New soft robotic nano structure for sustainable process

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Introduction

There is high potential for self-actuating structures, which create mechanical functions in response to external stimuli, to improve energy efficiency by harnessing ambient energy unused by conventional sustainable practices. Current designs have shown desirable self-actuation properties such as high actuation range–the percent change in movement–and load strength **[1]**. Yet, they deform easily from high stress and strain during actuation, limiting repetitive use. We propose a light responsive structure exhibiting self-opening and closing built by sandwiching graphene between polymer and metal, with reversible actuation up to 10 times larger than industry norm. We design and test six hexagon-shaped shutters to determine the effect of curvature and neck width on actuation and reversibility.

Theory

Graphene, of negative thermal expansion (-3.26 μm m-1°K-1 **[2]**), is sandwiched between polydimethylsiloxane (PDMS) and aluminum (of relatively high thermal expansion 310 μm m-1°K-1 and 23.03 μm m-1°K-1 respectively **[3][4]**), which is then bonded to a low expanding base layer (glass) with pressure sensitive adhesive (PSA) bonding layer. When heat is applied, the graphene shrinks while the PDMS expands which causes bending of the flaps outwards from the graphene as the two are bonded together. The high thermal conductivity of graphene and aluminum allows more efficient transfer of light to heat, further increasing actuation percentage.

Methods

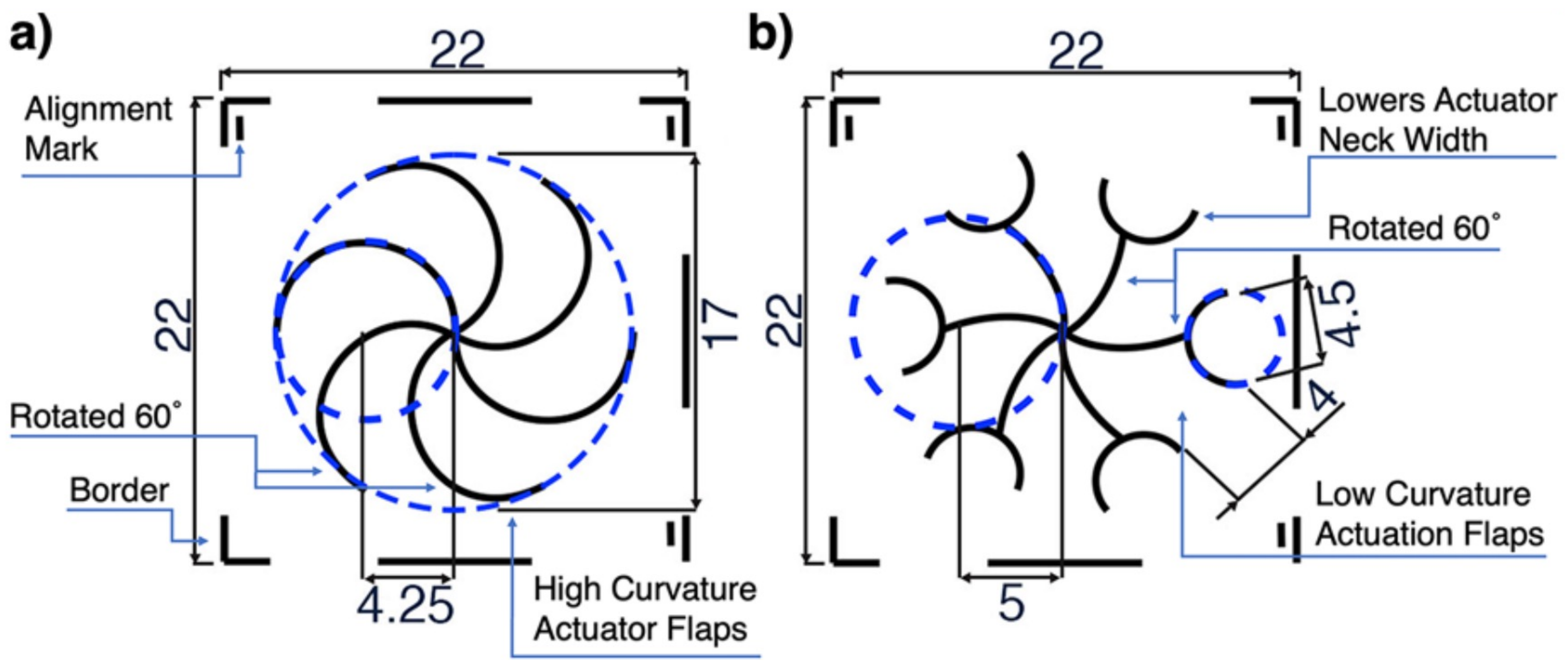

Figure 1. Annotated schematic for the graphene coated aluminum layer. Curvature of the flaps are based on the blue circles. (**a**) 'Spiral Shutter' with outer circle d = 17mm and inner half circle of d = 8.5mm. (**b**) 'Tooth Shutter' with flap curvature from circle d = 10mm and neck width from half circle d = 9mm.

