Ultrasoft Multifunctional Nanocomposites for Wearable Electronics

Oliver Tomes, Han Zhang, Emiliano Bilotti, Mufeng Liu, Dimitrios G. Papageorgiou

Introduction

There is a growing demand for flexible and soft electronic devices for use in advanced applications. In this work, highly stretchable elastomer nanocomposites are synthesised for wearable electronics. A three-roll mill was used to disperse reduced graphene oxide (rGO) in a silicone rubber (SR) matrix. Electrical percolation was achieved at low loadings (Fig. 1b), facilitating a multitude of high-end functionalities for SR/rGO films, including strain sensing capabilities with favourable sensitivities over large working ranges. Finally, a new model is presented which allows for accurate calibration of these and other similar strain sensing materials over the entire conducting strain range.

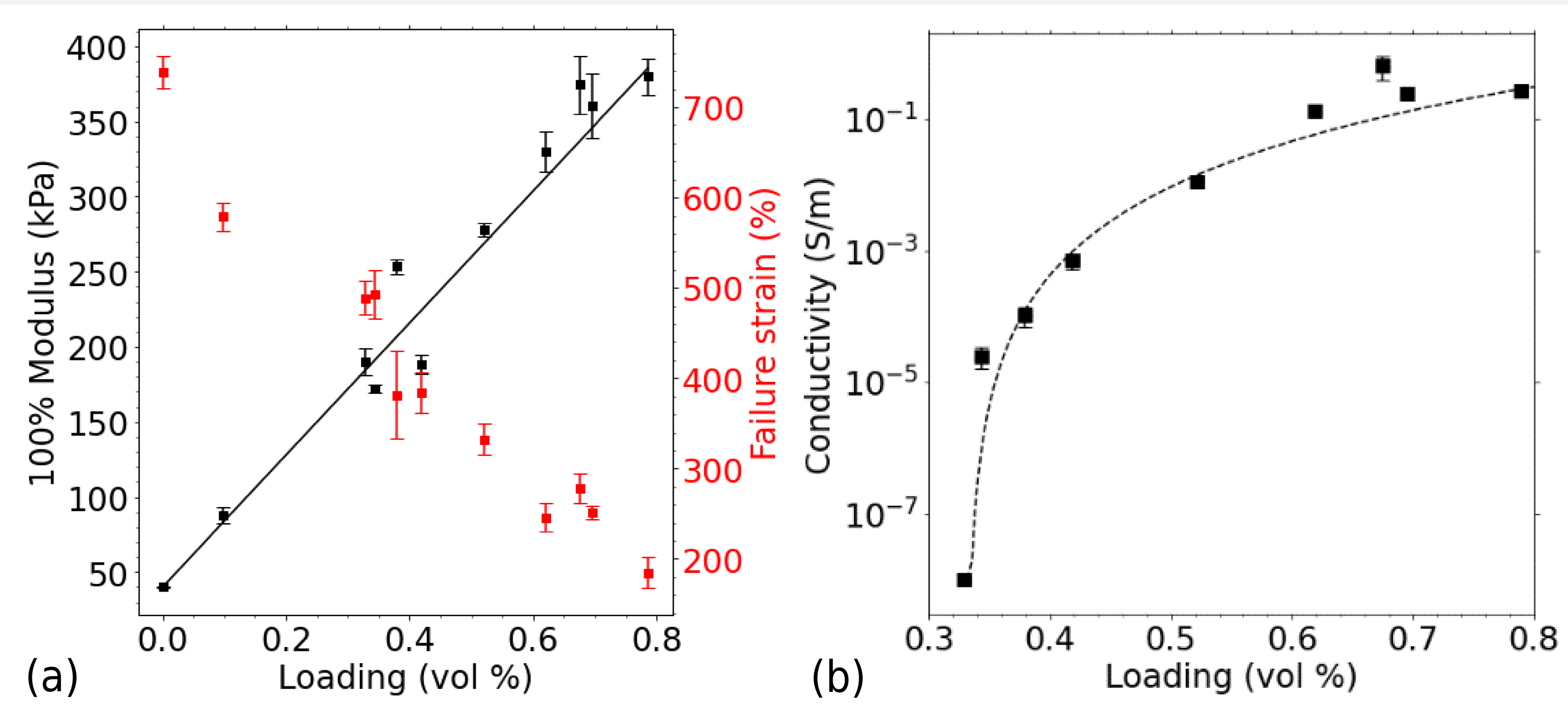

Fig. 1. SR/rGO nanocomposites. (a) 100% modulus (black) and strain at break (red). (b) Electrical conductivity displaying percolation at 0.33 vol %.

Wide-ranging applications

- Repeatable strain sensing for e.g. joint movement or pulse monitoring from comfortable skin-mountable device (stiffness 0.17 – 0.38 MPa similar to that of human skin 0.08 – 0.60 MPa) (Fig. 2a,b).
- Heated wearable devices for regulation of body temperature. Temperature can be controlled via application of DC voltage (5-10V 29-40ºC) (Fig. 2c).
- SR/rGO can also provide shielding from electromagnetic radiation where typically rigid metals would be used. 1mm blocks 92% of X-band radiation (11dB shielding effectiveness) (Fig. 2d).

