

# BORON NITRIDE NANOTUBES FOR ENHANCED THERMAL MANAGEMENT IN PRINTED FLEXIBLE ELECTRONICS



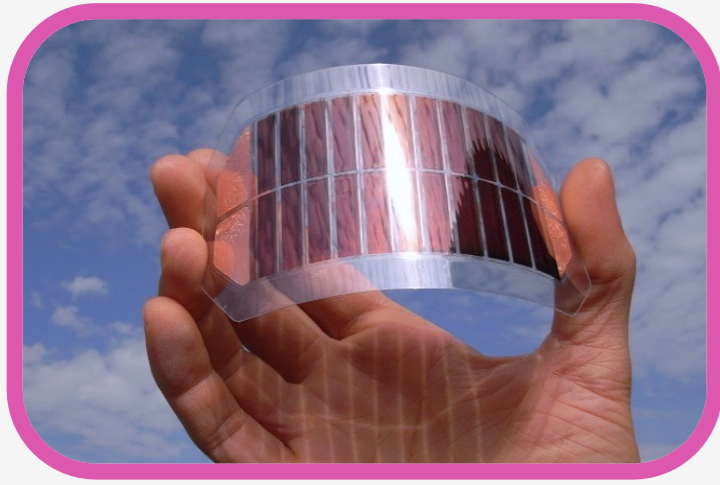
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## 1 Thermal challenges in printed electronics

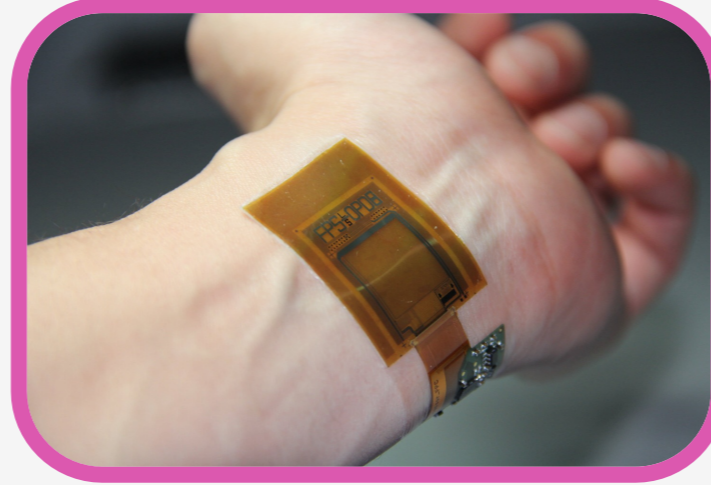
Printed electronics use metal inks (Ag, Cu, Au) to create flexible electrodes on plastic substrates using established manufacturing technologies like screen printing and roll-to-roll printing.



Flexible solar cells<sup>1</sup>



Moldable bioelectronics<sup>2</sup>



Bendable sensor arrays<sup>3</sup>

When manufacturing printed electronics, we need **fast, reliable, & economically viable** processes. However:

### Fast processing = High temperatures

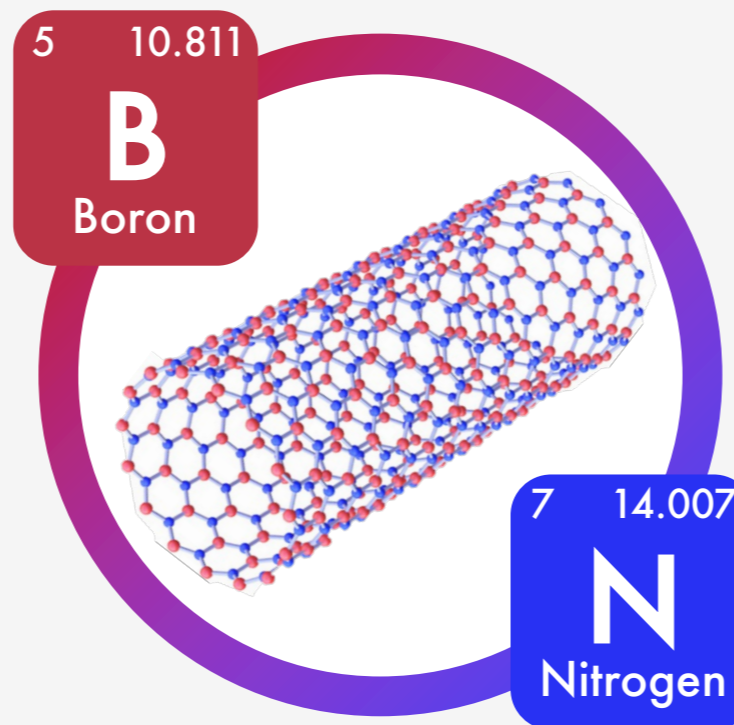
Our plastic polyethylene terephthalate (PET) substrates are inexpensive, but temperature-sensitive (~120°C). This limiting factor, known as the glass transition temperature, currently inhibits us from using fast & high-energy processes.

