Flexible Carbon Nanotube-Based Strain Gage Sensors

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Abstract: Aging brings about dramatic changes in the skeleton and other organ systems. Major skeletal diseases associated with aging include osteoporosis and 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 upwards of 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 likely. 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.

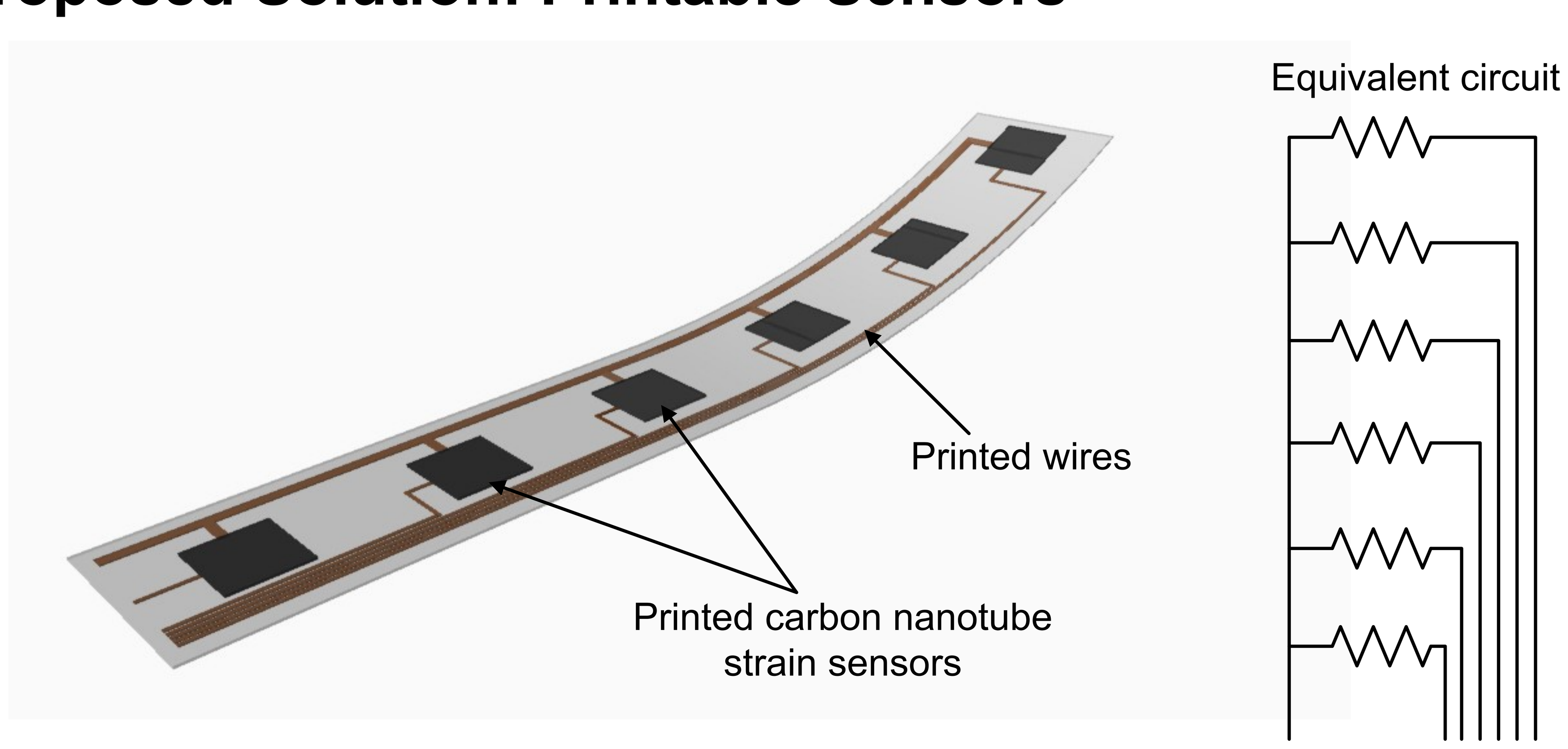
This poster outlines the fabrication of printable strain gage sensors for use in prosthetic implants and bone biology studies. ***The authors have completed the preliminary and feasibility studies and are looking for a partner to fund the project.*** The proposed strain gages are fabricated employing desktop inkjet printers and can be printed on flexible substrates. Special inks based on carbon nanotubes (CNT) and copper nanoparticles are prepared and used in the printing process. The proposed strain gage sensors have several advantages over the conventional metallic alloy gages currently used in biomedical studies. First, CNT-based strain sensors have gage factors of up to 25. In contrast, metallic gages have gage factors of 1.2. The improved gage factors translate into better sensor sensitivity and correspondingly into the detection of 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 in different geometries. 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.

