COMPARISON OF LASER-INDUCED GRAPHENE ON DIFFERENT TYPES OF SYNTHESIZED CROSSLINKED POLYIMIDES

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INTRODUCTION

Laser-induced graphene (LIG) enables rapid, low-cost conversion of carbon-rich precursors into graphene, with **applications in flexible electronics, sensors and electrochemical electrodes**. Polyimides are especially suitable precursors, yet studies on synthetically tailored polyimides remain limited.

In this work graphene was induced on a series of newly synthesized polyimide substrates. The polyimides were obtained by polymerization in solution at elevated temperatures using *N*-[3-(2,5-dioxo-2,5-dihydro-1H-pyrrol-1-yl)phenyl]acetamide in combination with selected diamine compounds with terminal amino groups: urea, 4-[(4-aminophenyl)sulfonyl]aniline (APSA) and 1,2-diaminoethane (EDA). After successful graphene induction, the resulting materials were analyzed to determine their nanomechanical, optical and electrical properties, with a focus on potential applications in electrochemical systems. Characterization techniques included Raman spectroscopy, XPS, XRD analysis, adhesion testing, water contact angle and sheet resistance measurements. The results provide valuable insights into the correlation between the molecular structure of polyimide and the efficiency and quality of laser-induced graphene, underlining the promise of these materials in electrode applications.