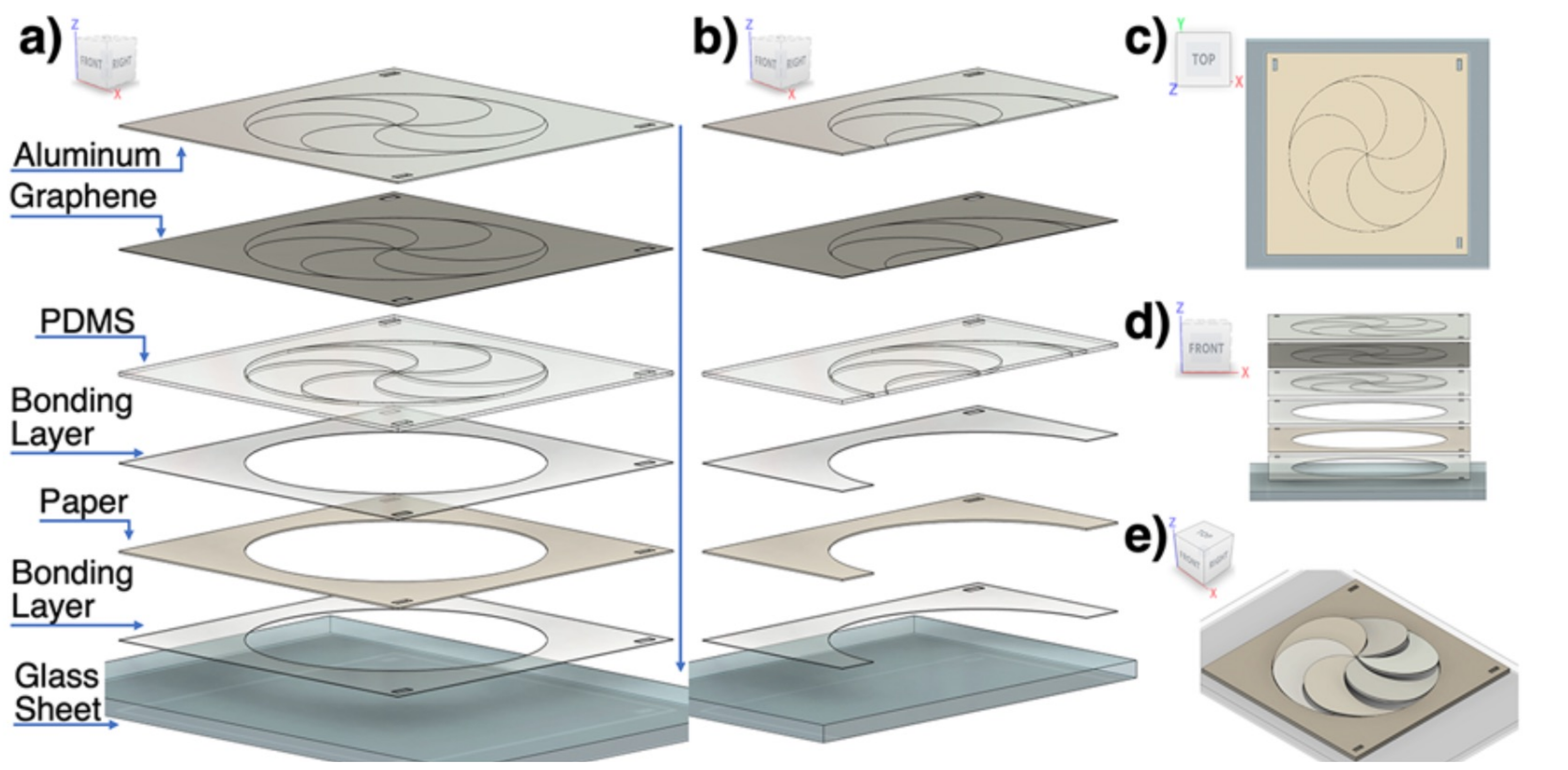

Figure 2. Layer assembly for Spiral Shutter. (**a**) Annotated orthogonal view of separate and closed layers. (**b**) Orthogonal view of cross-section, separate and closed layers. (**c**) Top view of layers. (**d**) Top-angled front view of separate and closed layers. (**e**) Orthogonal view of joined and opened layers.

