UPISC UNIVERSITY OF PITTSBURGH INFRASTRUCTURE SENSING COLLABORATION WORKSHOP

NATIONAL ENERGY TECHNOLOGY LABORATORY

NANO PRODUCT LAB — Bedewy Research Group

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CONTROLLING THE MORPHOLOGY, CHEMISTRY, AND PROPERTIES OF NANOCARBONS IN THE NANOPRODUCT LAB

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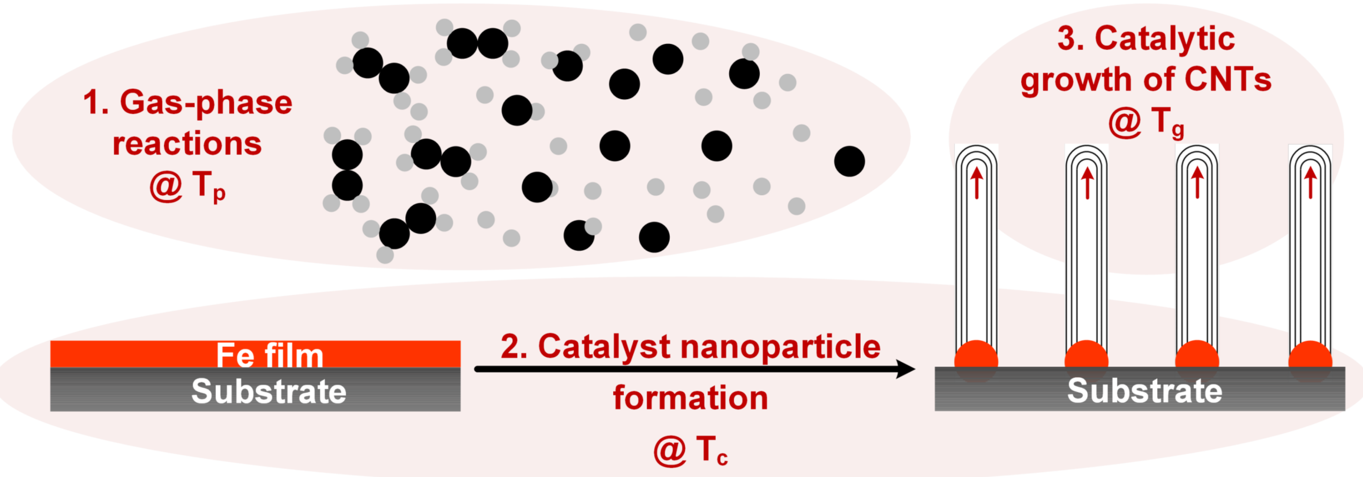
Catalytic CVD of Carbon Nanotubes (CNTs)

Typically <u>gas-phase decomposition of hydrocarbon precursor</u>, <u>catalyst nanoparticle formation by thin film dewetting</u>, and <u>catalytic surface reactions in CNT nucleation/growth</u> are coupled.