How can we decouple the thermal processing requirements from the thermal limits of polymer substrates without compromising high-throughput manufacturing?

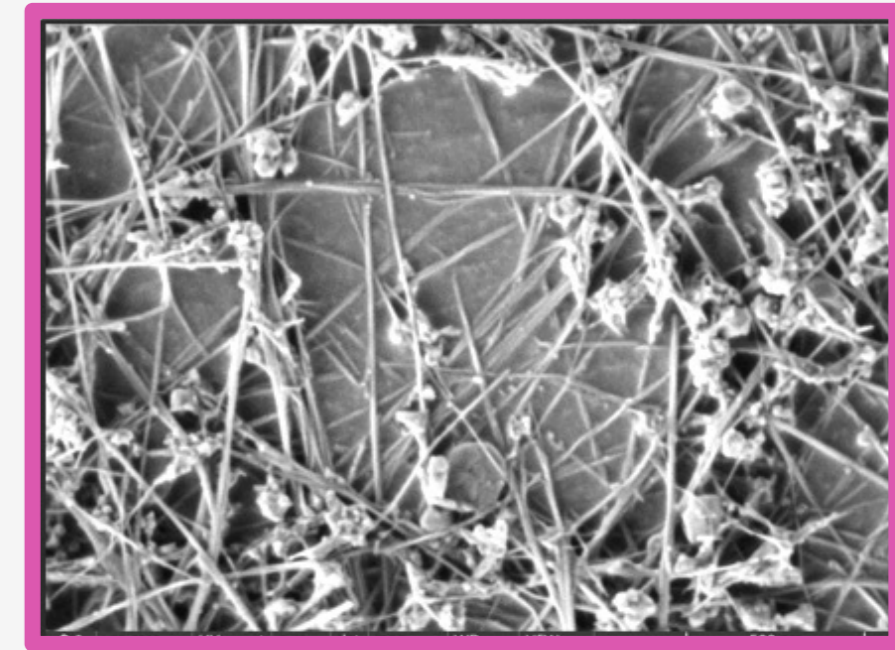
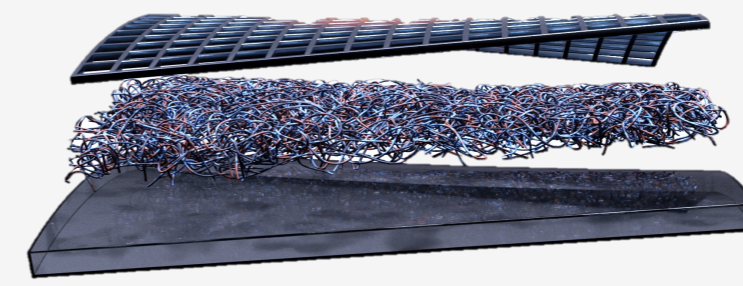
## 2 Why do we use BNNTs

Boron nitride nanotubes (BNNTs) are used as thermal management tools due to their high thermal conductivity (350 W/m·K), mechanical durability, and ability to withstand high temperatures (≥ 900°C).<sup>4</sup>

Functionalizing BNNTs with certain polymers is necessary to improve their dispersion in solution, enabling integration into scalable processing.

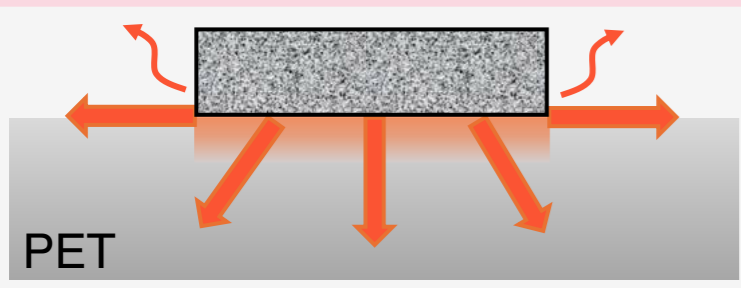


We hypothesize that functionalized nano-thin films of BNNTs will act as a **protective interlayer** between the electrode and substrate.