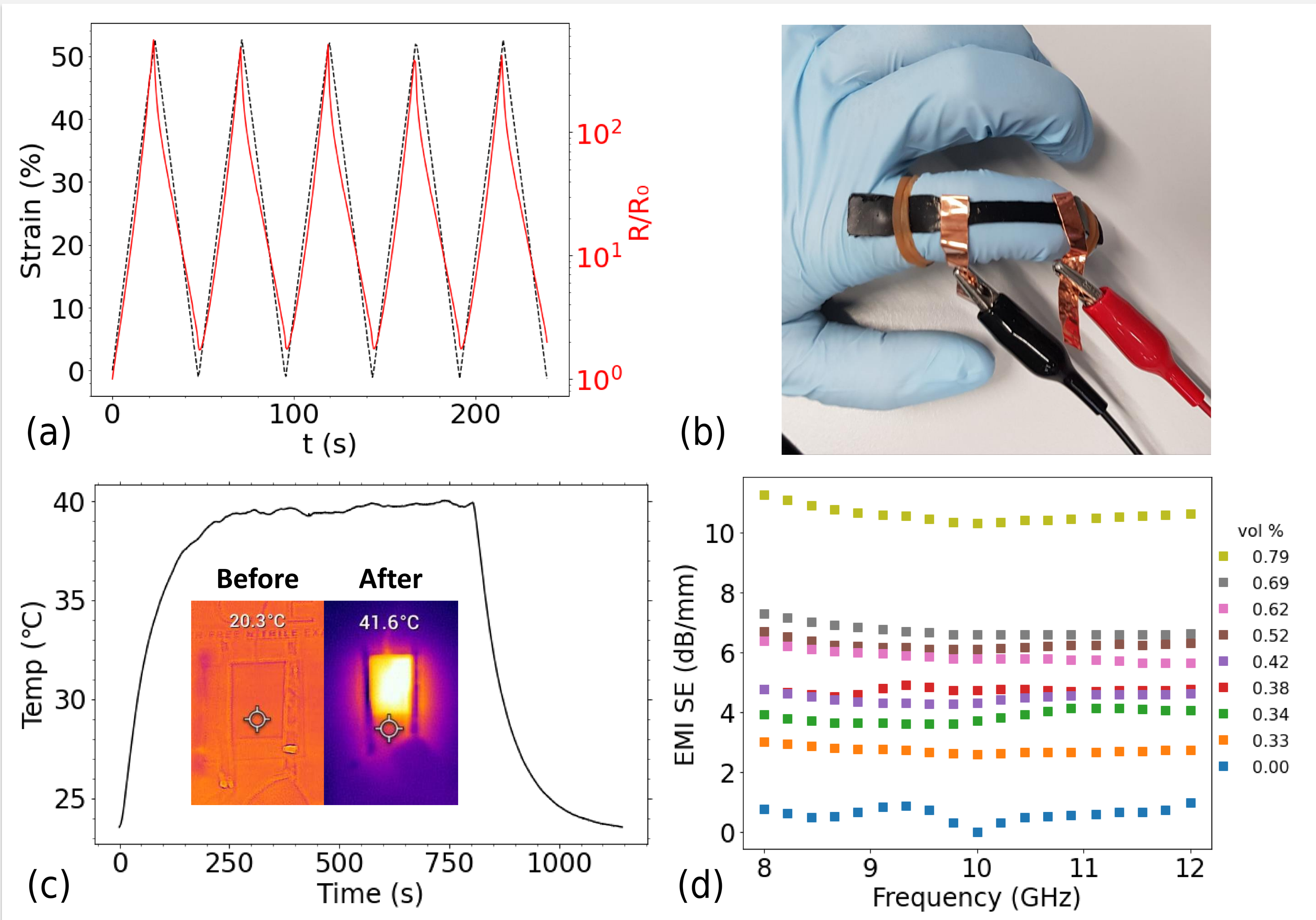

Fig. 2. Multifunctional properties. (a) Cyclic strain sensing. (b) Wearable strain sensor measuring repeated finger bending. (c) Joule heating at 10V. (d) EMI shielding.

Stretching sensing capabilities

- SR/rGO films can remain conductive up to 240% strain (metals/silicon <5%).
- We have designed the *depercolation model* which can accurately predict resistance changes with increasing strain ($r^2 \geq 99.5\%$) over the whole conducting strain range.
- Using two well defined parameters, we can maximise the sensing range of this and other highly stretchable strain sensors via a non-linear calibration.