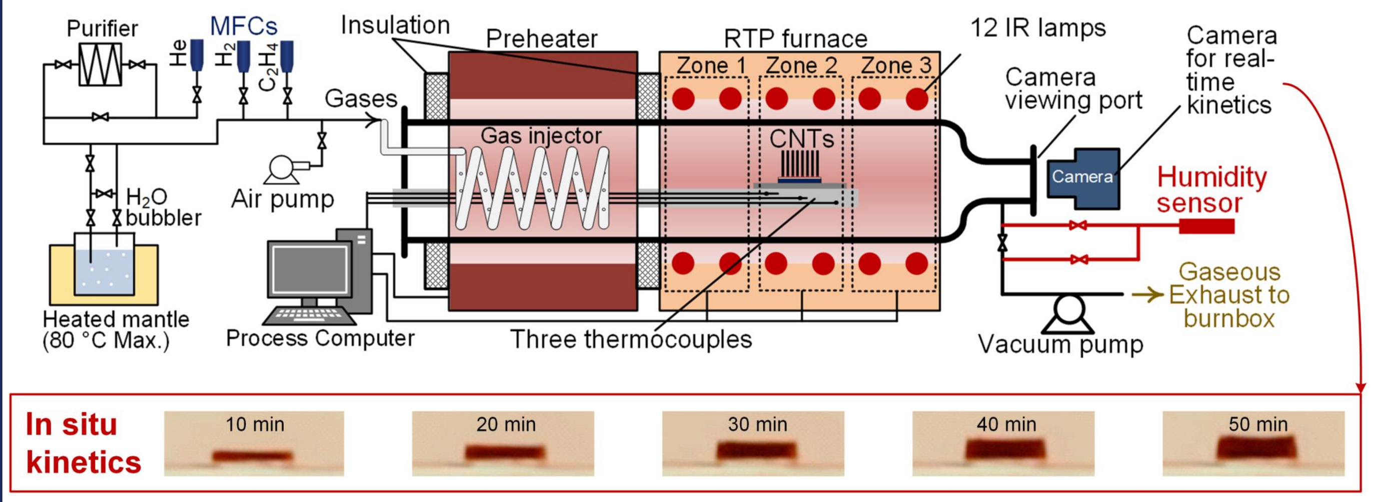


Why decouple?

1. It's difficult to fully understand each process independently
2. It's more challenging to optimize growth in coupled recipes

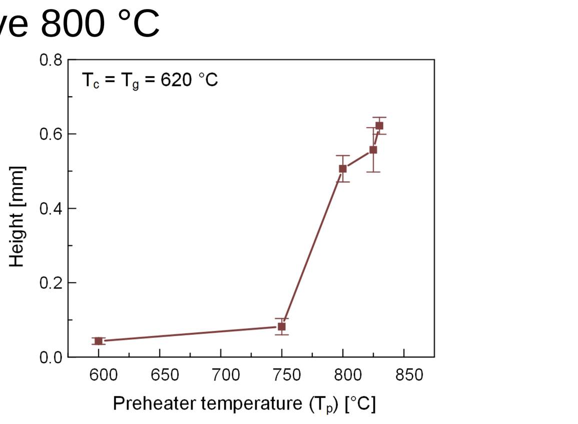
Custom-designed RTP-CVD reactor for decoupling

<u>Custom-designed reactor:</u> resistive preheater for decomposition of gas-phase hydrocrabon and IR furnace (heating rate > 200 °C/s) for catalyst treatment and CNT growth

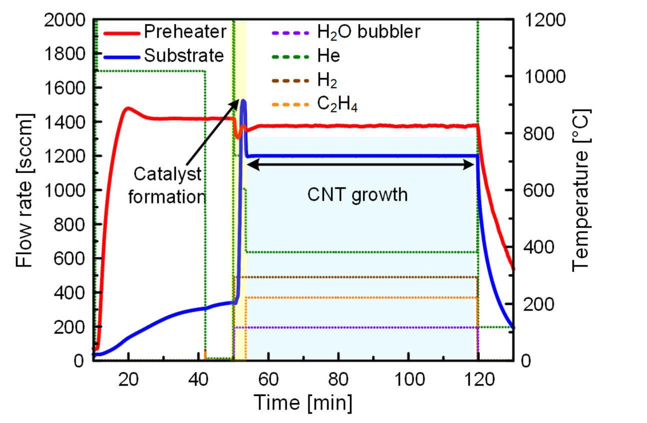


Decoupling T_p, T_c, T_g in this RTP-CVD reactor

More than 12-fold increase in forest height by heating the gases as they go through the spiral gas injector above 800 °C