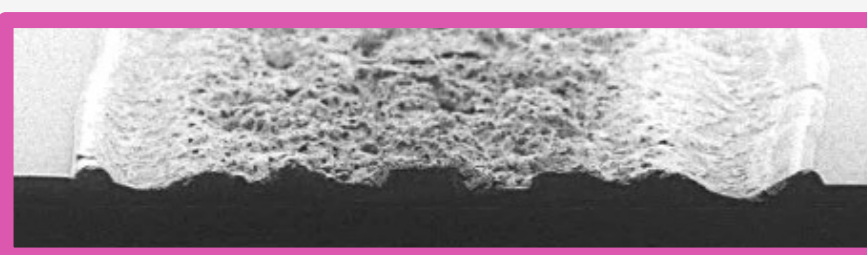


## 3 A novel thin-film heat management tool

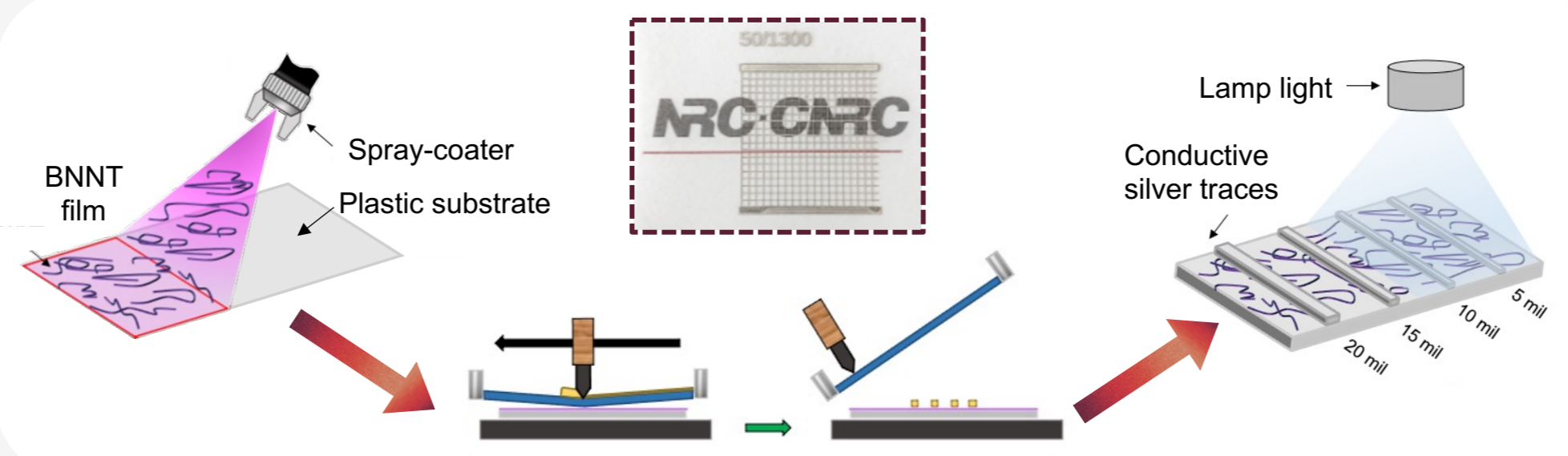
### Unprotected substrate



Sheet Resistance = 285 mΩ/sq



### Spray-coating BNNTs ⇒ Screen printing silver ink ⇒ Curing

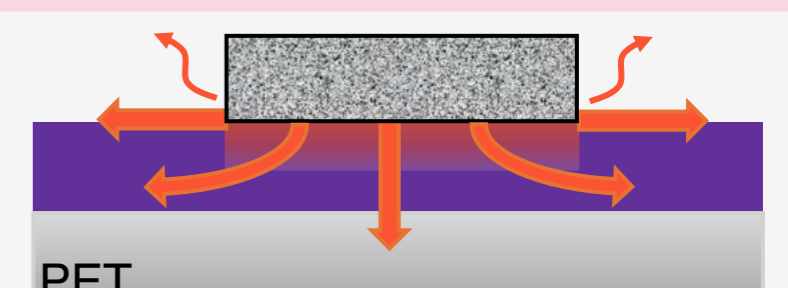


The heat generated in the electrode is injected directly into the substrate, warping it along with the electrode, resulting in high resistance and poor heat distribution.<sup>5</sup>

