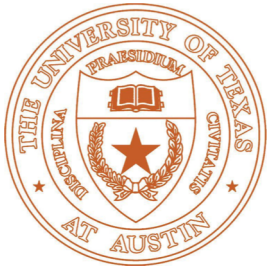


EE 396V | Graphene Electronic Tattoos and Biosensor Applications

Thomas Plantin & Naiqiao Yang

10/21/19

EE 396V | Overview

What are GETs (Graphene Electronic Tattoos)?

How GETs are made

Mechanical Properties - Design for optimum stretchability

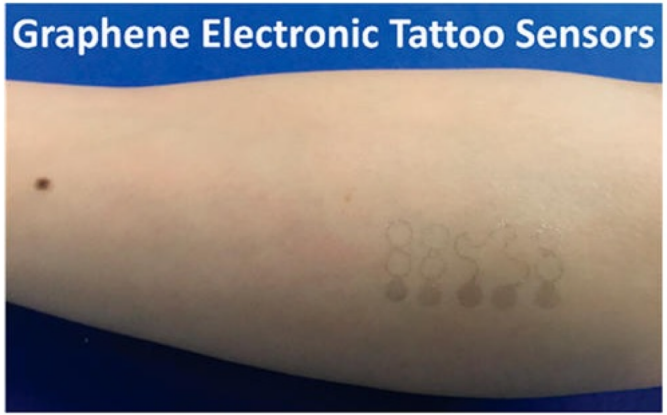
Key potential applications

Comparison with commercial gel electrodes

Conclusion

EE 396V | What are GETs (Graphene Electronic Tattoos)?

- Electronic tattoos made of graphene and used as biosensors.
- Some applications include:
  - Electrophysiological sensor.
  - Resistance Temperature detector.
  - Skin Hydration sensor.



EE 396V | How GET (Graphene Electronic Tattoos) are made

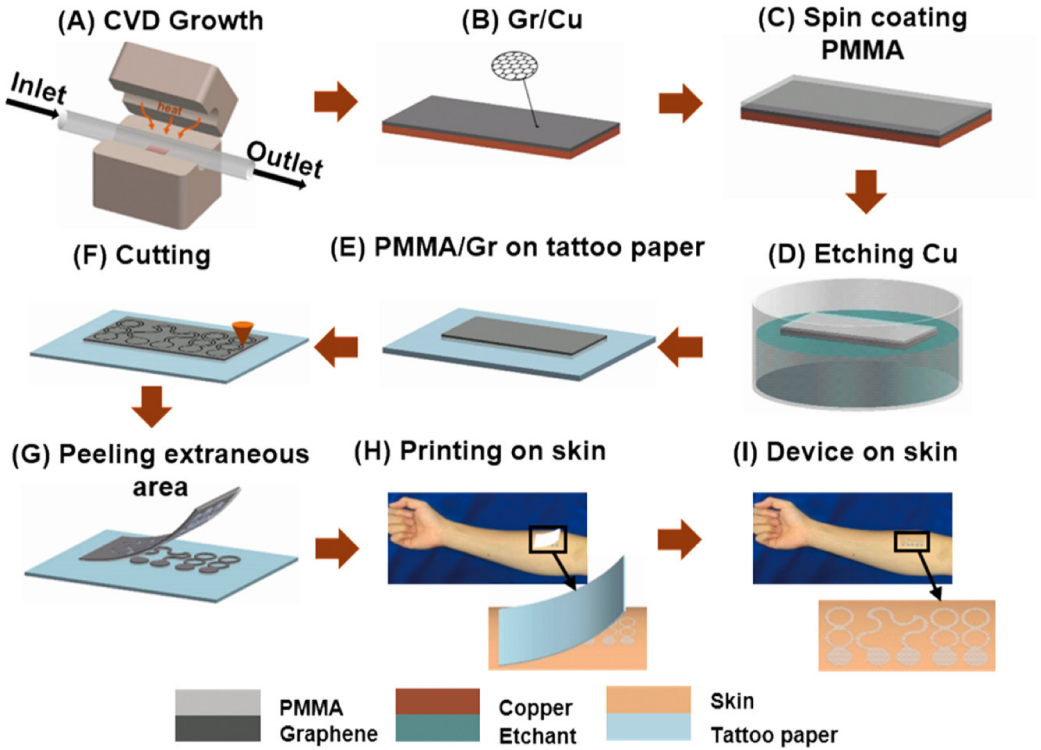
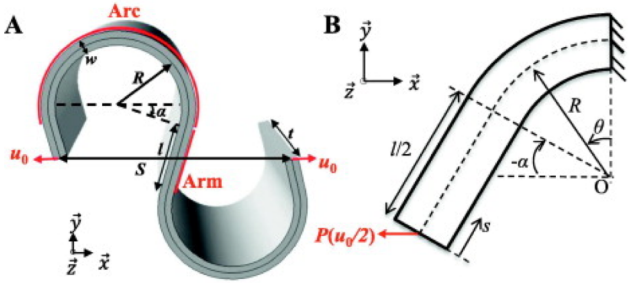
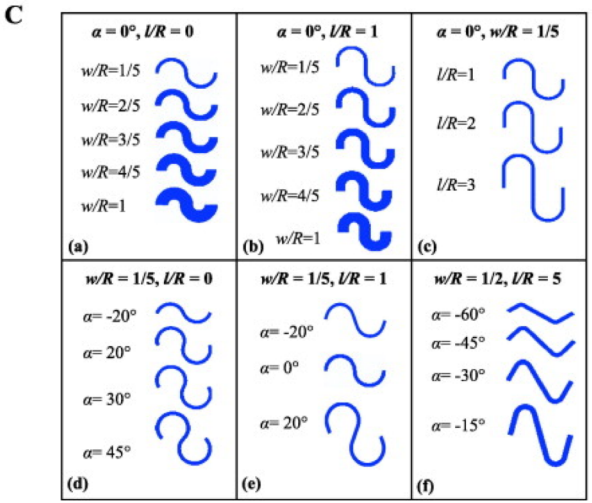