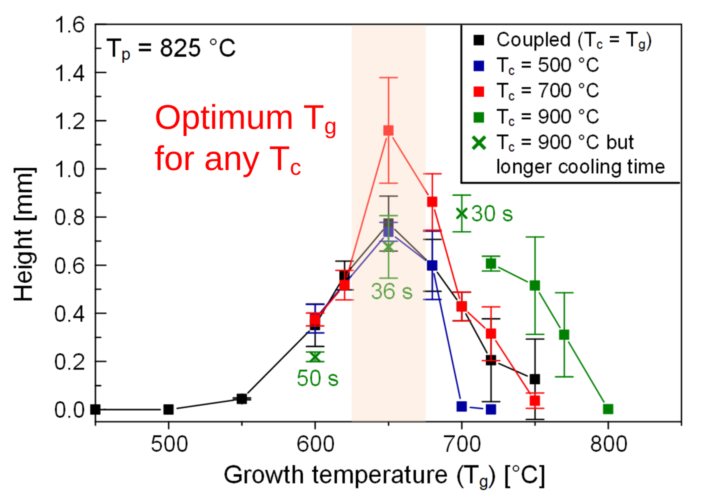


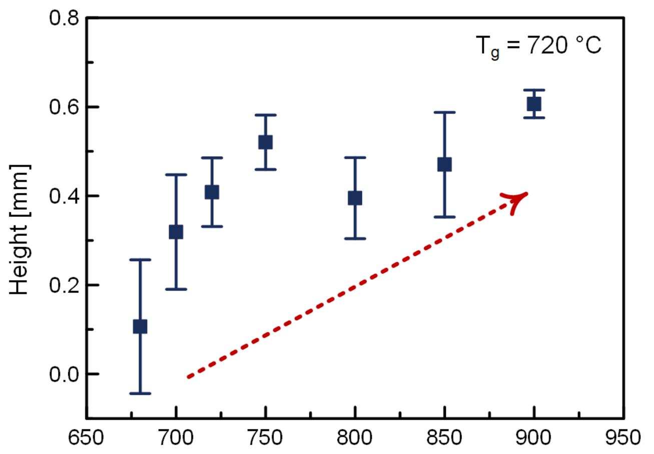
Decoupled recipe ➔ temp. is ramped in a separate catalyst formation step before the CNT growth step



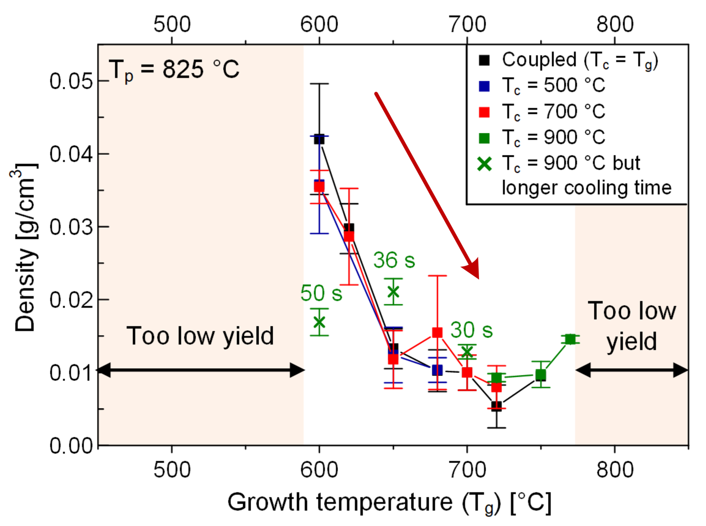
Density & Height Control of VACNT in this Reactor

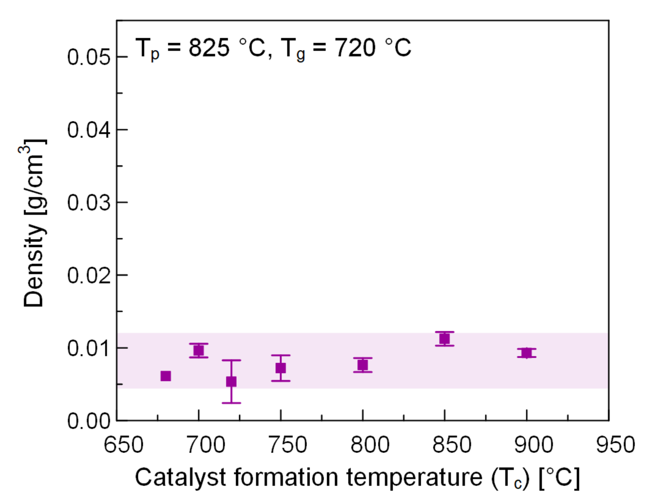
I. CNT forest height is directly proportional to catalyst formation temp. (T_c) at the same growth temp. (T_g).





II. CNT forest density is inversely proportional to growth temp. (T_g), regardless of the catalyst formation temp. (T_c).





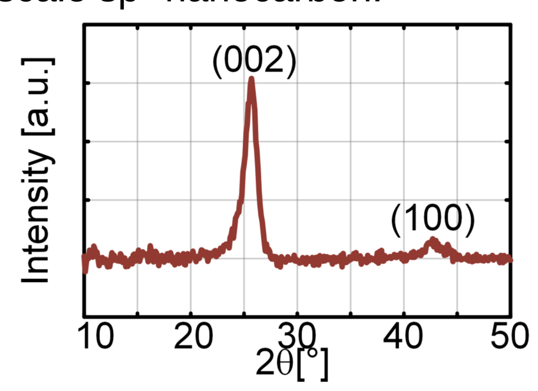
Density is nearly independent on T_c, suggesting that catalytic activation density is mainly dependent on T_g

