

# Low-impedance tissue device interface using homogeneously conductive hydrogels chemically bonded to stretchable bioelectronics

## Authorship

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## Intro

Young's Modulus ( $E$ )  
hydrogels (hagels)  
impedance ( $Z$ )

Most stretchable devices developed have high  $E$ ; high  $E$  likely means microscale nonconformal contact, which leads to higher impedance

Hydrogels are promising, but there are many issues like electrical performance, material homogeneity, and integration reliability

We want hagel that has low impedance, appropriate  $E$ , and high conductivity

## Results (1)

PEDOT:PSS (PP)  
polyacrylamide (PAAm)  
polyaniline (PANI)  
polyurethane (PU)

## 2 strategies:

- 1) incorporating low conc PEDOT:PSS into PAAm hagel, then decorating with PANi; inside elastomeric PU well and connected to stretchable Cr/Au/Ti electrode
- 2) adhesion between hagel and stretchable device by modifying PU well w/ chemical anchoring groups

## Resulting hagel:

- conductivity in between metal filler hagels and polymer hagels
- very low impedance and  $E$  (desireable for tissue)

There are generally two types of hagels: metal filled and polymer-based. Both of these have tradeoffs in terms of  $E$ ,  $Z$ , and conductivity. This paper tries to create a mix of the two

Results (2)	PAAm has good E, but bad conductivity; mixing it w/ conducting fillers usually leads to poor homogeneity <i>low conc.</i>
PEDOT:PSS - PAAm ↳ 2-mode gel	In PEDOT:PSS - PAAm gel, PEDOT:PSS particles dispersed thru PAAm
PEDOT:PSS - PANi - PAAm ↳ 3-mode gel	Adding PANi to composite establishes 3D conducting pathways in gel matrix homogeneous PEDOT:PSS dispersion maintained at 3.3% wt; jumps from 20 mS/cm to ~24 S/cm w/ PANi functionalization
	Fig 2D-F: 3-mode composite shows much lower and more consistent impedance spectrum across pH; frequency, but higher E than the 2-mode gel ↓ Fig S4
	low impedance PANi achieved/saturates when precursor ratio of aniline (mL)/acrylamide (g) is greater than .5 - saturates at ~1.5 → molecular interactions
	2 conducting mechanisms of 3-mode gel: 1) HCl in aniline solution leads to secondary doping of PP 2) PANi molecules are synthesized along doped PP network
The gel uses PP, PAAm, and PANi. The gel shows a very consistent impedance across frequencies and relatively lower impedance at higher pHs.	

<p>Results (3)</p> <p>X-ray photoelectron spectroscopy (XPS)</p> <p>conductivity (<math>\kappa</math>)</p>	<p>secondary doping - adding additional dopants into material that's already been doped</p> <p>phase separation between PEDOT : PSS; PEDOT benzoid state changes to quinoid state <math>\rightarrow</math> 3D fibrous structures  <math>\hookrightarrow</math> more conductive</p> <p>PANI forms uniform layer along 3D PP quinoid structures due to <math>\pi-\pi</math> and coulombic interactions  <math>\rightarrow</math> less PSS to act as insulating shell</p> <p>impedance of 3-mode hydrogel at higher pHs significantly lower than 2-mode (<math>157\ \Omega</math> vs <math>\sim 620\ \Omega</math>)</p> <p>from 0-300% stretching range, 3-mode resistance increased by <math>\sim 39\%</math></p> <p>hydrogel would need to be covered w/ encapsulation layer to prevent dehydration  <math>\hookrightarrow</math> leads to <math>E \uparrow</math>, stretchability <math>\uparrow</math>, and <math>K \uparrow</math></p>
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The HCl in the aniline soln leads to secondary doping of the PP, which changes its state. The quinoid state creates a sort of scaffold for the PANI to go along with. This results in relatively homogeneous 3D conductive pathways in the hydrogel matrix.

Results (4)	<p>TMSPMA treatment to anchor hydrogel to PU well; much better interfacial toughness      ↳ energy needed to propagate a crack</p>
	<p>TA treatment to further increase interfacial toughness</p> <p>Fab for stretchable bioelectronics: Si/SiO<sub>2</sub> wafer → Au patterning      → epoxy → PI isolation → attach tapes/films → laser cutting      → remove → spray mold release agent</p> <p>cell viability tests went well</p> <p>impedance relatively stable on live rat skin with regular skin, mild burn, and severe burn</p>
Discussion	<p>3-mode gel to increase conductivity, lower impedance, and lower E</p> <p>Various treatment methods to increase adhesion</p>

There were further treatments w/ TMSPMA to the PU well and TA to the hydrogel to improve adhesion properties. The resulting product is biocompatible multi-channel sensor array for Z and pH measurement in vivo/vitro