Figure 1: GETs are manufactured by a low-cost "wet transfer, dry patterning" process on tattoo paper.



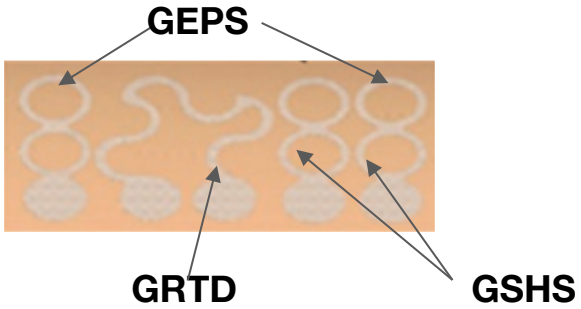


Optimum stretchability when:

Small w/R

Large l/R

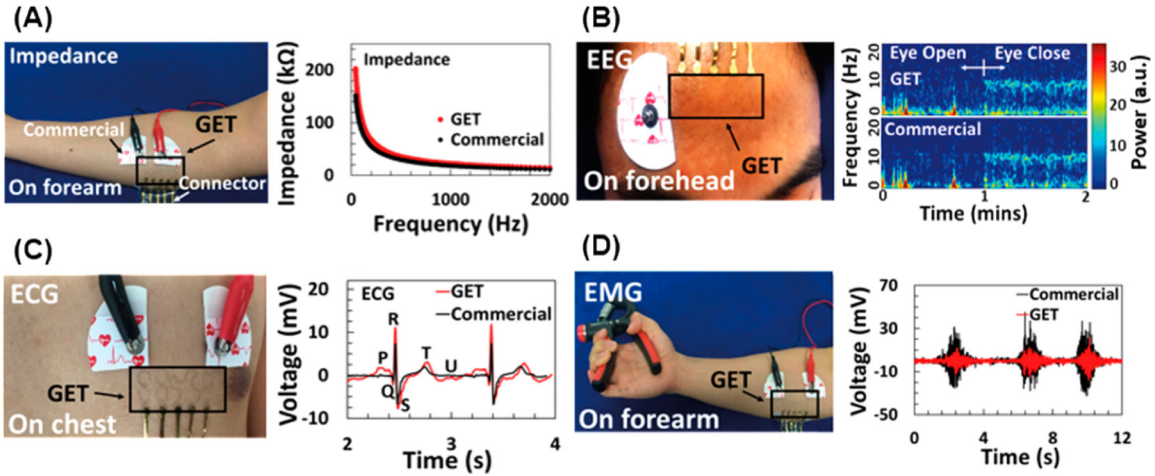
Large α



EE 396V | Why Graphene?

- Intimate sensor-skin integration
- Optically imperceptible
- Mechanically robust
- Electrochemically stable
- ...

