible substrates. Special inks based on carbon nanotubes (CNT) and copper nanoparticles are prepared and are used in the printing process. The proposed strain gage sensors have several advantages over the conventional metallic alloy gages currently being used in biomedical studies. Firstly, CNT-based strain sensors have gage factors of up to 25 while metallic gages have gage factors of 1.2.The improved gage factors translate into better sensor sensitivity and correspondingly help to detect smaller strain variations. The commercially available metallic gages have a relatively large size. In contrast, the proposed strain sensors can be made very small due to the fine resolution of inkjet printers and can be custom shaped. Furthermore, the sensors can be arranged in arrays enabling the measurement of strain at different points along the bone or the prosthetic implant. Finally, CNT-based strain sensors have better biocompatibility when compared to the metallic gages. Their biocompatibility has been demonstrated in several studies.

1. INTRODUCTION

Strain sensors are important in many fields of science and engineering. One of the main limitations of existing conventional sensors such as strain gauges is that they are discrete point and fixed directional sensors, and are separate from the material or structure that is being monitored, hence not embedded at the material level. There is a need to develop new sensors that can be embedded into the material and can be used for multidirectional and multiple location sensing. Carbon nanotube based strain sensors are attractive to existing conventional metallic, semiconductor and capacitive strain gages and fiber optic strain sensors.

Why Carbon nanotube based sensors?

Carbon nanotube based sensors are attractive as alternatives to existing conventional metallic, semiconductor and capacitive strain gages, and fiber optic strain sensors because they

- can be used as surface mounted large area strain sensor skins that can act as highly responsive, complex nervous systems. The achievement of such a system would provide a cost effective monitoring capability which is more reliable than current techniques
- can provide a wide range of tunable strain sensitivities depending on the volume content of carbon nano tube and fabrication technique
- can be designed to provide highly flexible and robust strain sensors that can easily confirm to different surface shapes
- can be embedded into structural materials to provide not only structural reinforcement but also intelligent capabilities for the purpose of active control of strain sensing in composite materials and damage detection
- can provide sensors with high resolution at both the nano and micro scale Single-wall carbon nanotube sensors: Single-wall carbon nanotubes (SWNTs) offer attractive alternatives for developing new sensors because of their superior mechanical and electrical properties. In addition, they can be used as fibers in composites for producing a high strength material capable of strain sensing. Moreover they offer thermal conductivity, good mechanical strength, optional semiconducting/metallic nature and advanced field emission behavior. To date, several experiments have studied the effect of mechanical strains on the electronic properties of SWCNTs on the nanoscale. SWCNTs are Raman active and many researchers have studied the effect of stress or strain on the Raman-active modes.

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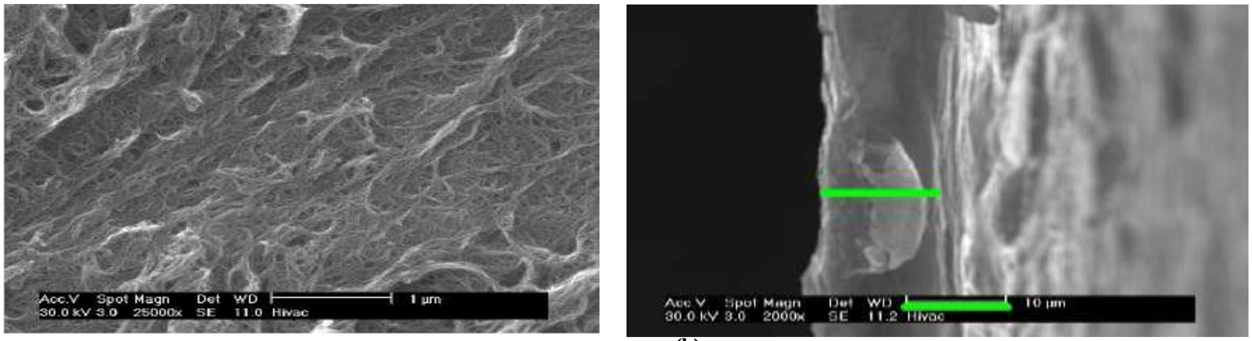
(a) **(b)** (b)

Figure 1: Scanning Electron Microscope (SEM) image of the carbon nanotube film: (a) carbon nanotube film made up of entangled bundles of SWCNTs; (b) thickness of the carbon nanotube film.

2. SWNT THIN FILM SENSOR FABRICATION

Since the discovery of the single-walled carbon nanotube in 1991, researchers have come to understand their unique electrical, chemical and mechanical properties. With optimal properties in mechanical strength, electrical conductivity, and mass density, carbon nanotubes exceed the performance of many current engineering materials. Carbon nanotubes are allotropes of carbon with cylindrical nano structure of length to dia ratio 132,000,000:1. Individually, each carbon nanotube is a graphene sheet rolled to form a cylindrical structure whose diameter can span from 0.7 to 10.0 nm. Moreover, the graphene cylindrical structure provides for the great mechanical strength of SWNT. Many researchers have attempted to determine the mechanical properties of carbon nanotubes. In this study the fabrication of the SWNT-based thin film strain sensor is accomplished using ink jet fabrication method to create a thin film on substrate.

