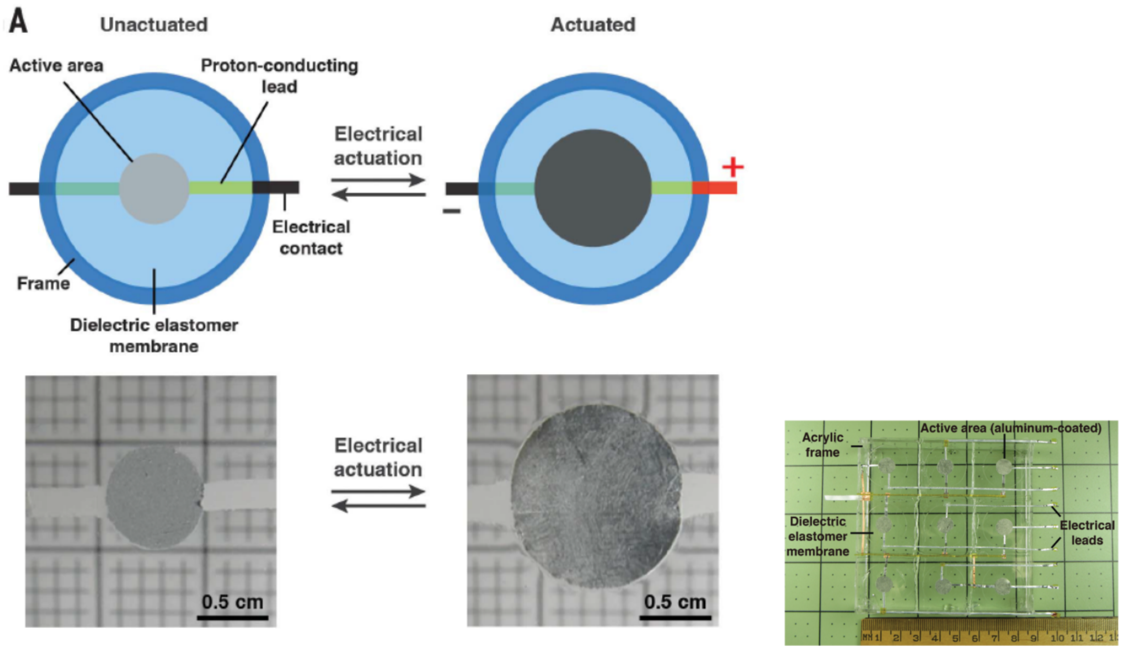
Problem Set 6 (EXTRA CREDIT!): Bioinspired Cephalopod Camouflage Devices
ENGN/BIOL 267—Winter 2020
Due: 22 April 2020, 5pm



(a) (b)

Figure 1: (a): Dielectric Elastopher IR reflecting "chromatophore" by Xu et al. (b):The actual bioinspired system on a lab bench. Science, 2018, 359:1495:1500.

1. **Squeeeeeeze!**

   In class, we studied the bioinspired IR-reflecting system by Xu et al[1]. The core component of this system was a dielectric elastomer upon which various layers (aluminium or metal oxides) could be deposited to reflect IR light. One variant of the system integrated electrical actuation. The conducting electrode layers can be charged akin to a parallel plate capacitor (Figure 2) The opposite charged plates want to pull in toward one another, which generates a force to squeeeeeeeze the dielectric elastomer membrane, thus causing it to deform and change the exposed area of the IR reflector. Let's quantify a bit further!

   (a) The capacitance of the electrodes is given by the well-known formula for parallel plate capacitors:

   $$C = \epsilon_r \epsilon_o \frac{A}{d} \tag{1}$$

   where $\epsilon_r \approx 4.7$ is the relative permittivity of the dielectric elastomer (3M VHB 4905); $\epsilon_r \approx 8.85 \times 10^{-12}$ F/m is the permittivity of free space, A is the area of the plates, and d is the distance between them.
   Given this information, compute the capacitance for the bioinspired IR reflector device described in Xu et al 2018. State any assumptions you make, quote any sources for any values you use in the calculation.

[1]C. Xu et al. Adaptive infared-reflecting systems inspired by cephalopods. Science, 2018, 359:1495:1500.

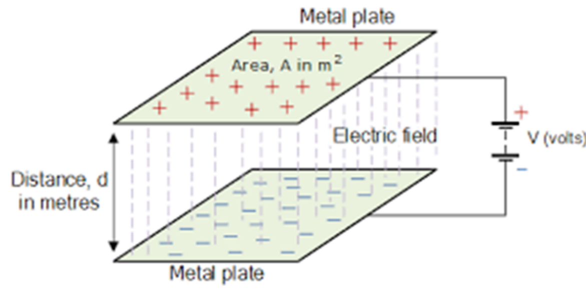


Figure 2: Charged capacitor model. The force generated by the charged plates squeezes (strains) the dielectric elastomer, causing the chromatophore to expand. Discharging the plates lets the chromatophore relax back to a smaller radius.

(b) The electrical energy stored in a capacitor is given by:

$$E_C = \frac{1}{2} C U^2 \tag{2}$$

where U is the applied voltage. Compute how much energy is stored in the plates when actuating the device with $U = 3$ kV. As before, state any assumptinos, quote any sources for values you use in the calculation.

(c) Now the punchline–just how hard is the dielectric elastomer being squeezed? Recall that energy (work) is force acting over a distance and energy: $E = \int F dx$. If the force is constant over the volume we care about (e.g. think gravity near the surface of the earth), then the integral is super easy to compute. Indeed, this is the case for the parallel plate capacitor (at least approximately if we neglect the fringing electric field at the edges). Therefore, compute the force applied to the elastomer given the actuation is 3 kV. Also, compute the compressive stress $\sigma = F/A$. Compare these values to something you know from everyday life: for instance, how many equivalent bricks would you have to stack upon a dielectric layer to achieve the same force as the electrical actuation.

(d) Lastly, for bonus extra credit: explain why the Areal strain vs. voltage curve is (roughly) parabolic–see Figure 3E in the Xu et al paper. Assume the elastomer is a linear elastic material: stress = youngs modulus time strain.