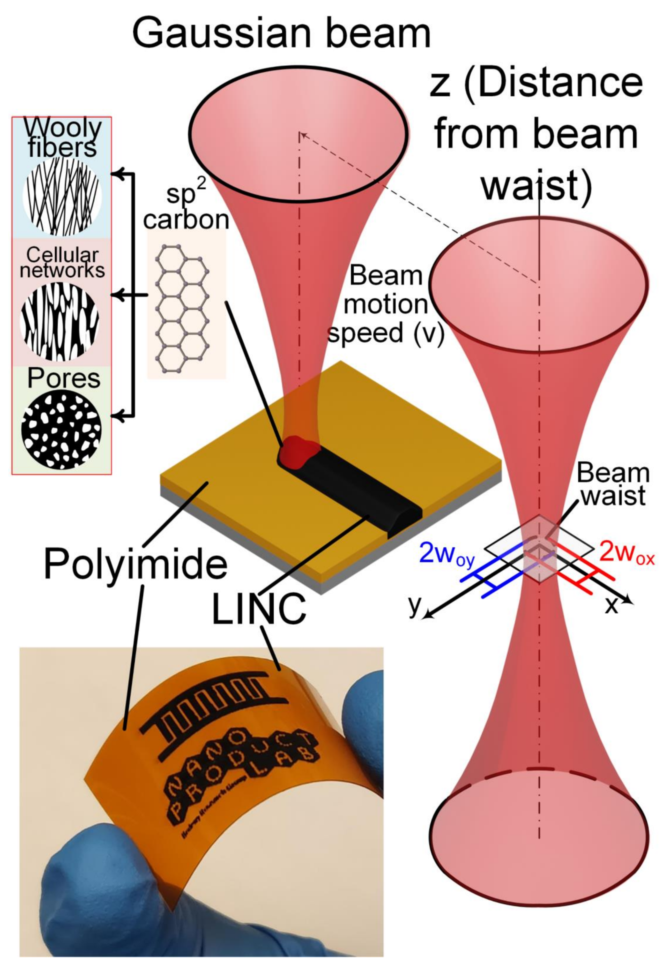
Laser Induced Nanocarbon (LINC)

Laser carbonization of polymers is an emerging technique that enables directly patterning conductive carbon electrodes for a plethora of flexible devices, including supercapacitors and sensors.

A continuous beam with <u>power P</u> is scanned across the polyimide film at a <u>speed v</u> with the sample surface at a <u>distance z</u> from the beam waist.

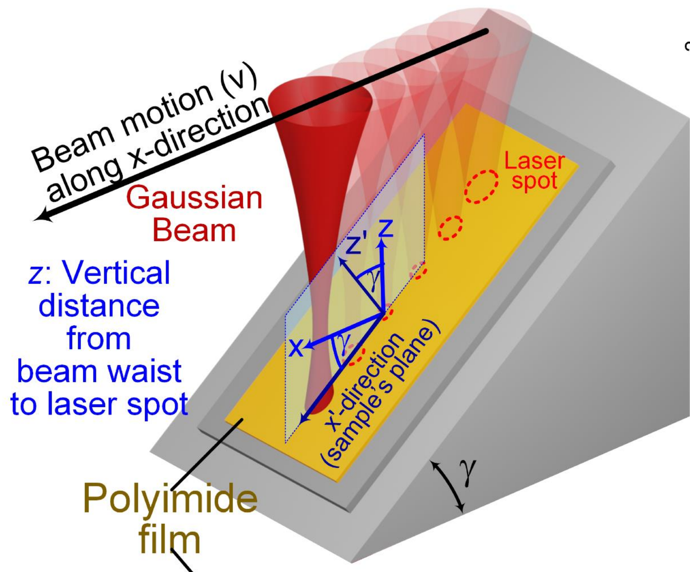
Photothermal interactions from the radiation absorption by the polyimide drive a rapid temperature increase that carbonizes polyimide locally and forms nanoscale sp^2 nanocarbon.

