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Nanocrystalline Diamond-Like Carbon Coatings Boost Field-Emission Efficiency of Silicon Nanowires

Kalyan Sarkar[1*], Sucharita Saha[2]
[1,2]Senior Research Fellow, Energy Research Unit, School of Materials Sciences, Indian Association for the Cultivation of Science, Kolkata.
E-mail: [1]erks@iacs.res.in, [2]erss2@iacs.res.in

INTRODUCTION & AIM

- **Field emission (FE)** involves electron tunneling under high electric fields and is essential for devices like flat-panel displays, X-ray sources, and electron microscopes.
- **Silicon Nanowires (SiNWs)** offer excellent FE enhancement due to their sharp tips and high aspect ratio but suffer from oxidation and emission instability.
- **Nanocrystalline Diamond-Like Carbon (nc-DLC) coatings** add chemical stability, high sp^3 content, and negative electron affinity (NEA), improving emission performance.
- This study combines **SiNWs with nc-DLC coatings** to enhance FE efficiency.
- We investigate how the **coating time (or coating layer's thickness)** influence the overall hybrid material **(SiNW/nc-DLC)** structure and field emission behavior.

METHOD

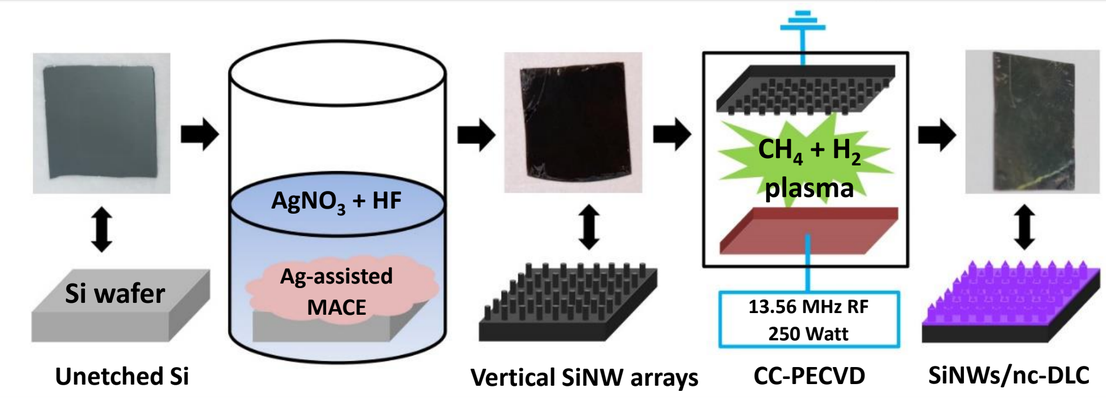
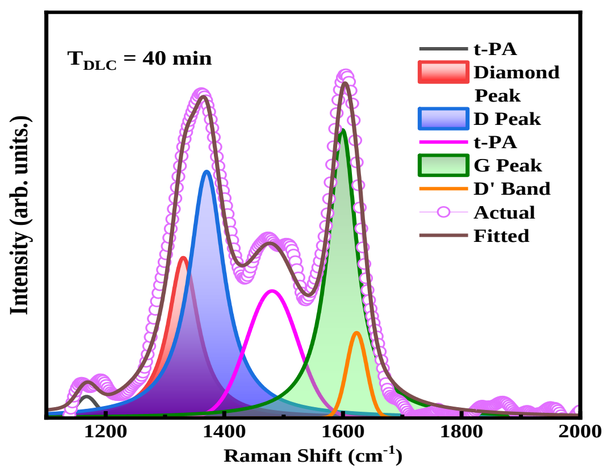


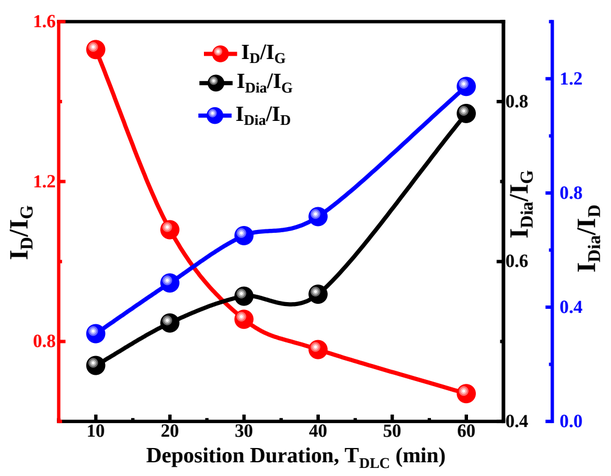
Fig. 1: Schematic of the sequential steps forming SiNW/nc-DLC hybrid structures