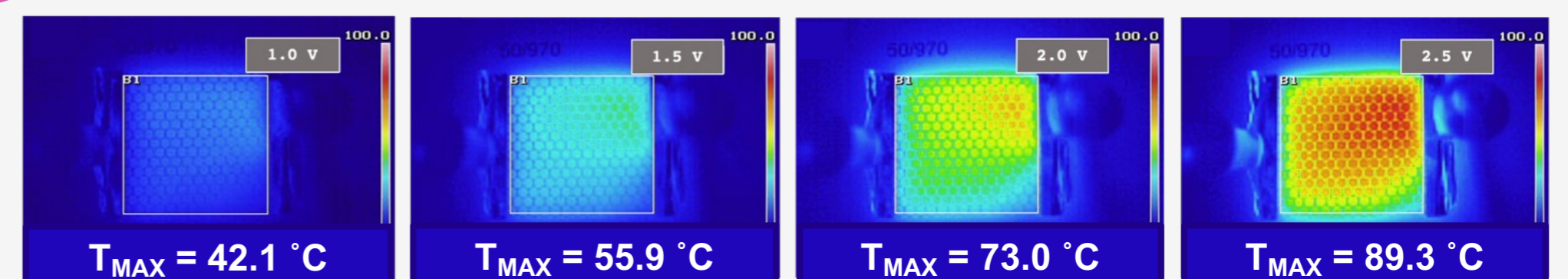
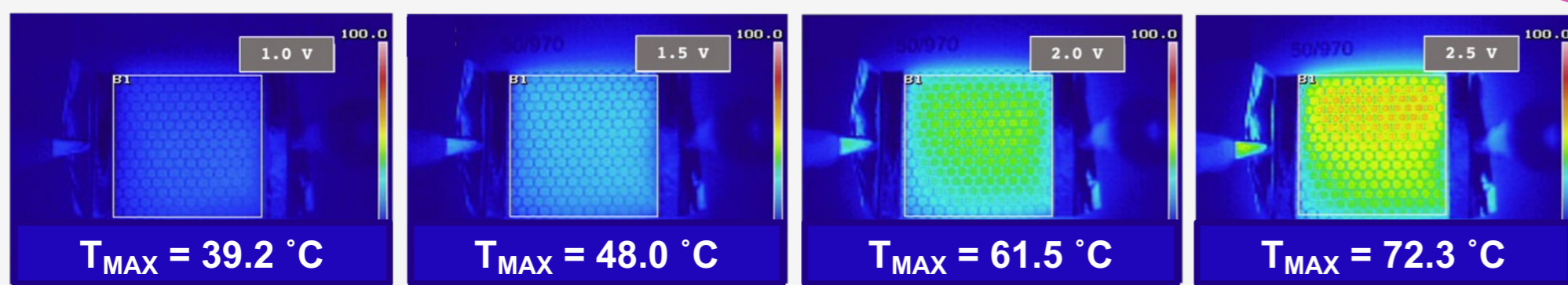
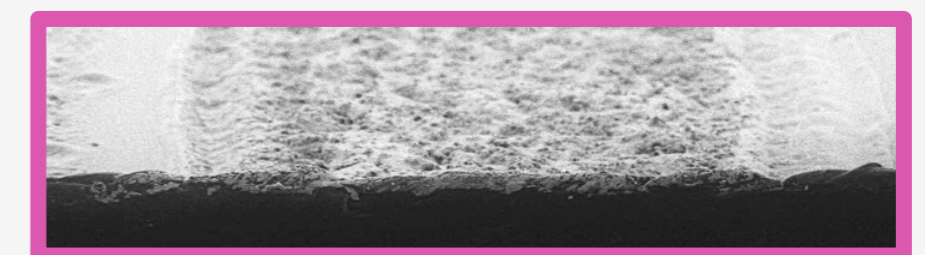
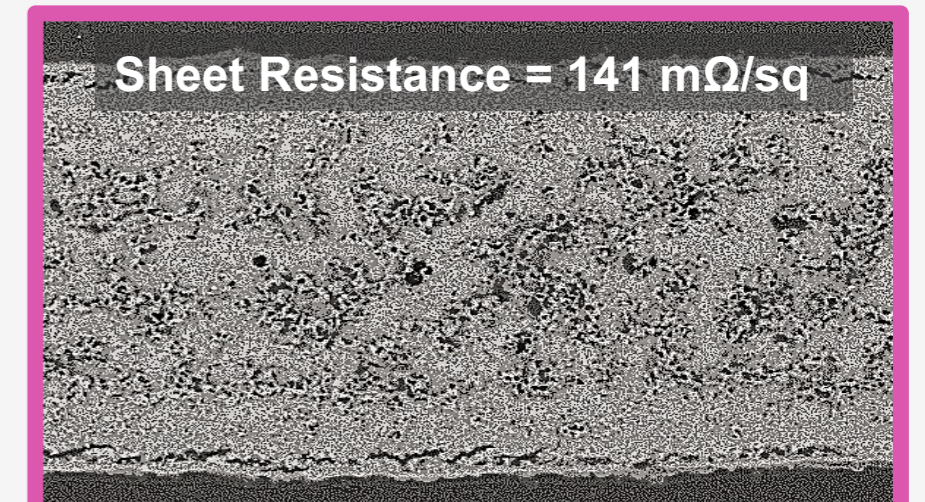
VS.