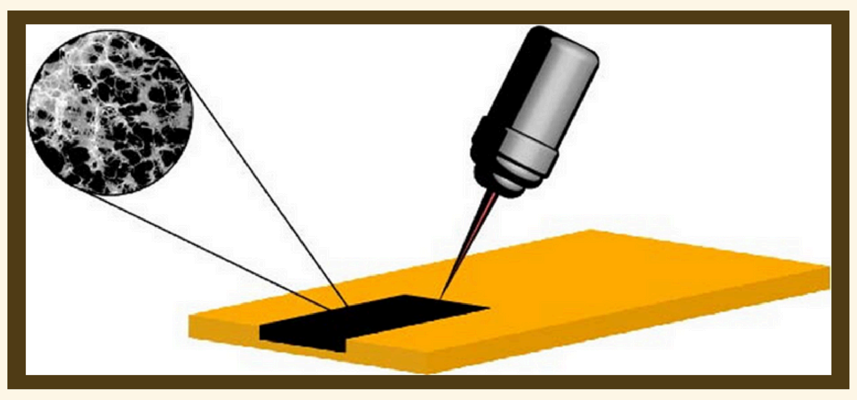

Figure 4. Production of LIG by CO_2 laser beam

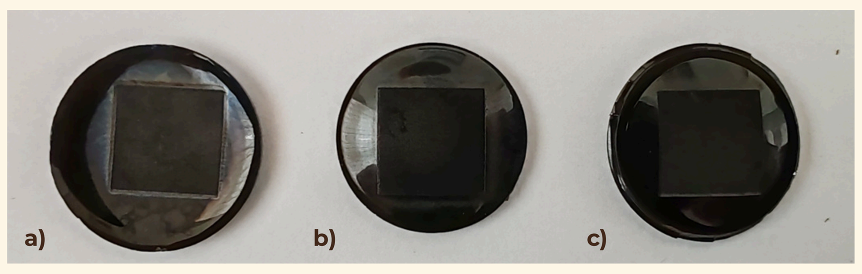

Figure 5. Photographs of LIG on PI samples
a) APSA-LIG, b) EDA-LIG, c) UREA-LIG

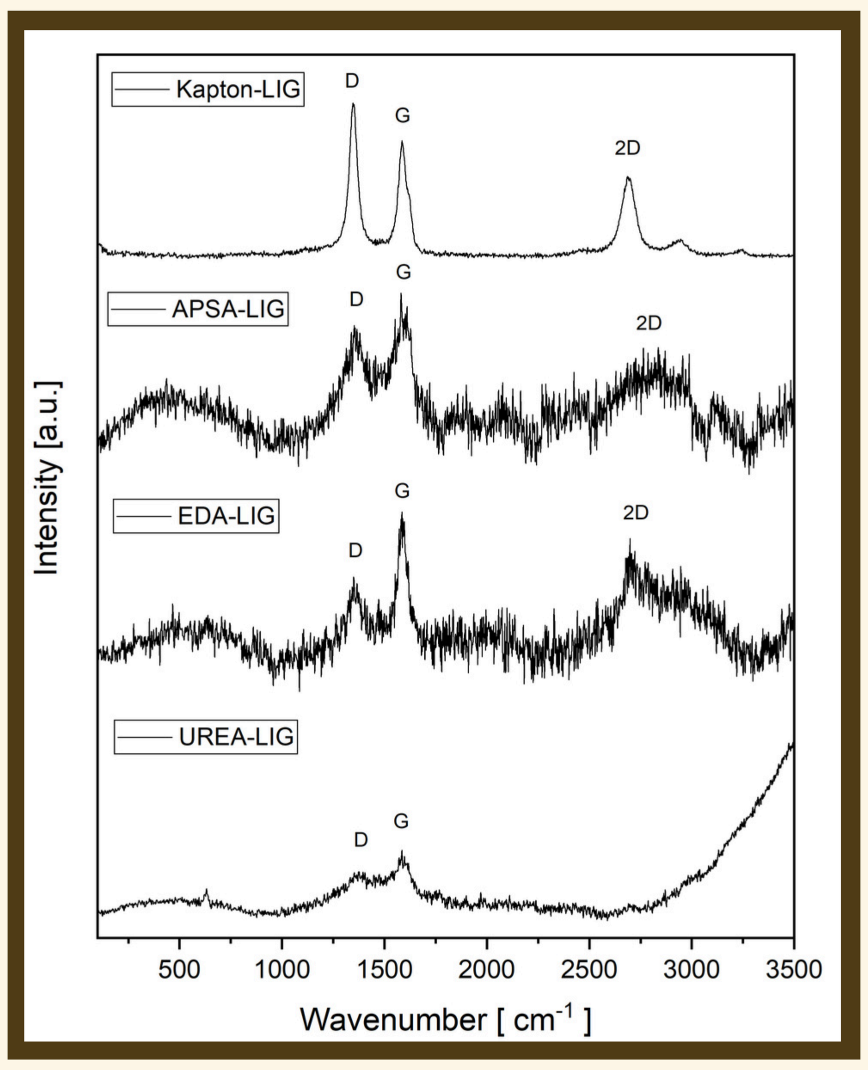

Figure 6. Raman spectra of Kapton-LIG and PI-LIG samples

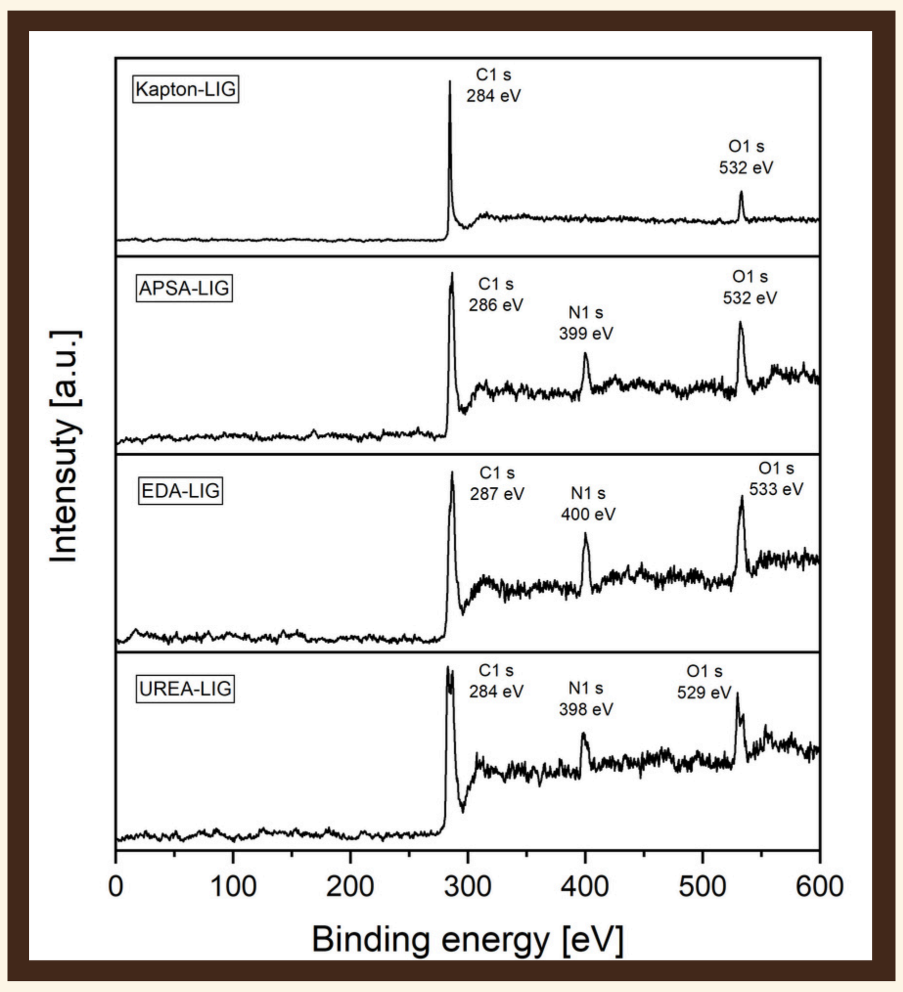

Figure 1. XPS spectra of Kapton-LIG and PI-LIG samples