- **GET electrodes**



Electrical performance of GET vs Ag/AgCl gel -skin interface

Classical electrical circuit concept suggest that the electrode-skin interface impedance is inversely proportional to the contact surface area.

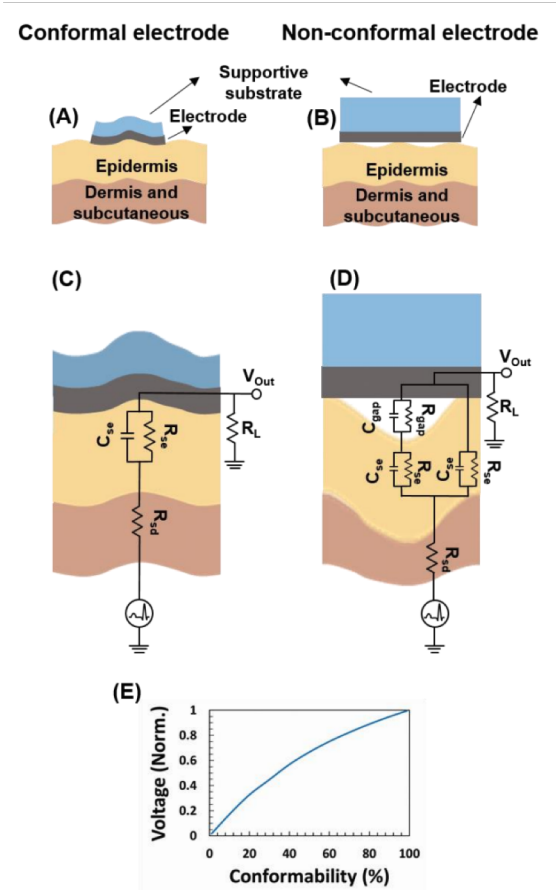
Low contact impedance is essential for a high SNR in electrophysiological measurements.

Higher surface charge density and surface electric displacement field of graphene results in more efficient capturing of electrical potential, and thus higher SNR.

EE 396V | Key applications

- **More on GET electrodes**

Circuit models and simulations for conformal and non-conformal electrodes.



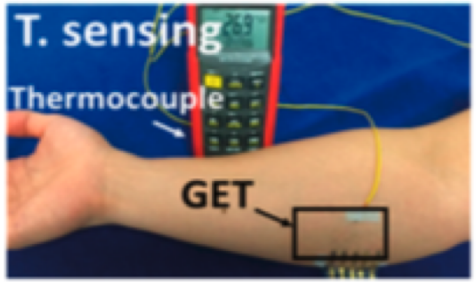
- **Resistance temperature detector(RTD)**

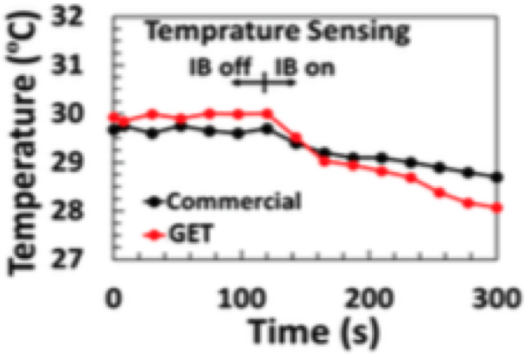
$$\frac{\Delta R}{R_0} = \alpha \Delta T$$

For a given temperature change, a large ΔR requires a large R_0.

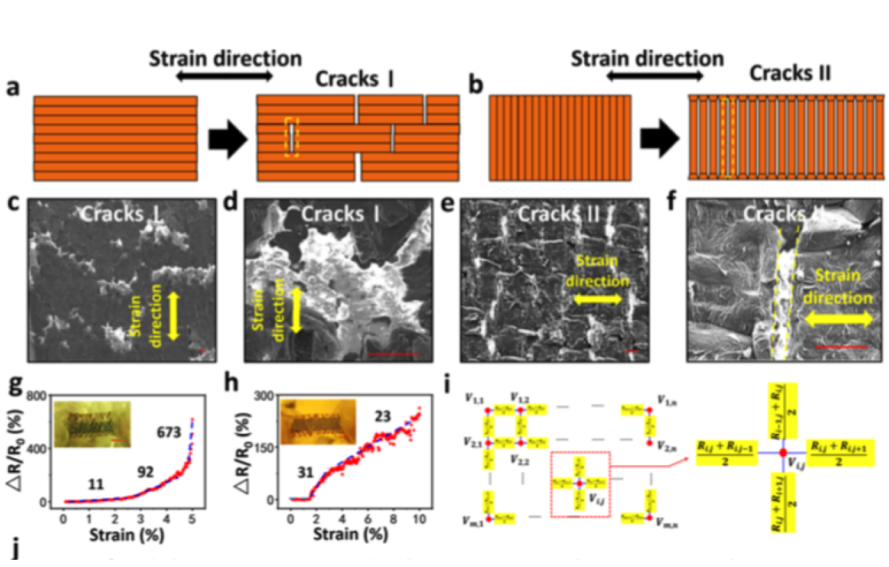
Since metal in general have lower resistivity. A large R_0 requires longer metal wire.