With the BNNTs present, heat instead diffuses throughout the nanotube network, maintaining the integrity of the substrate and electrode, leading to higher temperature outputs.<sup>6</sup>

### BNNT-protected substrate



Sheet Resistance = 141 mΩ/sq

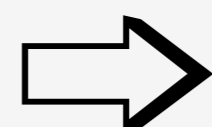


## 4 Incorporating sustainable chemistry

BNNTs are a versatile material, operating just as effectively in 'green' solvent alternatives as they do in traditional harmful chemicals, allowing for more sustainable manufacturing and environmental practices.<sup>7</sup>

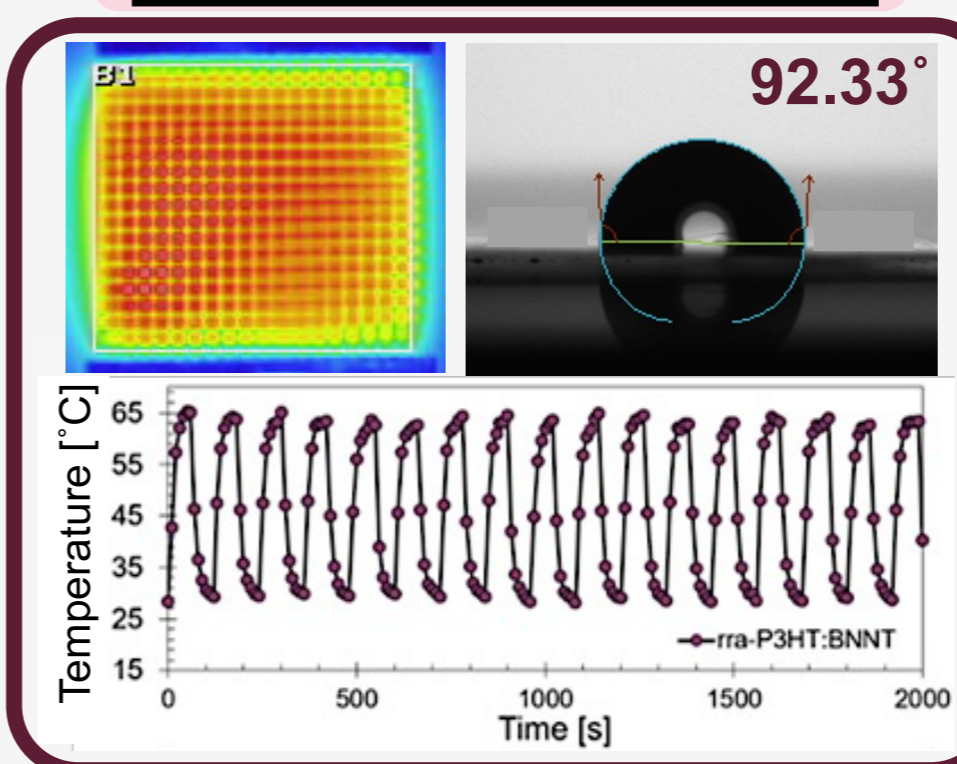


rra-P3HT:BNNTs + Chloroform

