

AUTONOMIC RESTORATION OF CONDUCTIVITY IN DAMAGED SILVER PARTICLE CIRCUITS

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Keywords: Self-healing, microcapsule, circuit

ABSTRACT

Fault-tolerant electronic circuits are relevant for electronic applications in which regular human intervention is not possible or is costly. The ability to autonomically restore function to damaged electronic components could allow for fewer repairs and replacements of circuit materials. Our recent efforts toward producing self-healing circuits initially focused on delivering suspensions of conductive materials to sites of electrical damage from core-shell microcapsules. Our initial studies included microcapsules containing suspensions of carbon nanotubes[1] and solutions of precursors to a conductive charge transfer salt.[2] In these cases, rupture of core-shell microcapsules delivers conductive particles, which partially restore conductivity to gold lines with gaps of 5 – 100 microns.

Our present work focuses on healing circuits comprised of metallic particles housed in a polymer binder. Our circuits are specifically made of silver particles (<20 microns) encased in an acrylic polymer that is soluble in common organic solvents. For scratch testing, three circuits are painted onto an acrylic substrate, and a layer of hexyl acetate-containing microcapsules encased in a polyurethane elastomer is cured on top using a PDMS mold.

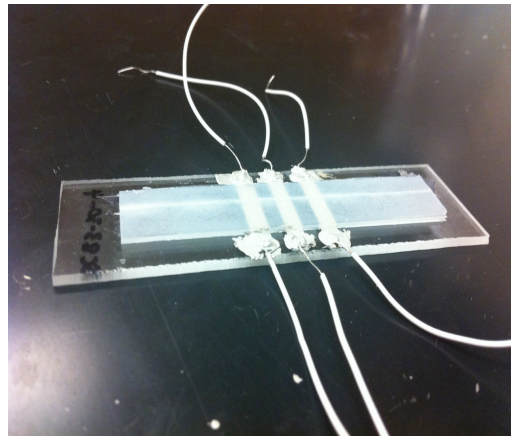


Figure 1. A silver particle circuit after scratch test.

We tested samples using scratch damage and have explored mechanical cracking with a 4-point bend set-up. The conductive metal in each specimen acts as one resistor in an unbalanced constant voltage Wheatstone Bridge circuit. The voltage source is a BK Precision DC Power Supply (model 1710). The voltage gauge and voltage source are monitored either by LabVIEW DAQ or a digital oscilloscope (LeCroy LC584A). Scratch damage was applied using a Corrocutter with razor blades at forces ranging from 28-30 N.

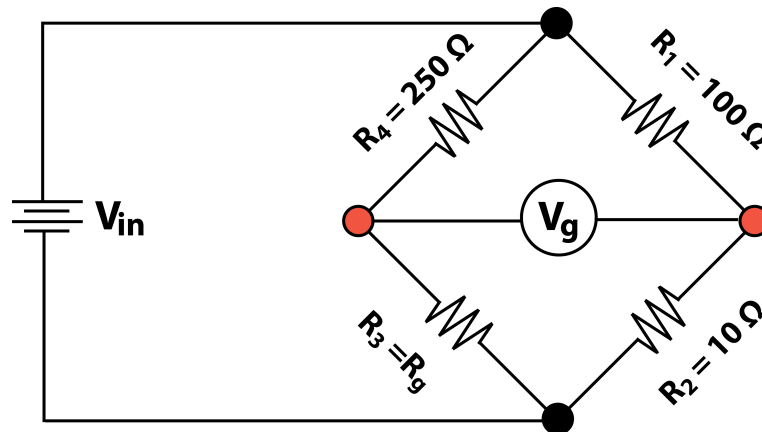


Figure 2. Wheatstone bridge set-up for measuring electrical healing.

To date we have demonstrated the autonomic restoration of conductivity of mechanically damaged silver particle circuits using hexyl acetate-filled poly(urea-formaldehyde) microcapsules. Upon circuit failure by scratch or crack damage, microcapsules are ruptured, releasing the healing solvent to the damage size. The solvent locally dissolves the circuit's polymer binder, allowing the silver particles to redistribute in the damaged area, thus restoring the electrical conductivity of the circuit. Electrical healing begins within minutes of initial damage.

The healed circuits were sliced in half perpendicular to the direction in which the scratch was applied. Cross-sectional images were obtained using optical microscopy and scanning electron microscopy (SEM). By optical microscopy, the scratch damage is evident as a slice through the polyurethane layer that extends through the silver particle layer. Displacement of the silver particles is observed. SEM analysis also shows that the scratch extended through the silver circuit into the underlying acrylic substrate. Elemental mapping of silver shows where the silver circuit is within the cross-sectional image.

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