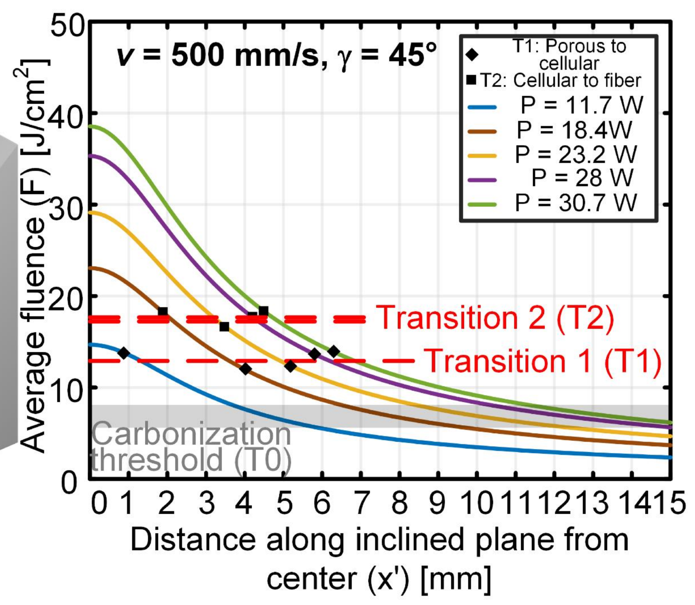


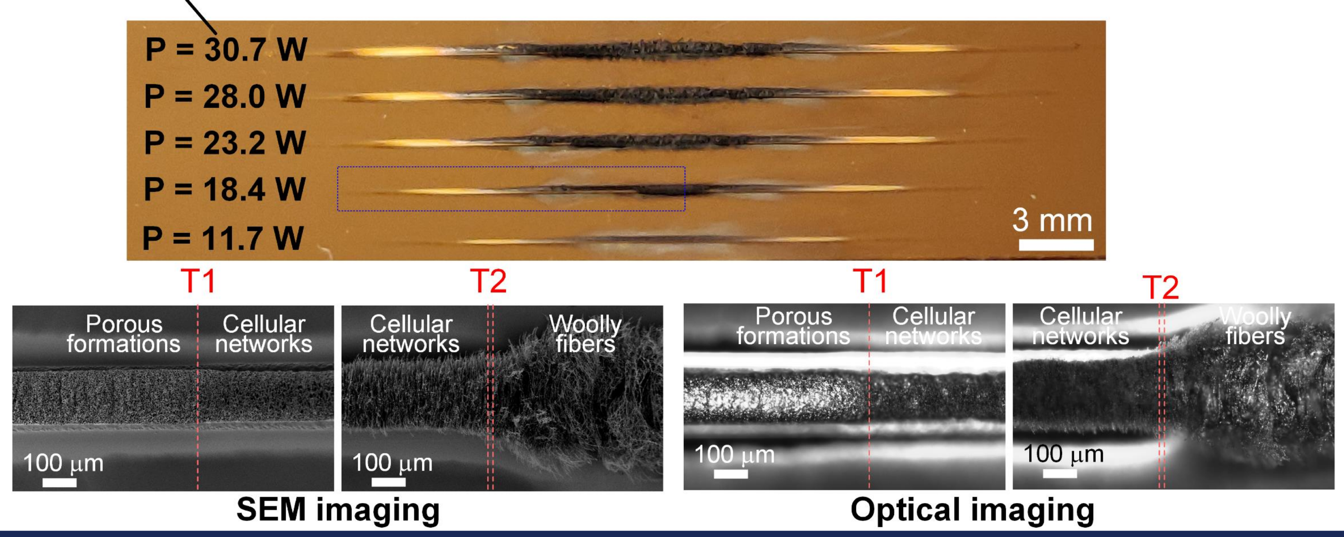


Fluence gradients for control of LINC Morphology

Tilting the sample allows scanning the sample with different fluence values and hence investigate how fluence affects morphology of LINC. Discrete morphological transitions noted.