The estimated cost of chemicals and reagents to prepare enough ink to fill several cartridges is around $650. Equipment and lab facilities are available at UMKC. Carbon nanotubes are commercially available from NanoLab Inc. Copper nanoparticles and other chemicals can be acquired from Sigma-Aldrich. A timeline of one year will be needed to fine tune the fabrication process and characterize the strain gages.

Motivation

- 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.
- We propose to address these problems by fabricating custom strain sensors based on carbon nanotubes.
- Carbon nanotube strain sensors with gage factors of up to 25 have been demonstrated. In comparison, the metallic strain gages we currently employed (Vishay SR-4) have a strain factor of 1.2.
- The proposed strain sensors can be made very small, they can be custom made using inexpensive ink-jet printing techniques with resolutions below 50 μm and can be fabricated on flexible substrates.
- Carbon nanotube strain sensors have improved biocompatibility when compared to the metallic gages.
- Besides their use in bone studies and orthopedic implants monitoring, the proposed strain sensors can be employed in building structural health monitoring. A 2D array can be employed to measure the strain distribution on surfaces such as airplane wings.

Proposed Solution: Printable Sensors



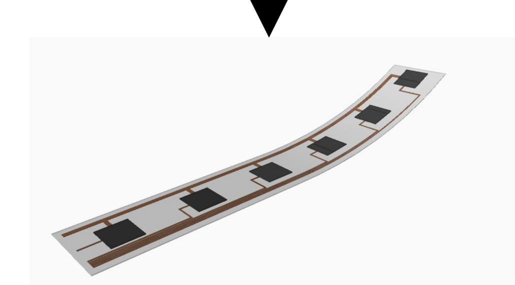
Inkjet Printing Fabrication Method

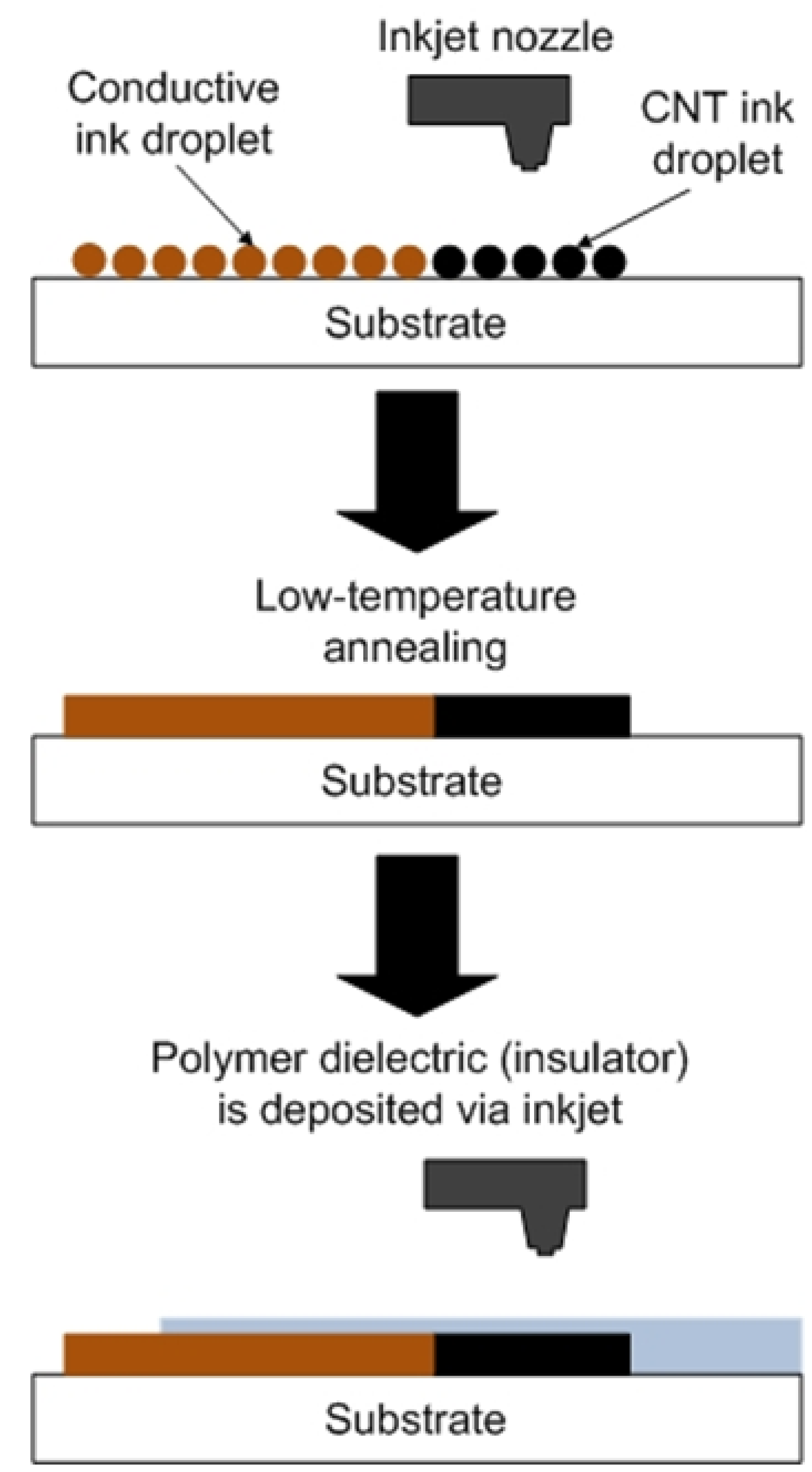
- Carbon nanotubes, copper nanoparticles, PMMA and solvents are acquired from vendors

- Two types of ink are prepared: one based on carbon nanotubes and the other based on copper nanoparticles.
- Printer cartridges are filled with these inks

- The strain sensors and wires are patterned with an inkjet desktop printer

