**🔬 Research Problem**

* Femtosecond laser writing on PDMS film resulted in **surface burning** instead of clean patterning.
* The excessive energy from the laser caused **thermal damage**, compromising the integrity of the PDMS surface.
* A reliable method was needed to **prevent burning** and enable precise laser inscription.

**✅ Proposed Solution**

* **Photoinitiators** were doped into the PDMS matrix.
* These additives **absorbed excess laser energy**, reducing thermal stress.
* Enhanced **curing efficiency** led to clean, controlled laser writing without surface degradation.

### 🔬 Research Problem

* The initial solution using photoinitiators in PDMS showed promise, but **optimization was needed**.
* It was unclear how different photoinitiators would affect the **optical properties**, especially the **refractive index** of the PDMS matrix.
* A systematic study was required to evaluate **multiple photoinitiators** and their impact on laser writing precision and material behavior.

### ✅ Proposed Solution

* Several **photoinitiators** were tested within the PDMS matrix.
* Their influence on the **refractive index** was carefully measured and analyzed.
* The study identified specific photoinitiators that **enhanced optical clarity** and **improved laser inscription quality**, paving the way for more refined microfabrication techniques.

### 🔬 Research Problem

* In SERS nanotagging applications, **anchoring xanthene-based chemosensing dyes** onto silver (Ag) nanoparticles posed a challenge.
* Direct attachment risked **altering the dye’s intrinsic sensing properties** due to uncontrolled binding or structural distortion.
* A **precise and stable linkage** was needed to ensure targeted positioning without compromising dye functionality.

### ✅ Proposed Solution

* A **suitable crosslinker** was carefully selected to bridge the dye molecule and Ag nanoparticles.
* This crosslinker enabled **controlled anchoring** of the dye at specific sites on the nanoparticle surface.
* The approach preserved the **basic chemical and optical properties** of the dye, ensuring effective SERS performance and reliable chemosensing.

### 🔬 Research Problem

* **Bacterial cellulose (BC) film** was identified as a promising material for water filtration.
* However, its native surface lacked the **chemical functionality** needed to selectively filter out **cations, organic nutrients, and bacteria**.
* A key challenge was to design a surface modification that would be **selective, efficient, antibacterial**, and **resistant to biofouling**.

### ✅ Proposed Solution

* A **custom molecule** was synthesized to chemically functionalize the BC surface.
* **Silane compounds** were selectively modified to introduce tailored functional groups.
* These groups enabled **targeted pollutant filtration**, while also providing **antibacterial properties** and **biofouling resistance**, enhancing the film’s long-term performance in water purification.

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### 🔬 Research Problem

* **Lanthanide-doped gadolinium nanomaterials** are highly promising for **biological imaging**, but require precise structural control for optimal performance.
* Sodium gadolinium fluoride (β-NaGdF₄) is an ideal host for **luminescent lanthanide ions**, yet its full potential in **dual-modality imaging** (CT and MRI) needed to be explored.
* A challenge remained in engineering a **multifunctional nanostructure** that could combine **X-ray absorption**, **magnetic resonance enhancement**, and **luminescent properties**.

### ✅ Proposed Solution

* Developed **core-shell nanocrystals**: β-NaGdF₄ doped with **Yb/Er** as the core, coated with β-NaGdF₄ doped with **Nd** as the shell.
* The **core (Yb/Er)** enabled **upconversion luminescence**, while the **shell (Nd)** enhanced **near-infrared emission** and added functionality.
* **Gadolinium’s heavy atomic nature** allowed strong **X-ray absorption** for CT imaging.
* Its **seven unpaired electrons** and **long electronic relaxation time** contributed to **MRI contrast enhancement**.
* **XRD analysis** confirmed the successful synthesis of host, core, and core-shell structures with high crystallinity.

### 🔬 Research Problem

* **Nitrous oxide (N₂O)** emissions pose a serious **environmental threat**, contributing to greenhouse gas accumulation.
* The **primary source** of N₂O emissions is agricultural activity, especially the widespread use of **urea-based fertilizers**.
* A solution was needed to **reduce N₂O emissions by at least 30%** without compromising soil fertility or crop yield.

### ✅ Proposed Solution

* Developed a **three-layer coating system** for urea granules to mitigate N₂O release:
  + **First coating**: Slowed down urea dissolution by **3×**, reducing immediate N₂O formation.
  + **Second coating**: Chemically converted released N₂O into **nitrates**, minimizing gaseous loss.
  + **Third coating**: Incorporated **denitrifying bacteria** to biologically suppress N₂O emissions.
* Achieved a **37% reduction** in N₂O emissions compared to uncoated urea.
* Designed an **automated monitoring system** to simultaneously track emissions from five sample types:
  + Soil without urea
  + Uncoated urea
  + Urea with first coating
  + Urea with two coatings
  + Urea with all three coatings

### 🔬 Research Problem

* **Traditional silicon-based electronics** struggle to perform reliably in **dynamic biological environments** due to their rigidity.
* There is a growing need for **soft, stretchable materials** that can integrate with human motion for **wearable and biocompatible technologies**.
* A key challenge was to develop a material that could **mimic neural feedback**, translating mechanical strain into meaningful electrical signals.

### ✅ Proposed Solution

* Designed a **stretchable polymer fiber** capable of converting **mechanical strain into electrical signals**, emulating neural feedback.
* Demonstrated dual functionality through two targeted applications:
  + A **feedback-controlled oscillator** for digital event detection
  + A **wearable goniometer** for analog strain sensing
* Developed a **proof-of-concept system** where movement patterns from a healthy muscle were recorded and transmitted to an actuator on a weakened muscle, enabling **targeted motor recovery**.
* This work lays the foundation for **neural-mimetic interfaces** that are **scalable, adaptive**, and seamlessly integrate with **human motion**, advancing assistive rehabilitation technologies.

### 🔬 Research Problem

* The demand for **versatile materials** that can address multiple environmental and technological challenges is growing.
* Traditional hybrid materials often lack **multifunctionality**, **regenerability**, and **cross-domain adaptability**.
* A solution was needed to create a **universal molecular platform** capable of performing across disciplines—from environmental remediation to advanced packaging.

### ✅ Proposed Solution

* Synthesized **POSS-3N**, a polyamine-functionalized silsesquioxane via a **catalyst-free, optimized route** with reduced synthesis time and improved yield.
* Characterization confirmed a **centimeric molecular architecture**—featuring **uniformly spaced reactive amine sites** that enable **multivalent interactions**.
* This unique structure endowed POSS-3N with **multitasking capabilities**, making it a **universal molecule** adaptable to diverse applications:
  + **Low-pressure CO₂ capture**
  + **Selective sorption of heavy metals** (Cu²⁺ > Pb²⁺ > Cd²⁺)
  + **Integration into gelatin-based films** for supporting **green-synthesized silver nanoparticles**
* Statistical and thermodynamic modeling reinforced its **mechanistic robustness** and **cross-functional performance**.
* The molecule’s **centimeric qualities** position it as a **scalable, regenerable, and multifunctional platform** for **environmental, biomedical, and industrial applications**.