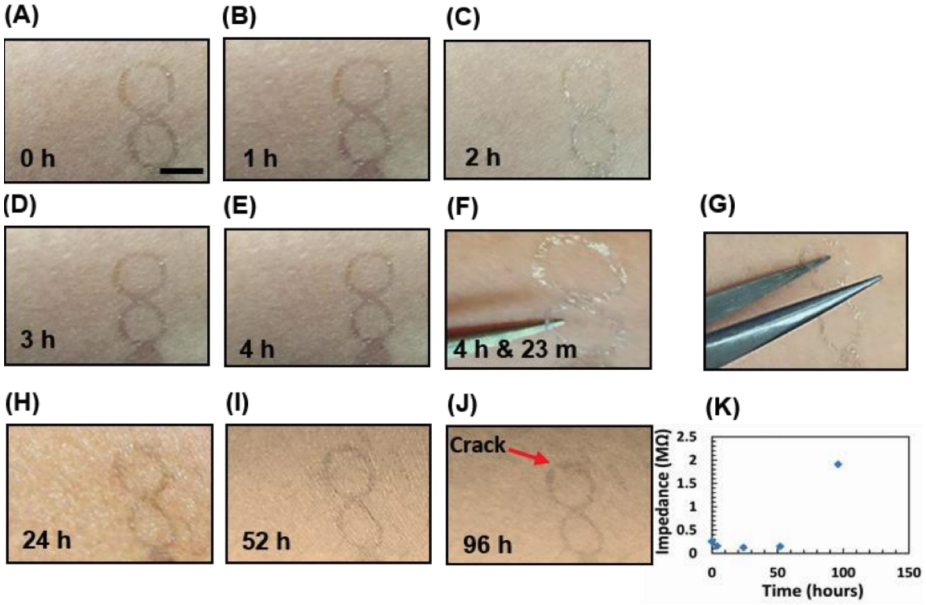
Graphene has a sheet resistance of ~2kΩ and RTD can be shorter in length and smaller in size.





