

# AN IMPLANTABLE LOW-COST MULTILAYER SCREEN-PRINTED CARBON THICK-FILM STRAIN SENSOR

C.A. Gutierrez, A. Cho, J. Geathers, L. Yu, T. Abram and E. Meng  
University of Southern California, Los Angeles, CA, 90089 USA

## ABSTRACT

We present a rapid low-cost process for fabrication of screen-printed carbon thick-film strain sensors with 0.01-2% strain resolution. The sensors are suitable for implantation and designed specifically for strain or fullness measurements of the skin and bladder, respectively. Thick-film carbon paste sensors are screen-printed using an etched brass screen onto polydimethylsiloxane (PDMS) and encapsulated by a second layer of PDMS. This method can quickly produce multilayered devices by superposition of different screen printable materials. Single strain gauge devices as well as arrayed elements have been fabricated and tested using a latex balloon model of a bladder.

**KEY WORDS:** Carbon Thick-Film, Polydimethylsiloxane (PDMS), Screen Printing, Strain Sensor

## INTRODUCTION

Measurement of strain or fullness is a critical enabling technology in (1) rheological studies of skin expansion which is necessary for tissue regeneration and grafting in burn victims and (2) in detecting the state of the bladder in the neural prosthetic treatment of incontinence. Bone strain measurements were successfully demonstrated *in vivo* [1] with traditional thin-film metal gauges; these, however, are low strain, high stiffness conditions, which are limited to bone only. There is an unmet need for high-strain, flexible sensors which are mechanically matched to tissue. These devices must exhibit long-term implantability, operate passively, and be mechanically robust [2].

We present a rapid low-cost process for fabrication of implantable thick-film carbon based strain sensors. Carbon paste 7082 (Dupont) is selected as a high resistance, strain-responsive material. Carbon thick-films are straightforward to implement in sensors, compatible with established microfabrication techniques, and are inexpensive to process compared to traditional metal thin films. Furthermore, carbon patterns are readily microfabricated on flexible polymer substrates that are mechanically-matched to tissue. Carbon films (15 $\mu$ m) exhibited an average resistivity of 1.5 $\Omega$ ·cm, which is several orders of magnitude greater than metals; this simplifies the design of carbon sensing elements (obviating the need for serpentine structures usually required by thin film metal sensors to achieve appreciable resistances) and results in greatly reduced sensor footprint.

## FABRICATION AND RESULTS

The carbon sensors were patterned by screen printing through an etched brass screen mounted in a custom laser-machined frame. A metal blade squeegee was passed over the screen, pressing the carbon paste through lithographically defined openings in the metal screen onto the underlying substrate (*Fig. 1a*). Feature sizes down to 75 $\mu$ m were successfully patterned using this technique. Five sensor designs having the same basic layout (*Fig. 1b*) were fabricated with unstrained resistances in the range of 5-50k $\Omega$ .

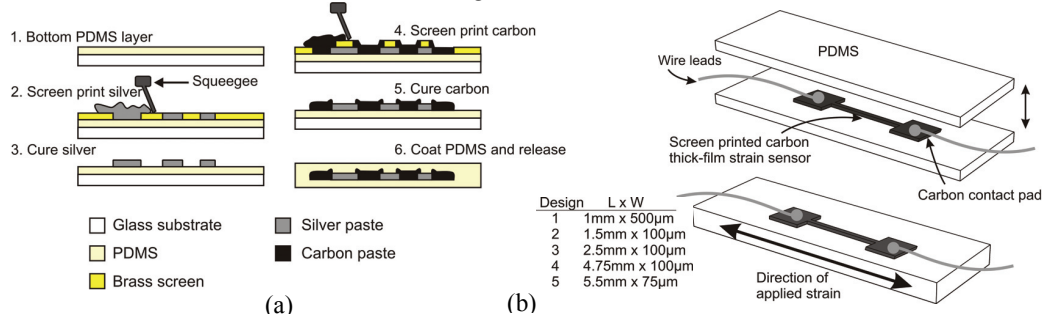


Figure 1: (a) Multilayer fabrication process flow. (b) Single layer carbon strain sensor

A Bose ELF3100 dynamic testing system applied controlled strain while resistance was continuously monitored by a Keithley 2400 multimeter. Sensor performance in low and high strain testing regimes was evaluated (*Fig. 2*). Under low strain, the sensors exhibited a linear response while the high resistance devices exhibiting the highest sensitivity or gauge factor (GF). For the high strain regime, high resistance devices exhibited a non-linear response followed by fracture of the carbon indicated by an open circuit reading. As the strain was reduced, the separated carbon sensor segments were brought back into contact as indicated by a finite resistance reading. Low resistance devices exhibited a linear response up to 2% strain.