- Many sensors can be printed on a flexible substrate





Fabrication Costs

Item	Vendor/Prod. Number	Price	Comments
Single-wall CNT	NanoLab/PD 15L5-20	$110 for 1gr	95 wt% research grade CNT
PMMA	Sigma Aldrich/200336	$118.0 for 100gr	Polymer matrix
NanoSperce AQ	NanoLab	$15.00 for 10 mL	Dispersant
DMF	Sigma Aldrich/279547	$41.00 for 100 mL	Solvent
Toluene	Sigma Aldrich/650579	$45.00 for 1 L	Solvent for metallic nanoparticles
Copper nanoparticles	Sigma/Aldrich 684007	$146.50 for 25 g	Metallic nanoparticles
Biomedical silicone	Dow Corning/3140 RTV	$100	Coating
Canon PIXMA iP3600	Canon	$79.00	Deskjet printer, 9600 dpi resolution

- The amount of chemicals in the above table will be enough to fill several cartridges. A typical cartridge has a capacity of 42 mL. The Canon printer with 9600 dpi resolution can deposit droplets down to 1 picoliter and print lines below 50 μm.
- The polymethyl methacrylate (PMMA) polymer will be used as the binding matrix material. A suspension of CNT in the solvent dimethyl formamide (DMF) is prepared first with a CNT concentration of 1.0 to 1.5 mg/mL. The suspension is put in a bath sonicator for 24 hours. The PMMA polymer is added to the suspension and mixed using shear force with a Dremel drill at 70 °C for 4 hours. The percentage of the CNT in the polymer mixture determines the gage factor.
- For the creation of the conductive ink, conducting polymers such as a polyacetylene (Sigma-Aldrich 446017) can be used. Another way that results in better conductivity is to use a dispersion of copper nanoparticles (Sigma-Aldrich 684007). Once printed, the metallic ink has to undergo a curing process. Fortunately, the curing temperatures and times are compatible with the CNT curing process. Thus, a single curing process can be used.