1) Make 2.5g PDMS with 10:1 of elastomer to curing agent. Composite PDMS/PSA, and graphene coated aluminum/PSA.
2) Cut layer designs from PDMS/PSA and graphene coated aluminum/ PSA composites and PSA. Cut paper pore layer for open at high heat.
3) Plasma treat PDMS at design perimeter for 1 minute.
   i. Heat graphene composite and PDMS composite at 100°C for 8 min prior to plasma treatment for closed at high heat.
   ii. Heat graphene, PDMS and PSA/glass composites at 100°C for 2 min.
4) Assemble structure according to open/closed at high heat orientation

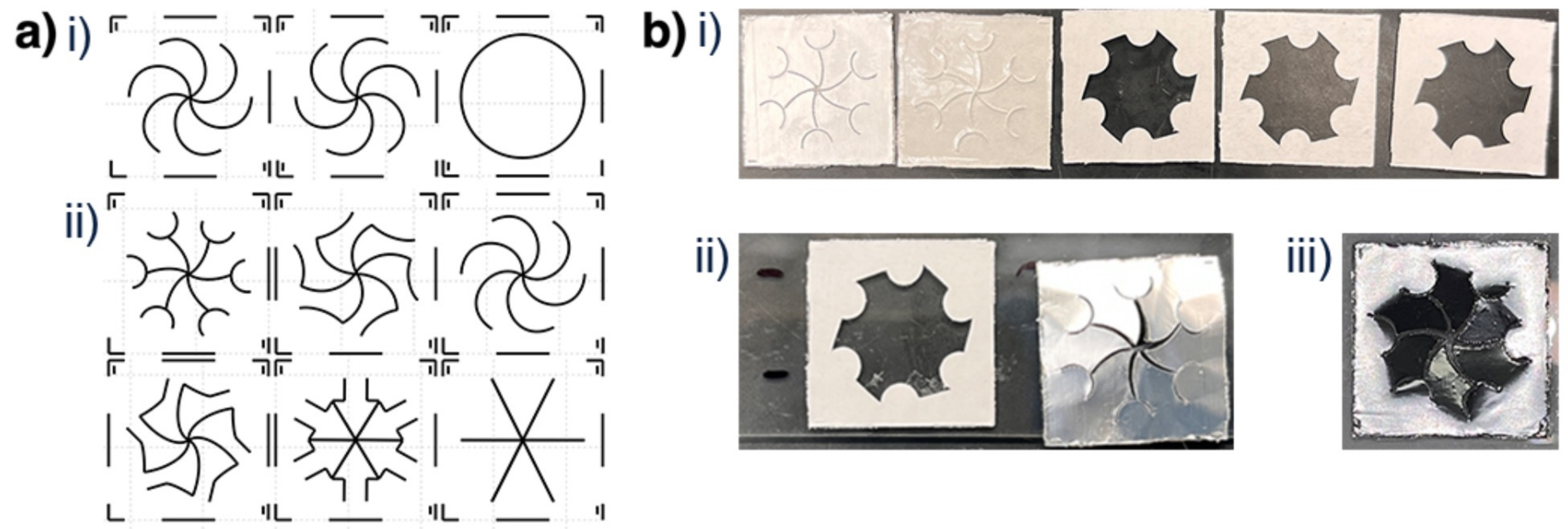

Figure 3. Top view of shutters and layer cutouts. (**a**) (i) Spiral shutter design: graphene/aluminum (left), PDMS (center), PSA (right). (ii) Six shutter designs tested: (top) Tooth shutter, Wide Hook shutter, Spiral shutter; (bottom) Hook shutter, Arrow-Hex; Tri-Hex. (b) (i) All Tooth shutter layers cutout and ordered for assembly as in **Figure 2. (a)**. (ii). (Right) Glass, PSA, and paper layers joined; (left) graphene/aluminum and PDMS layers joined, plasma treated, and flaps opened. (iii) Fully assembled structure.