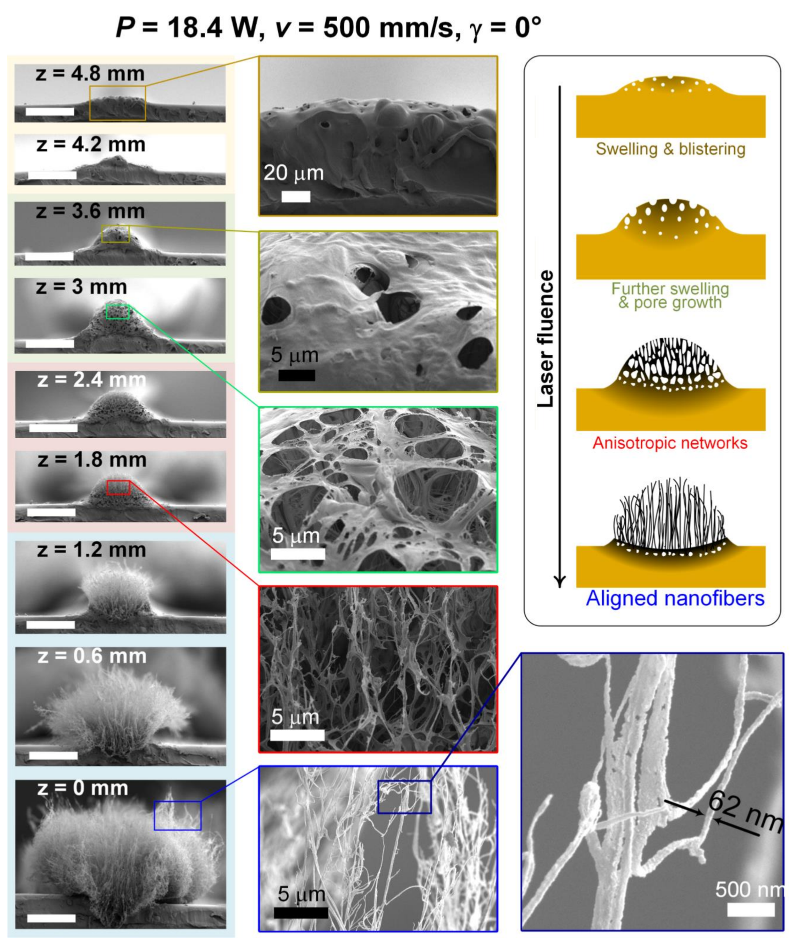
Fluence dependent tunability of LINC Morphology

To gain more insight into the obtained LINC morphologies, untilted polyimide films are lased at different z values for the same power P = 18.4 W

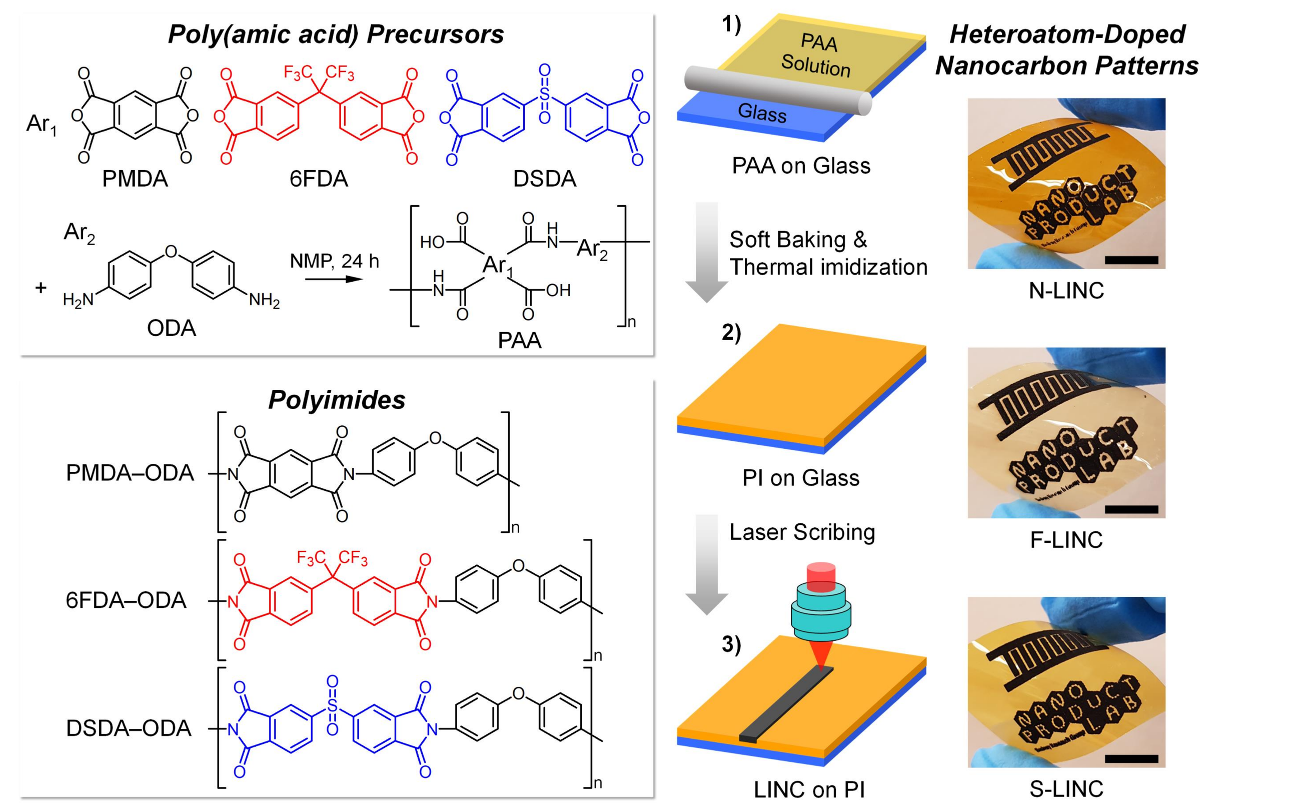
These transitions capture the evolution of LINC morphology with increasing average fluence values.