- **SiNW Fabrication**: via **metal assisted chemical etching (MACE)** from crystalline Si wafers
- **nc-DLC Deposition**: in **capacitively coupled plasma enhanced chemical vapour (CC-PECVD)** deposition using CH_4/H_2 gas mixture ratio 1:1, 450 °C, 250 W RF power, 4 Torr pressure
- **nc-DLC Coating Time (T_{DLC}) Variation**: 10–60 min
- **Characterization**: Raman, XPS, SEM, TEM, FE characteristics

RESULTS & DISCUSSION

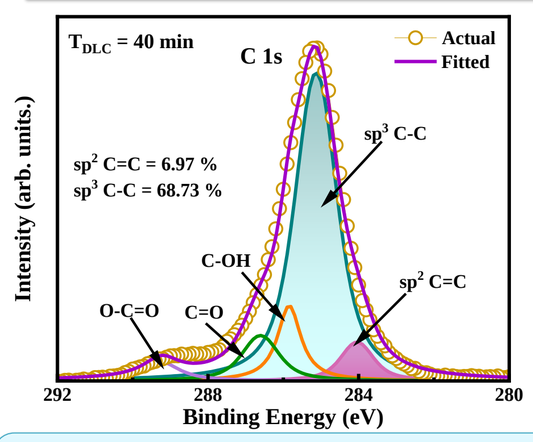
Raman Spectroscopy of nc-DLC layer coated on SiNWs

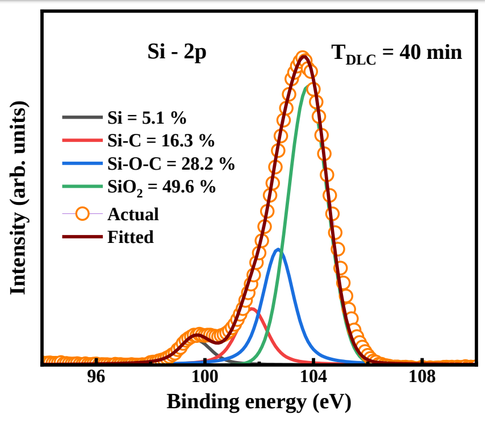




- At T_{DLC} = 60 min, Min I_D/I_G = 0.67, max I_{Dia}/I_D = 1.17 and max I_{Dia}/I_G = 0.79
- Min I_D/I_G corresponds to lowest disorder
- Higher I_{Dia}/I_D and I_{Dia}/I_G indicates more diamond-like crystalline orientation (sp^3 C-C) relative to the disorderness and graphitic (sp^2 C=C).
- At T_{DLC} = 40 min, a moderate nano-crystallinity is obtained.

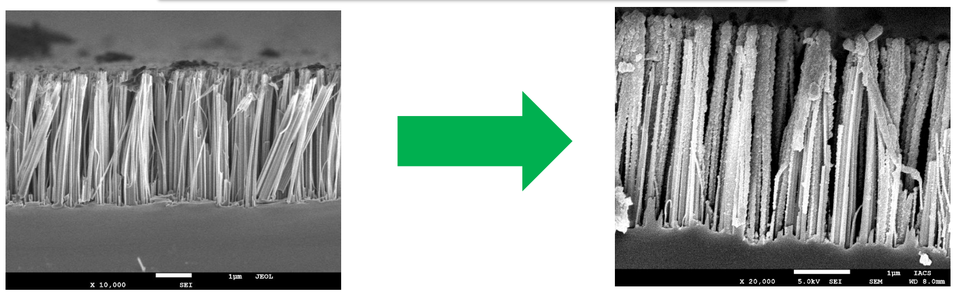
X-ray Photoelectron Spectroscopy of nc-DLC layer coated on SiNWs