Results / Discussion

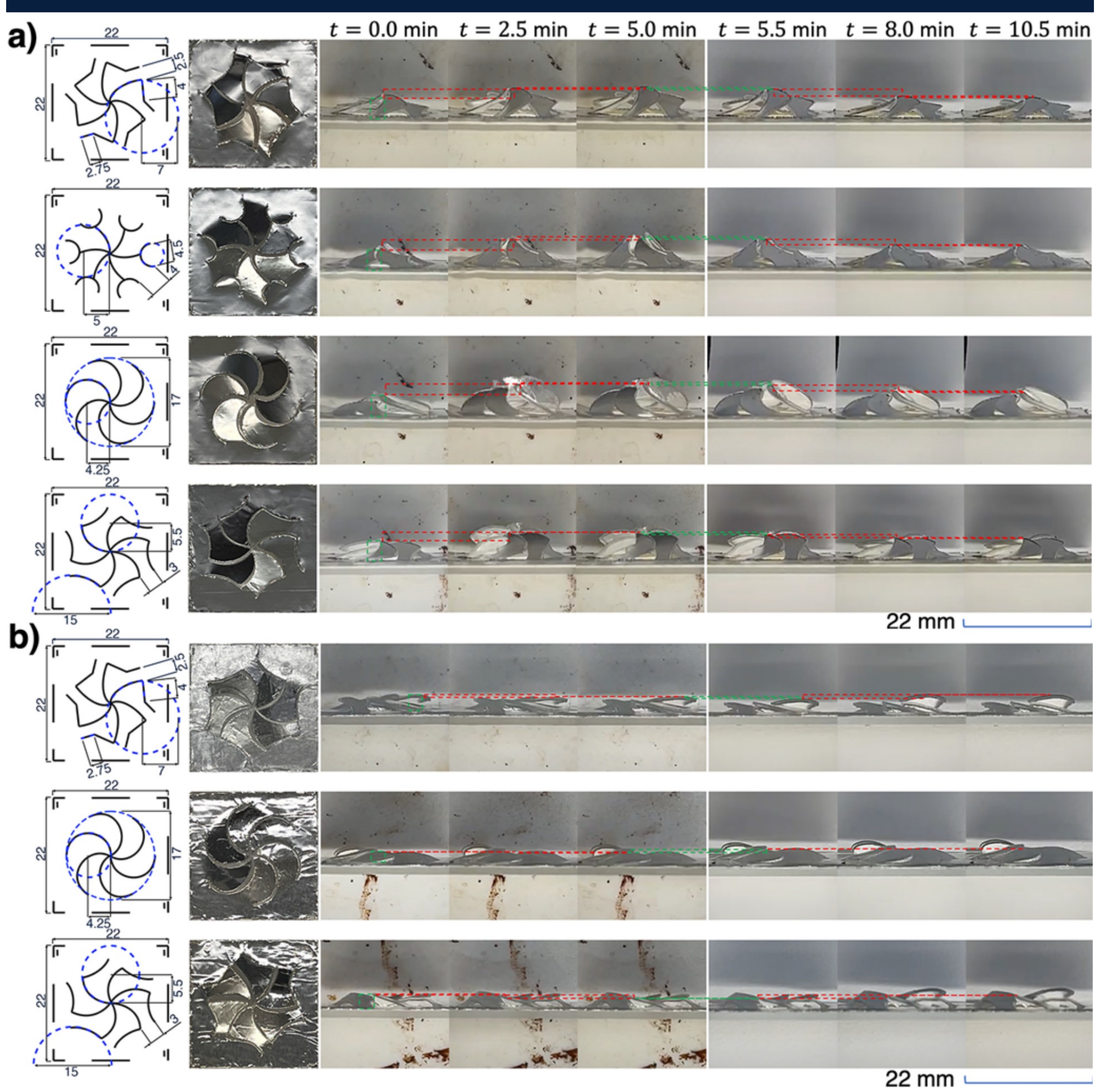

Figure 4. Cyclic testing of spiral shutters under high heat T = 100˚C (t = 0.0 min to t = 5.0 min), and low heat T = 22˚C (t = 5.5 min to t = 10.5 min) with schematic and top view of fabricated structure. Actuation shown by green (indicating starting actuation) and red dotted lines. (**a**) Structures open in high heat and closed in low heat ordered downwards: Hook Shutter, Tooth Shutter, Spiral Shutter, Wide Hook Shutter. (**b**) Structures closed in high heat and opened in low heat ordered downwards: Hook Shutter, Spiral Shutter, Wide Hook Shutter.