A model of these fluence-dependent transitions is illustrated schematically

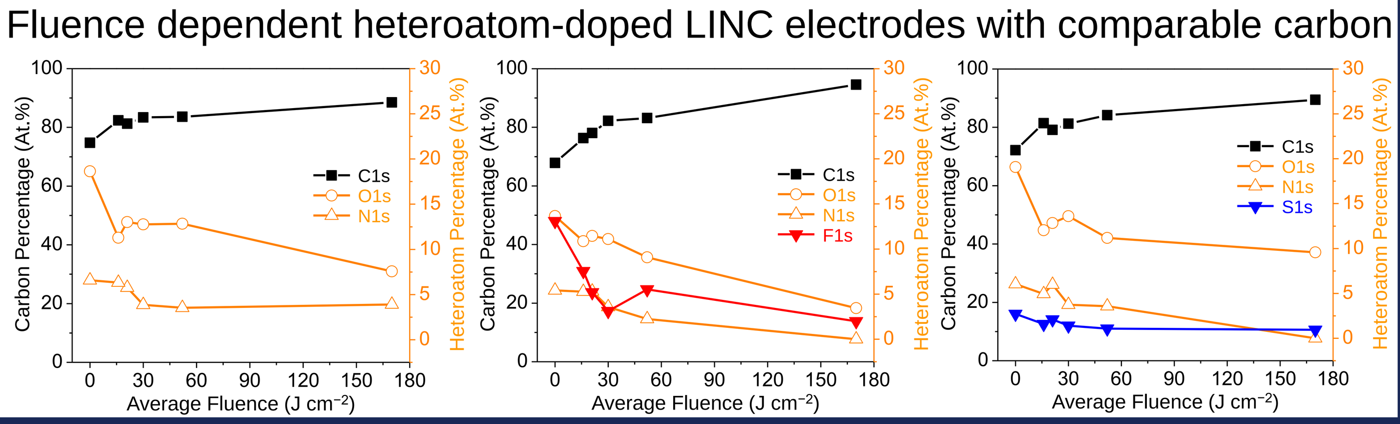
It shows the phenomenon of swelling and blistering of the polyimide, followed by the formation of pores that gradually increase in number, size, and anisotropy, leading to the formation of anisotropic cellular networks then wooly fibers