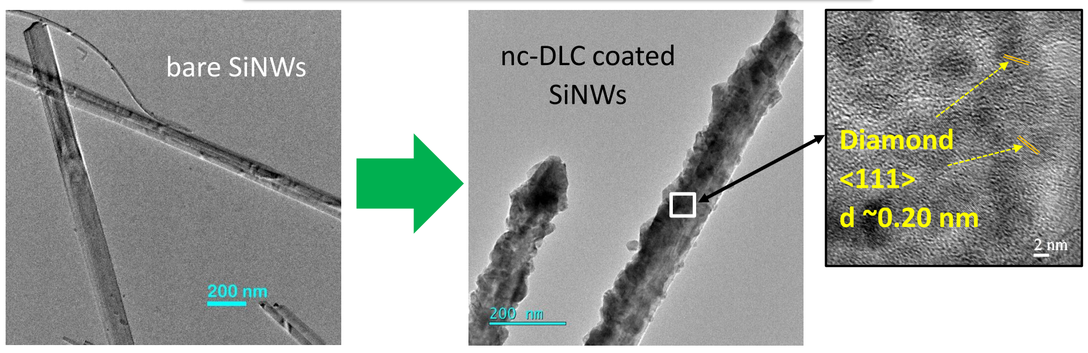
- At T_{DLC} = 40 mins, C 1s XPS shows sp^3 C-C content = 68.73%
- From Si-2p, the Si-C = 16.3%, which is the highest in the series.

Cross-Scanning Electron Microscopy

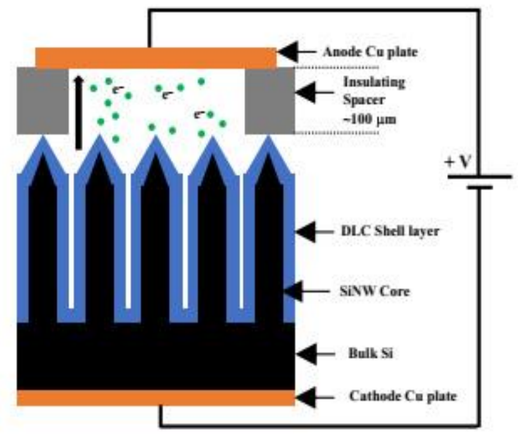


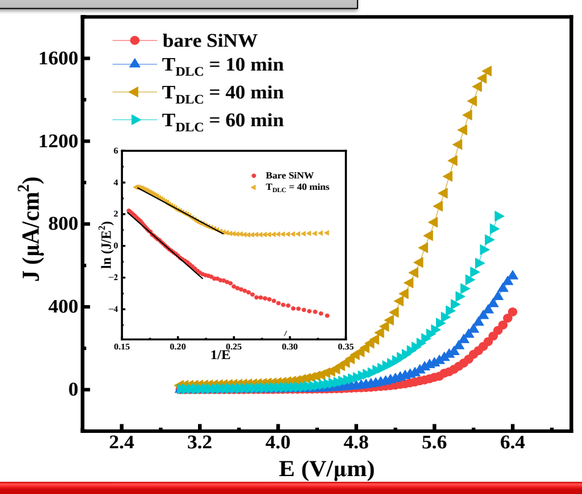
Vertical bare SiNW arrays — nc-DLC coated SiNW arrays

Transmission Electron Microscopy



Field Emission Characteristics





CONCLUSION

- SiNW/nc-DLC hybrids **show significantly enhanced FE performance** compared to bare SiNWs, Increasing sp^3 content and nanocrystallinity with T_{DLC}, lowers the surface potential barrier and improves electron tunneling
- **Optimal DLC coating time (T_{DLC} = 40 min) yields the best performance**: Turn-on field (E_{ON}) reduced from ~5.80 V/µm (bare) to 4.60 V/µm, Emission current density (J_e) peaks at 1393.46 µA/cm², Field enhancement factor (β) rises to 1676.01
- **Over-coating (T_{DLC} = 60 min) increases DLC thickness, leading to reduced emission** (E_{ON} = 5.05 V/µm, β = 1518.34), highlighting the importance of thickness optimization.
- **Enhanced FE is attributed to**: sp^3-rich nanocrystalline domains lowering the barrier grain boundaries and defects acting as emission sites.
- **Excessively thick coatings**, however, reduce β by increasing emitter tip radius and limiting electron escape