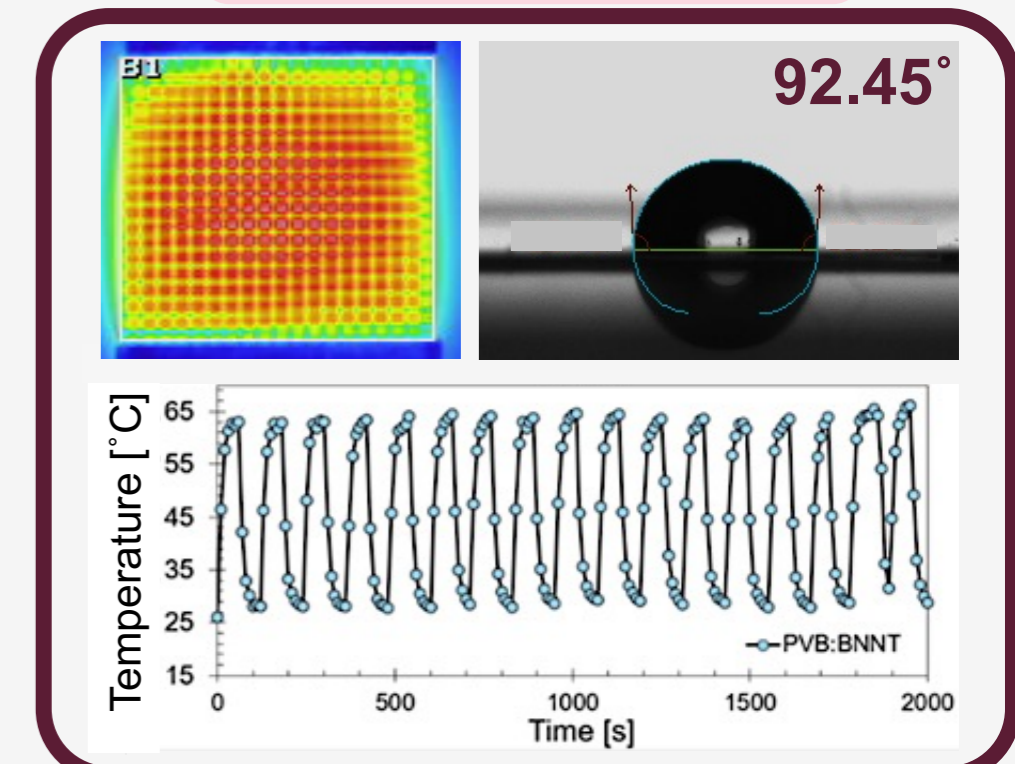


PVB:BNNTs + Ethanol

### BNNTs in chloroform



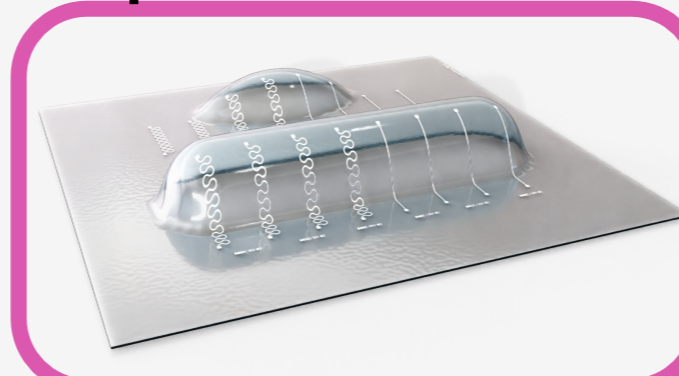
### BNNTs in ethanol



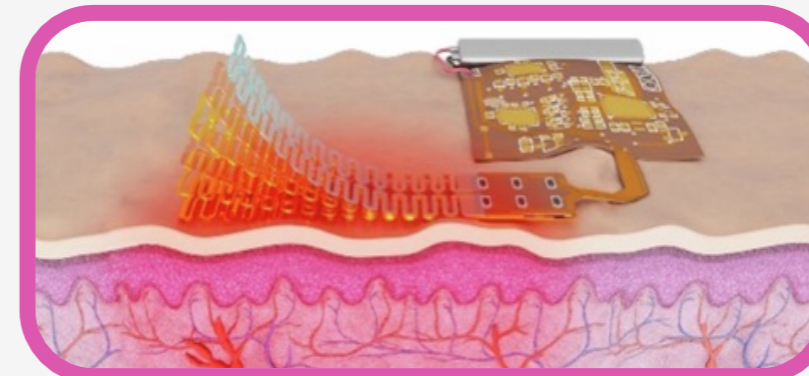
## 5 Impact & future applications

Our green-solvent BNNT interlayer removes a key thermal bottleneck in printed electronics, allowing for higher-temperature processing on low-cost polymer substrates while maintaining device reliability and roll-to-roll scalability.

### 3D-printed electronics<sup>8</sup>



### Biomedical devices<sup>9</sup>



### References

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