- **Durability**

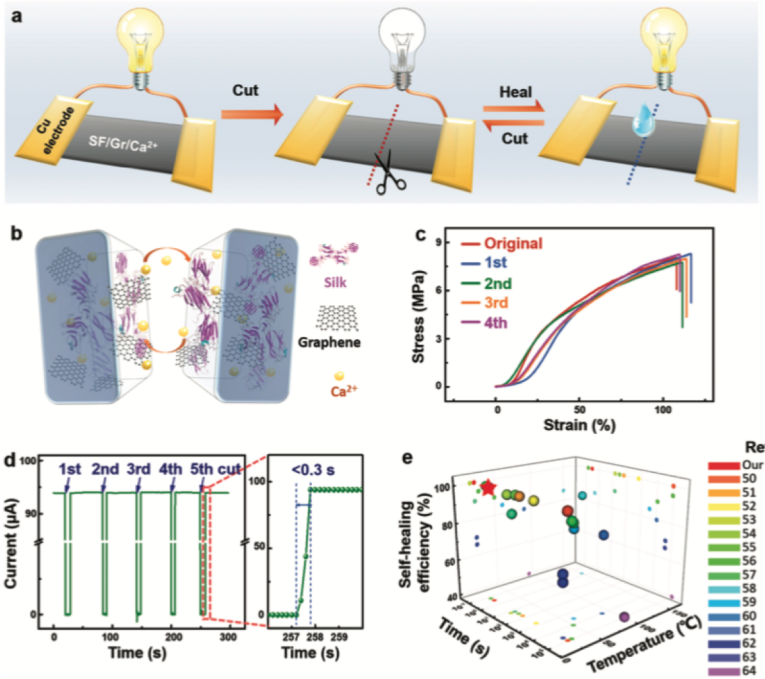




Reference: Multilayer Graphene Epidermal Electronic Skin

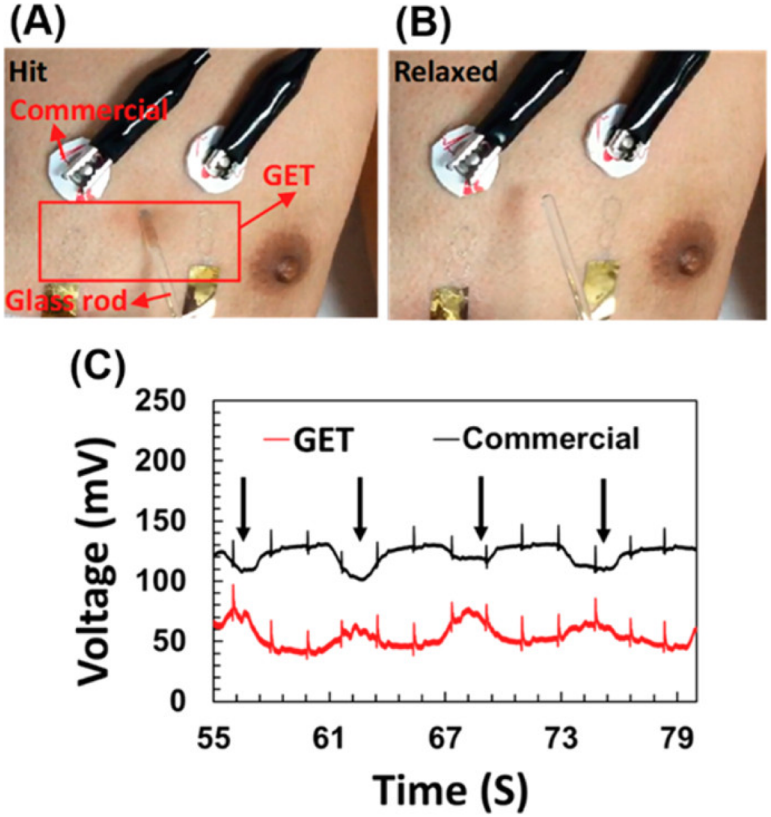
EE 396V | Some recent researches

- Self-healable E-tattoo by incorporating graphene with Silk Fibroin(SF)/Ca^{2+} films.
- Water molecules swell up SF chains and viscoelasticity of the film increased, leading to physical fusing of two parts.
- Intrinsic hydrogen bonds and coordination bonds between Ca^{2+} and -COO-.

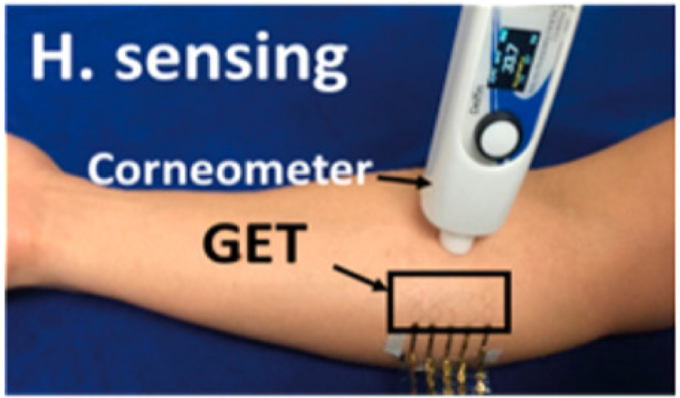


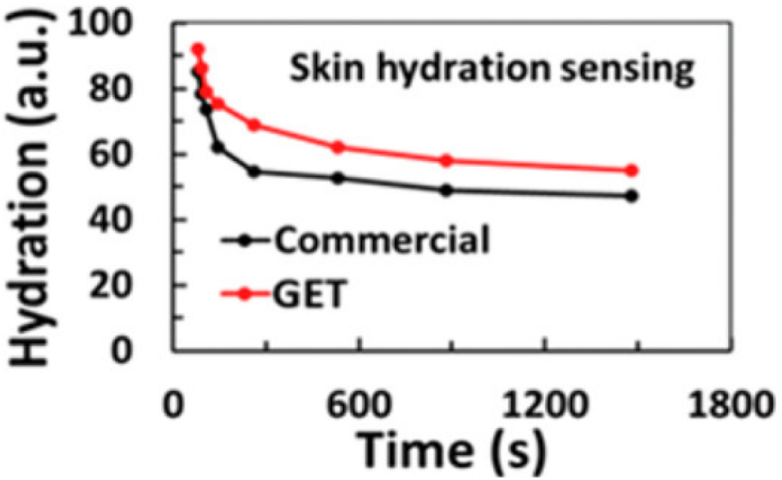
Reference: Self-Healable Multifunctional Electronic Tattoos Based on Silk and Graphene