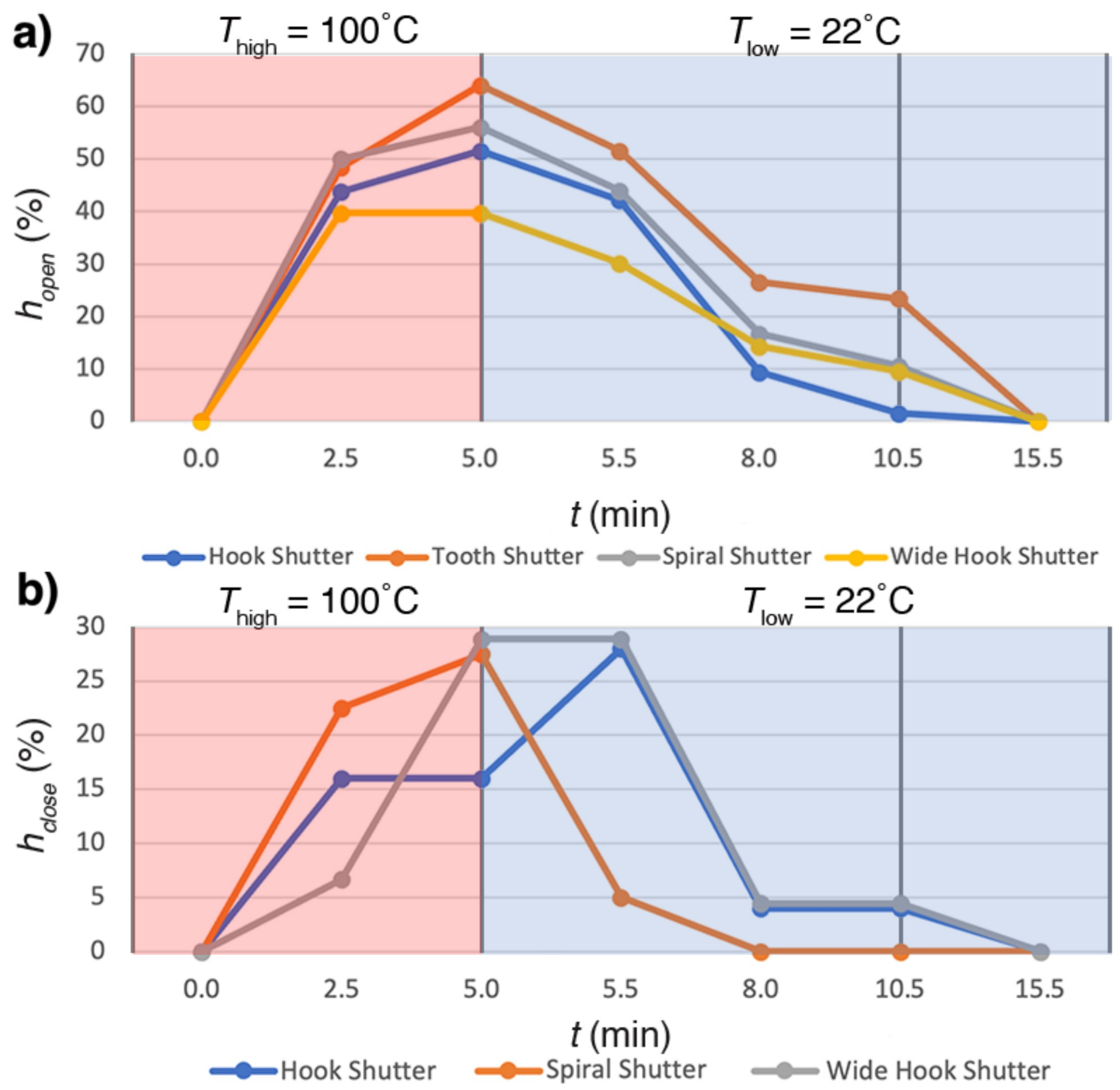

Figure 5. Height percent actuation from cyclic testing from T_{high} = 100˚C (t = 0.0 min to t = 5.0 min), and T_{low} = 22˚C (t = 5.5 min to t = 10.5 min). From t = 10.5 min to t = 15 min it is assumed percentage actuation returns to zero. (**a**) Hook, tooth, spiral and wide hook shutter open in high heat. (**b**) Hook, spiral, and wide hook shutter closed in high heat.

- High curvature creates more sideways/outwards actuation.
- Narrower necks (up to a point) may increase actuation.
- Current flap designs often impede each other (e.g. hook).
- Highest actuation percent is always at t = 5.0 min, though inconsistencies with closed in high heat structures.
- Actuation during high heat occurs faster than reverse actuation in low heat (though should go to zero).

Conclusion

We show layering metal, graphene and polymer improves light to thermal energy transfer efficiency in self-actuating structures. Further, the negative thermal expansion of graphene with the positive thermal expansion of metal and polymer lead to actuation up to ten times the industry norm. We report structures with higher curvature actuate more outwards, and that having a shortened neck may improve actuation. A key challenge is ensuring flaps do not impede one another and limit actuation, which was most common in the closed at Thigh structures and Hook shutters. Future steps include more precise research on design parameterization, indenting the neck to target the bending location; and improving the layer structure to reduce strain and deformation.

References

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