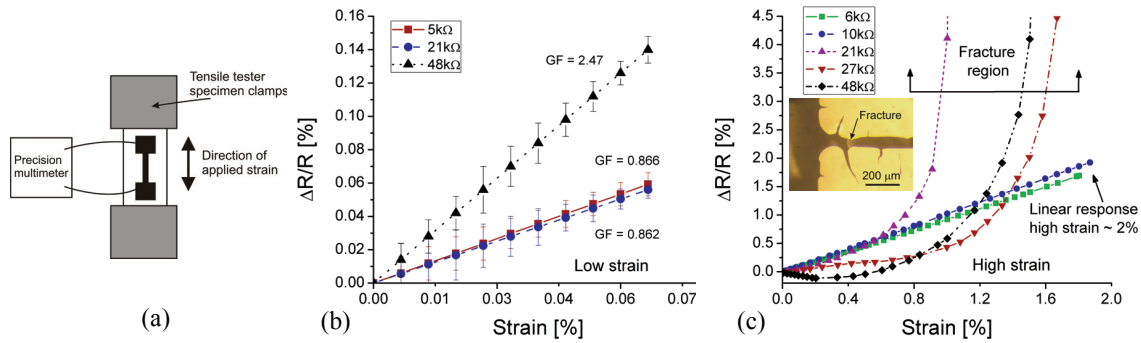


Figure 2: (a) Tensile test setup. (b) Linear response of sensors under low strain,  $\sim 0.01\%$  resolution. (c) Under high strain, high resistance devices fracture; low resistance devices linear up to 2%.

Bladder measurements were performed on a benchtop model consisting of a latex sheet (500 $\mu\text{m}$  thick) fastened into a laser-machined jig (10cm diameter opening). A custom-built air pressure control system inflated/deflated the bladder. Sensors were mounted to the latex surface with a USP Class VI biomedical super glue (Fig. 3).

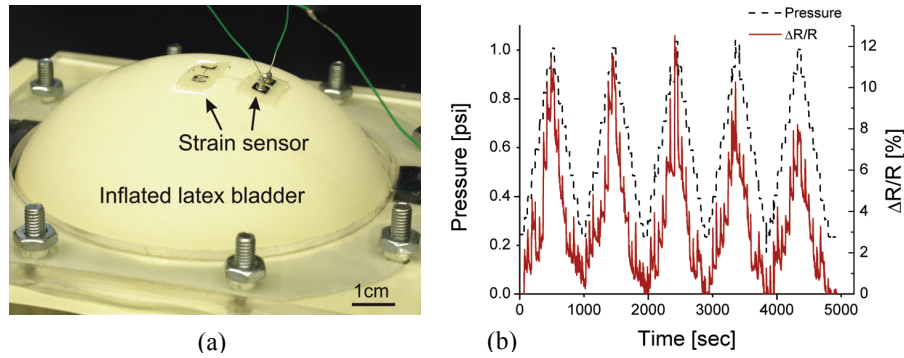


Figure 3: (a) Custom latex bladder setup with sensors attached. (b) Real-time data acquisition on bladder.

Strains of 20-30% on the latex bladder are an order of magnitude above the fracture limit of the sensors but this is mitigated by the dampening of strain experienced by the sensor due to the presence of the mounting glue. These results suggest that bladder measurements are feasible and require an appropriate attachment mechanism with either glue or suturing to preserve sensitivity for *in vivo* applications.

By implementing an additional screen-printing step, a multilayer strain sensing array was fabricated with orthogonally oriented carbon strain elements arranged in a half-bridge floret configuration with silver paste printed leads. The multilayer process limits the high resistance sensing area to the carbon only and enables connectivity without the need for expensive metallization steps (Fig. 4).

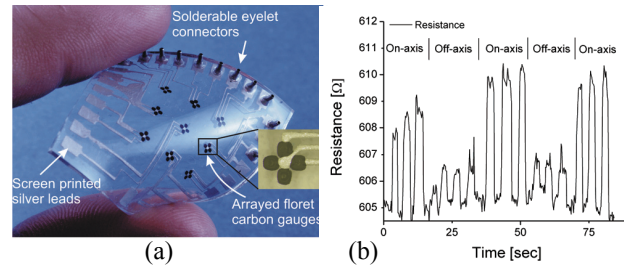


Figure 4: (a) Flexible multilayer array of carbon sensors. (b) On-axis/Off-axis response of one floret strain element.

## CONCLUSIONS

Simple, robust, low-cost carbon-based sensors were fabricated, tested and shown to be effective in measuring bladder fullness and strain. The process can be extended to include multilayer devices for arrayed applications. Work is underway for implantable *in vivo* bladder fullness measurements to complement neural prosthetic restoration of bladder function.

## REFERENCES

- [1] J. A. Szivek and F. P. Magee, "A Long-Term In Vivo Bone Strain Measurement Device," *Journal of Investigative Surgery*, vol. 2, pp. 195-206, 1989.
- [2] A. Prochazka, V. K. Mushahwar, and D. B. McCreery, "Neural prostheses," *The Journal of Physiology*, vol. 533, pp. 99-109, 2001.