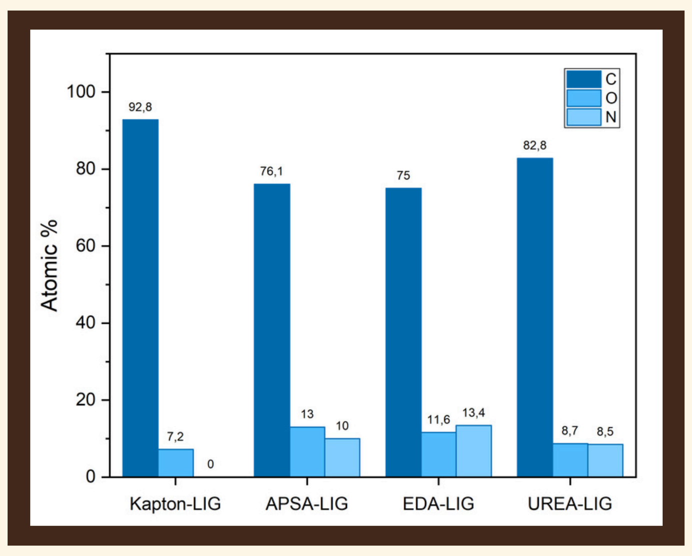

Figure 2. Comparative percentages of C, O, N in Kapton-LIG and PI-LIG samples

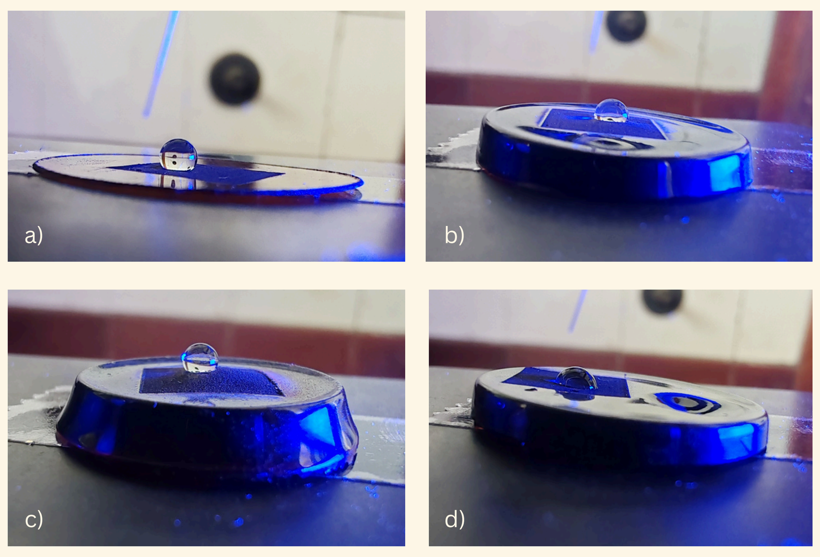

Figure 3. Water contact angle measurements. Water drop on Kapton-LIG (a), APSA-LIG (b), EDA-LIG (c), UREA-LIG (d)

Table 1. Sheet resistance of PI-LIG samples

Sample	R [Ω/sq]
Kapton-LIG	89.62
APSA-LIG	29.37
EDA-LIG	218.43
UREA-LIG	30.23

Table 2. Water contact angle measurements for PI and PI-LIG samples

Sample	PI [°]	PI-LIG [°]
Kapton	77 ± 3	104 ± 7
APSA	76 ± 7	104 ± 2
EDA	74 ± 4	101 ± 5
UREA	73 ± 4	76 ± 16

Table 3. LIG resistance before and after Scotch tape test

Sample	R_{before} [kΩ]	R_{after} [kΩ]
Kapton-LIG	0.357	13.6
APSA-LIG	0.064	0.08
EDA-LIG	0.170	13000
UREA-LIG	0.160	200