Chemistry Control in LINC

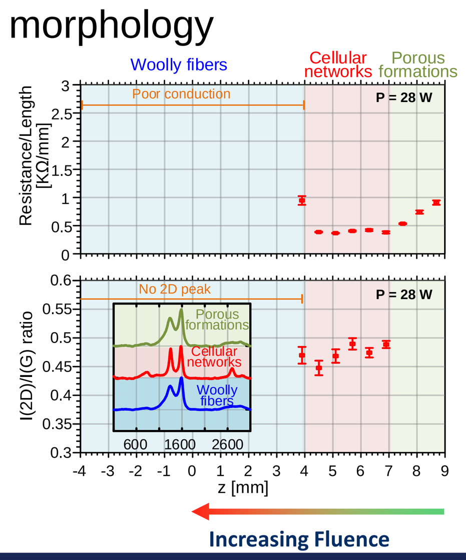


Fluence dependent heteroatom-doped LINC electrodes with comparable carbon

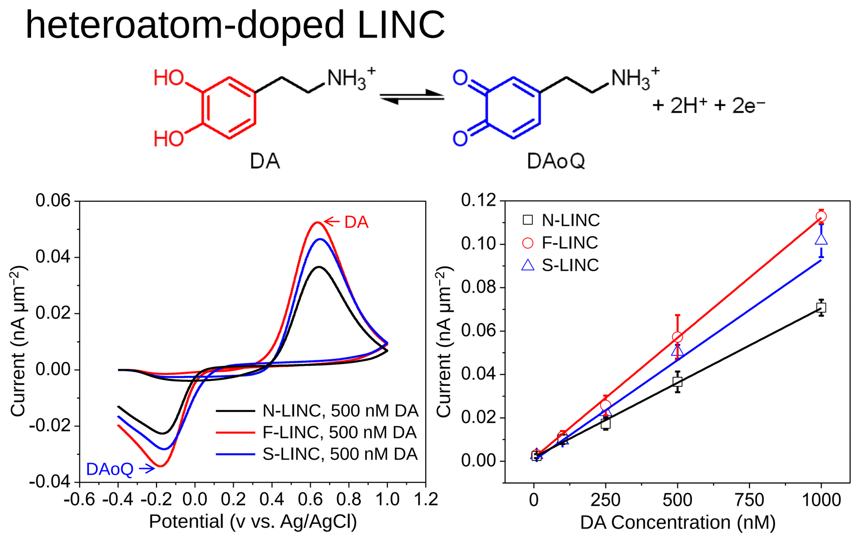


Conductivity & Electrochemical Sensitivity of LINC

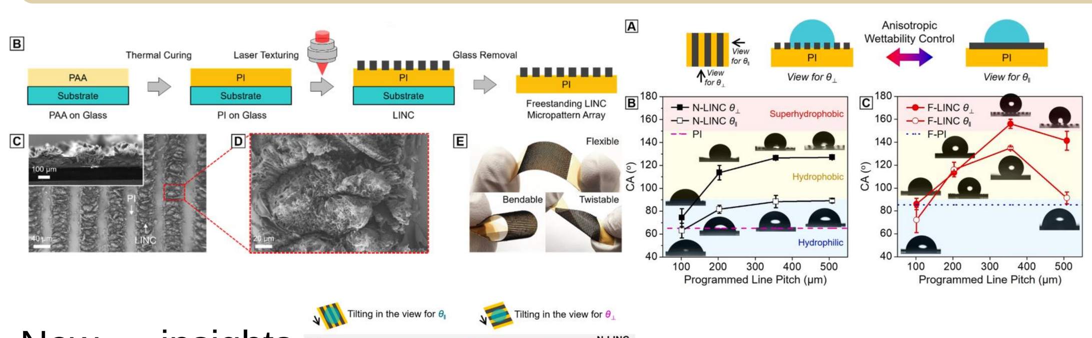
Fluence dependent resistivity correlates with Raman & morphology



Nanomolar sensitivity of LINC to dopamine detection depends on the chemistry of heteroatom-doped LINC

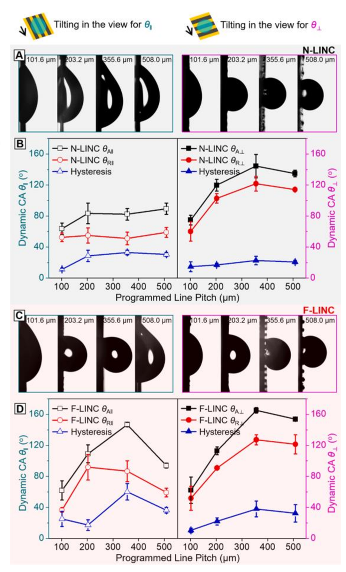


Super Hydrophobicity & Switchable Adhesion

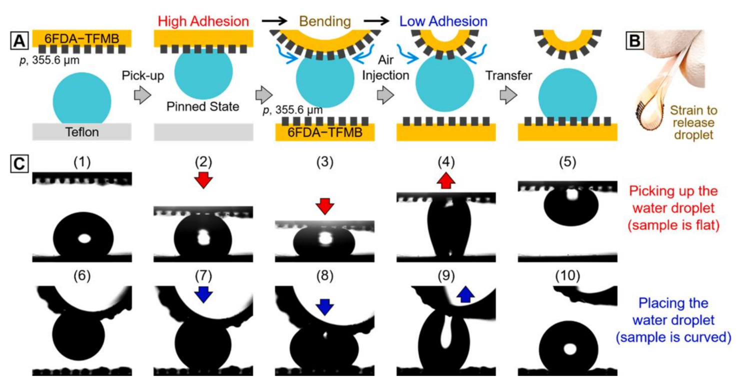


F-LINC shows high dynamic CAs on both directions (∥, ⊥) and highly anisotropic CA hysteresis

New insights into designing interfaces for droplet manipulation, pick-and-place applications, and localized control of reactions.



Transport of a water droplet via strain-induced reversible switching of droplet adhesion with no loss or contamination



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