Depercolation model

$$\frac{R}{R_0} = \frac{e^{G_d \varepsilon}}{1 - \frac{\varepsilon}{\varepsilon_d}}$$

G_d - Tunneling sensitivity

ε_d - Depercolation strain

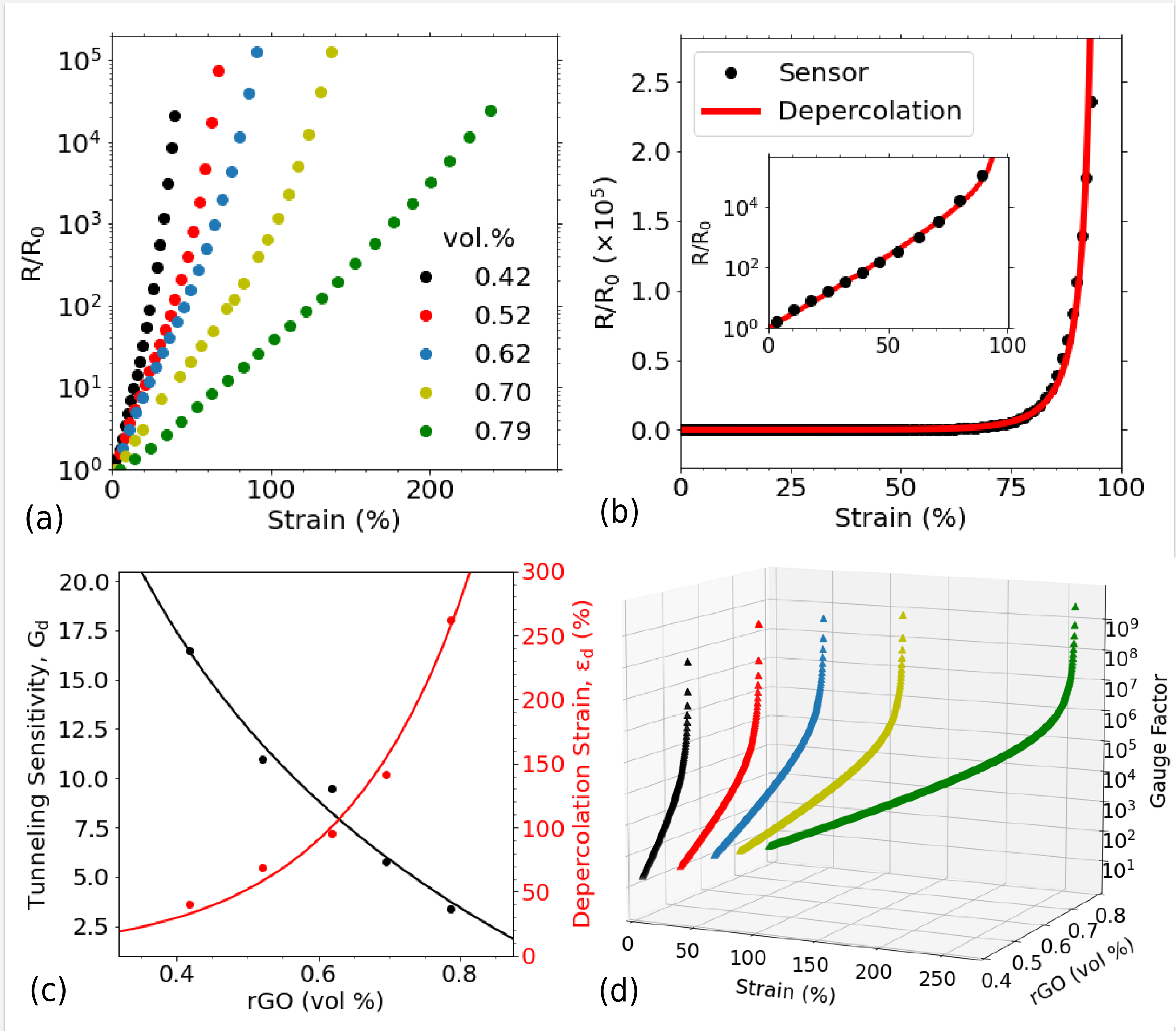

Fig. 3. Strain sensing. (a) Resistance variation of SR/rGO films under tensile strain. (b) Calibration using the depercolation model. (c) Depercolation model parameters for SR/rGO strain sensors. (d) Gauge factor of SR/rGO strain sensors as a function of strain, as predicted by the depercolation model.

- Using Simmons tunneling theory, we can predict that the tunneling sensitivity is determined by the potential barrier between filler and polymer (γ), distance between fillers at zero strain (s_0), and changes in network connectivity (ε_d).

$$G_d = \gamma s_0 - \frac{1}{\varepsilon_d} + 1$$

- Given this new model, factors such as filler dimensions, filler orientation and dispersion quality, and their effect on sensitivity and working range can thus be explored in the context of interparticle distance modelling.

Conclusions

Highly stretchable ultrasoft nanocomposites have been fabricated exhibiting multifunctional properties, including impressive strain sensing performance, ideal for applications in wearable devices, health monitoring and soft robotics. A new model has been developed, capable of accurately calibrating over the entire electromechanical response of the material. This model can be used to maximise sensing ranges for similar nanocomposite systems, as well as to improve our understanding and our ability to engineer for better strain sensing properties.

Queen Mary University of London
Oliver Tomes
Postgraduate researcher in Materials Science
QMUL SEMS, Mile End Rd, London E1 4NS, UK

E-mail: o.tomes@qmul.ac.uk
Phone: +44 207 882 87 70
Web: sems.qmul.ac.uk

Queen Mary University of London