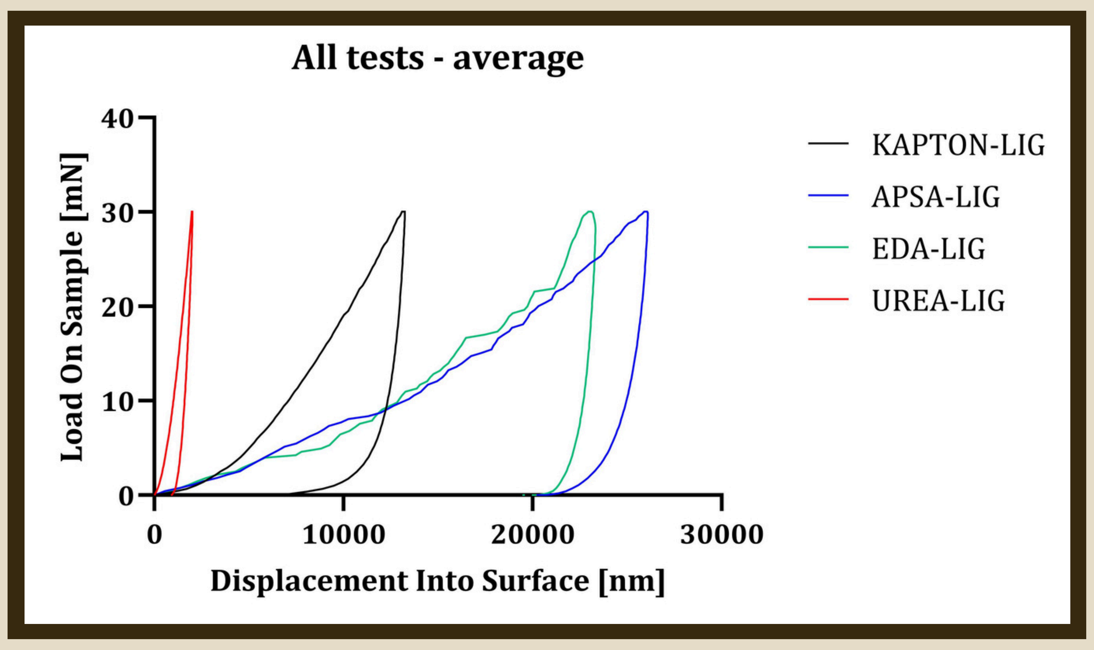

Figure 7. Average load-displacement curves for PI-LIG samples

Table 4. Nanomechanical properties of PI-LIG samples

Sample	Young's Modulus [GPa]	Hardness [GPa]	Plasticity (Ductility) Index
Kapton-LIG	0.452±0.081	0.008±0.002	56.50
APSA-LIG	0.185±0.065	0.002±0.001	92.50
EDA-LIG	0.379±0.222	0.003±0.003	126.33
UREA-LIG	6.627±1.065	0.458±0.055	14.48

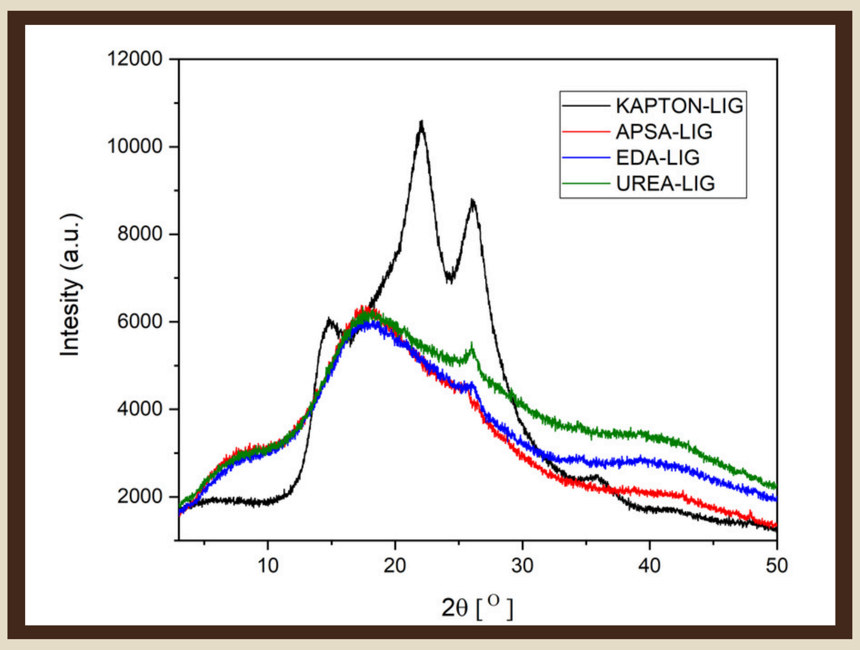

Figure 8. XRD spectra of LIG on Kapton and different types of synthesised PIs

CONCLUSION

In this work, three different types of polyimides were successfully synthesized and subsequently used for the production of laser-induced graphene (LIG). The structural characterization by Raman spectroscopy, XRD, and XPS confirmed the successful induction of graphene, while additional measurements of mechanical and electrical properties further demonstrated the high quality of the obtained materials. When compared to the reference LIG prepared on commercial Kapton, the newly developed systems exhibited superior performance.

In particular, the APSA-LIG and UREA-LIG samples showed significantly reduced sheet resistance, which is highly advantageous for applications in flexible and wearable electronics, advanced sensor platforms, and electrochemical energy storage devices. The adhesion of LIG to the APSA-LIG material is exceptionally strong, which is of significance for all applications. All the studied materials are hydrophobic when LIG is induced on them, except the one with UREA, which is important for wearable device applications. It is noteworthy that the mechanical properties depend on the substrate material and can thus be selectively tuned.

These outstanding results highlight not only the effectiveness of the synthetic strategy but also the remarkable potential of these novel polyimide-derived LIG materials for next-generation technologies. Their combination of high electrical conductivity, strong adhesion, and favorable optical properties makes them particularly suitable for multifunctional applications where mechanical robustness, durability, and performance are simultaneously required.

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POLYGRAPH