Inkjet Printing Fabrication Method

Ink jet printing (IJP) is one of the most promising techniques for inexpensive large area fabrication of plastic electronics. It is a popular method due to fine and arbitrary generation, non contact injection, solution saving effects, high repeatability and scalability. The advantages of IJP over thin film technique are its patterning capability, efficient use of material, high speed and low cost of the process. Three important parameters that influence the quality of ink jet printing are printer, ink and substrate. CNT patterns are fabricated by simply dispensing/printing the dissolved/dispersed particles on substrates sufficiently thick film is necessary to allow the SWNT strain sensor to be easily handled during fabrication and installation upon structural surfaces. The specific steps taken in the ink jet fabrication method are fully described herein.

Step 1: Carbon nanotubes, copper nanoparticles, PMMA and solvents are acquired from vendors.
Step 2: Two types of ink are prepared of which one is based on carbon nanotubes and the other is based on copper nanoparticles.

Step 3: Printer cartridges are filled with these inks.

Step 4: The strain sensors and wires are patterned with an inkjet desktop printer.

Step 5: Many sensors can be printed on a flexible substrate.

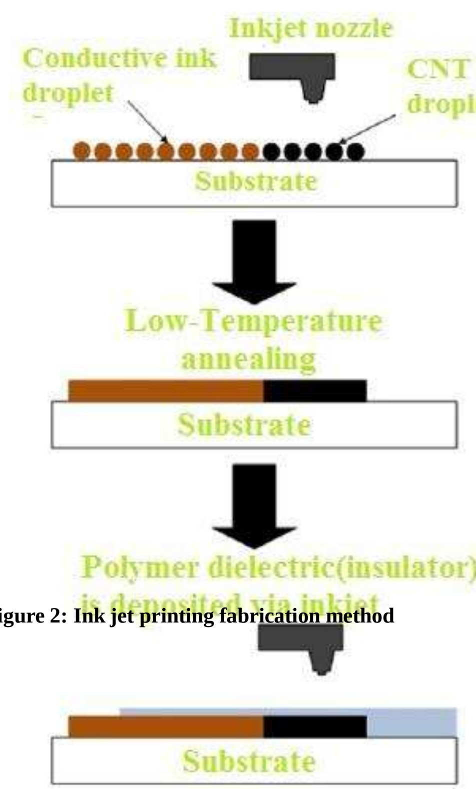

Figure 2: Ink jet printing fabrication method

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3. PROPOSED SOLUTION: PRINTABLE SENSORS

Current commercially available strain gages are based on metallic alloy foils. As the foil is deformed, it causes a change in its electrical resistance. Although reliable, metallic strain gages are not small enough to allow the measurement of load distribution at different points along the bone surface of small lab animals such as mice and rats. Moreover, metallic strain gages have a rather small gage factor which gives them a small sensitivity. Therefore we propose to address these problems by fabricating custom strain sensors based on carbon nanotubes of improved sensitivity, enabling the measurement of strain at different points along the bone or the prosthetic implant. Finally many sensors with high gage factor can be printed on a flexible substrate as shown in figure 3.

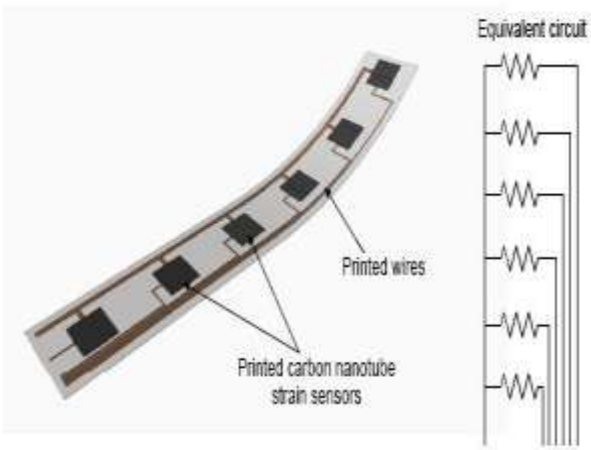

Figure 3: Printable sensors

4. CONCLUSION

In this paper, a simple and low-cost methodology for the fabrication of single walled carbon nanotube (SWNT) strain gage sensor using an ink jet fabrication method is described. The use of carbon nanotubes in the design of strain gage sensors is motivated by impressive mechanical and conductive electrical properties. Ink jet fabrication method is capable of producing thin films of desired thickness; in addition, bulk electrical and mechanical properties of the films can be tailored based on the concentration of SWNT and the type of substrate selected. Fabrication of printable strain gage sensors is used in prosthetic implants and bone biology studies. Furthermore, the sensors can be arranged in arrays enabling the measurement of strain at different points along the bone or the prosthetic implant. Finally, CNT-based strain sensors have better biocompatibility when compared to the metallic gages.

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