EE 396V | Comparison with commercial gel electrodes



EE 396V | Comparison with commercial gel electrodes





EE 396V | Conclusion

- As tattoo-like wearable skin hydration and temperature sensors, the GET has been validated by state of the art gold standards.
- It is believed that the GET has opened a door for two-dimensional materials to be applied in biosensing electronic tattoos, as well as many other applications.
- Challenges include increasing the durability of GETs, as they currently last up to 90-100 hours.
- Some recent researches proposed self-healable E-tattoo as a promising candidate for bio-sensing.

EE 396V | References

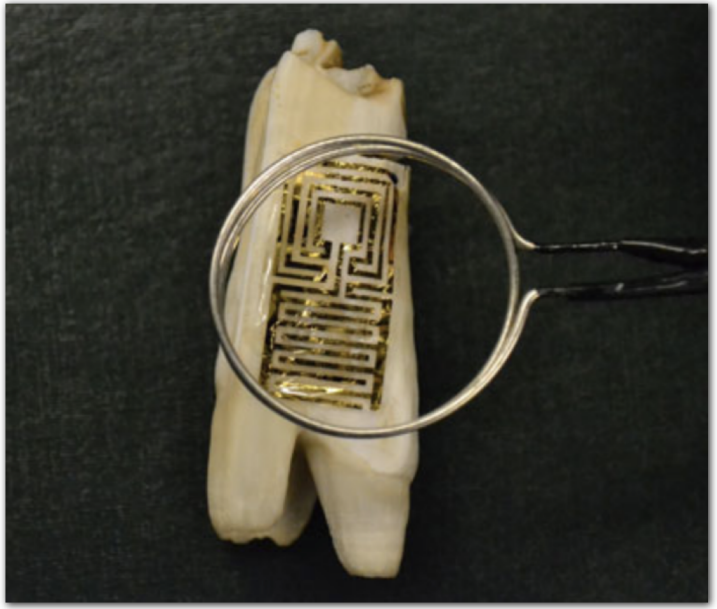
- [1] Ameri, S. K.; Ho R.; Jang, H.; Tao, L.; Wang, Y.; Wang, L.; Schnyer, D. M.; Akinwande, D.; Lu, N. “Graphene Electronic Tattoo Sensors” *ACS Nano*, vol. 11, no. 8, July 18, 2017. [Online]. Available: https://pubs.acs.org/doi/10.1021/acsnano.7b02182. [Accessed Oct. 10, 2019].

- [2] Widlund, T.; Yang, S. X.; Hsu, Y. Y.; Lu, N. S. “Stretchability and Compliance of Freestanding Serpentine-Shaped Ribbons” Int. J. Solids Struct. 2014, 51, 4026– 4037DOI: 10.1016/j.ijsolstr.2014.07.025 [Crossref], [CAS], [Google Scholar]

- [3] Qiao, Y.; Wang, Y. “Multilayer Graphene Epidermal Electronic Skin” *ACS Nano*, vol. 12, no. 9, July 24, 2018. [Online]. Available: https://doi.org/10.1021/acsnano.8b02162. [Accessed Oct. 14, 2019].

- [4] Wang, Q.; Ling, S. “Self-Healable Multifunctional Electronic Tattoos based on Silk and Graphene” *Advanced Functional Materials*, vol. 29, no. 16, February 25, 2019. [Online]. Available: https://onlinelibrary.wiley.com/doi/full/10.1002/adfm.201808695. [Accessed Oct. 14, 2019].

- [5] Ameri, S. K.; Kim M.; Akinwande, D.; Lu, N. “Imperceptible electrooculography graphene sensor system for human-robot interface” *Nature Partner Journals*, vol. 11, no. 3, July 24, 2018. [Online]. Available: https://doi.org/10.1038/s41699-018-0064-4. [Accessed Oct. 16, 2019].



Optical image of the graphene wireless sensor biotransferred onto the surface of a tooth. (Image: McAlpine Group, Princeton University)