DOI: http://doi.org/10.21698/simi.2026.ab04

CARBON NANO-ONION/POLYVINYLPYRROLIDONE FILMS ON FLEXIBLE SUBSTRATES: THERMISTOR PARAMETERS AND PERCOLATION-BASED DESIGN RULES FOR TEMPERATURE SENSING

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Keywords: *carbon nano-onions, flexible substrates, percolation, polyvinylpyrrolidone, temperature sensing*

Introduction

Flexible resistive temperature sensors depend on stable conductive pathways within the sensing film; nanocarbon/polymer composites allow that network to be tuned through filler content. Carbon nano-onions (CNOs) [1] are attractive fillers: inkjet-printed pristine CNO has a temperature coefficient of resistance (TCR) of −0.90 %/°C [5].

We previously reported the percolation threshold and TCR of CNO/polyvinylpyrrolidone (PVP) films [2]. *This communication reports no new measurements.* Its new elements are (i) conversion of the reported TCR into standard thermistor parameters, with benchmarking, (ii) a percolation-based rule for selecting the filler loading, and (iii) a humidity-induced temperature error budget, which together go beyond the measurements in [2] and support the patented flexible-device design.

Materials and methods

PVP (10 mg) is dissolved in 15 mL dimethylformamide by ultrasonication (30 min, 42 kHz) and CNO (2.5 mg) is dispersed for 6 h (20 wt% CNO). The dispersion is drop cast onto Kapton with gold linear or interdigitated electrodes, heated at 80 °C under vacuum for 2 h and then dried at 100 °C for 4 h. Films with 2–95 wt% CNO were characterized by SEM, Raman spectroscopy and room-temperature resistance, and films with 25–85 wt% CNO by heating/cooling between 25 and 150 °C, using R_T/R_{25} [2].

Data sources and derived quantities. Experimental values (Table 1, source [2]) were reported in [2] and the related patent application and are reproduced only for completeness. The quantities marked "this work" are new: $B_{25} = -\alpha T_0^2$ and $E_a = k_B B_{25}$ (T_0 = 298.15 K); loading sensitivity $d \ln\sigma/d\varphi = t/(\varphi - \varphi_c)$ from $\sigma \propto (\varphi - \varphi_c)^t$, with $t \approx 2$ [4]; humidity-induced temperature error $\delta T = (\Delta R/R)_{RH}/|\alpha|$.

Results and conclusions

Benchmarking. $|\alpha|$ of CNO/PVP (Table 1) is 2.7 times that of platinum and ≈17 % larger than that of printed pristine CNO [5], so the PVP matrix preserves the NTC behaviour of the CNO network while providing a flexible binder. $E_a \approx 0.08$ eV is consistent with thermally assisted inter-particle transport; $B_{25} \approx 930$ K is below the few-thousand-kelvin values of oxide NTC thermistors.

Table 1 - Reported and newly derived parameters of CNO/PVP films

Parameter	Value	Source
Percolation threshold φ_c	≈ 20 wt% CNO	[2]
TCR α, linear interval 25–50 °C	$\approx -1.05 \times 10^{-2}$ K^{-1}	[2]
R_{50}/R_{25} (linear model)	0.74	this work
B_{25}; E_a	≈ 930 K; ≈ 0.08 eV	this work
$\lvert\alpha\rvert$ / α_{Pt} (3.85×10^{-3} K^{-1})	≈ 2.7	this work
d lnσ/dφ at 25 / 50 / 75 wt%	0.40 / 0.067 / 0.036	this work
δT per 1 % RH-induced $\Delta R/R$	≈ 0.95 K	this work

Filler-loading rule. Near φ_c the baseline is highly sensitive to dosing errors: a ±1 wt% deviation changes σ by ≈ ±40 % at 25 wt%, but only ≈ ±7 % at 50 wt% and ≈ ±4 % at 75 wt% (weight used as a proxy for volume fraction). Loadings of 50–75 wt% CNO thus give reproducible baselines; the near-threshold 20 wt% film is unsuitable as a thermistor.

Linearity and humidity. An activated model with the same B_{25} predicts $R_{50}/R_{25} = 0.785$ instead of 0.74; the 4.7 % (≈ 4.5 K) gap at 50 °C means the linear calibration must not be extended beyond 25–50 °C without refitting. Because hydrophilic PVP absorbs water [3], every 1 % of humidity-induced $\Delta R/R$ reads as ≈ 0.95 K, so encapsulation or RH compensation is required for ±0.5 K accuracy.

The new contribution is the thermistor-level interpretation and the design rules, identifying 50–75 wt% CNO and humidity compensation as targets for the next experimental series.

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