1. Publishable summary

Summary description of project context and objectives

The project GLADIATOR (Graphene Layers: Production, Characterization and Integra-tion) has been driven by the vision of developing an approach to the production of high quality graphene (transmittance ≥ 90%, sheet resistance ≤ 10 Ohm/sq.) on a large scale and at low cost. This will make this type of graphene (produced by chemical vapour deposition - CVD) a compete¬tive alternative to electrode materials currently used in (flexible) organic electronics, such as indium tin oxide (ITO). The project has now finished after its 42 month duration and has achieved very promising and interesting results. Major re¬sults are outlined below:
• Doping to improve conductivity: A new doping system which is both stable over time and temperature has been identified. The dopant is applied by spray-coating and is fully scalable on large area. The best graphene dopant system featured sheet resistance (61 Ω/sq.) and transmission (84%) values which are very good.
• Process control: A spectroscopic ellipsometer (SE) has successfully been integrated into a graphene 150 mm CVD reactor to perform multiple in-situ and real-time optical measurements during graphene growth. From these data, first models on the growth mechanisms on Cu and Ni substrates are postulated. Arising from that a second SE tool has been installed into a 300 mm CVD production tool enabling the monitoring of the production process. A Raman spectrometer has been integrated into a 150 mm CVD, too.
• Characterisation of sheet resistance: A set-up based on contactless eddy current meas-urements has been developed, whereas sheet resistances up to 5,000 Ω/sq. can be evalu-ated. Edge effects compensation methods allow now measurements 3 mm close to the edge. Along with single point measurement, also maps including more than 250,000 measurements can be produced providing insights on defect density.
• Large volume production of undoped graphene: Both on 100, 150 and 300 mm wafer size, multiple (≥25) graphene growth processes have been performed and reliability has been verified by Raman spectroscopy. Scale-up studies have been carried out to pro-vide concepts how the graphene quantity can be increased and the production cost fur-ther decreased. It is estimated that graphene can be produced for 30 €/m2 (excluding the cost of target substrates).
• Hazard assessment: both graphene oxide (GO) and reduced GO were found to be toxic following pulmonary exposure at occupationally relevant dose levels, with GO being more toxic than reduced GO. Work place exposure measurements have been performed for an 8 h day having CVD reactors in a lab and production environment (with opening and closing the reactor) and revealed that no particles could be detected. Since the ex-posure levels are very low, the health risk is low even though both materials appeared quite toxic following pulmonary exposure.
• Large area graphene transfer on flexible foils and glass: Barrier foils with a water va-pour transmission rate ≤ 10-4 gm-2d-1 have been realized, which can also be used to per-form semi-dry graphene transfer. Additionally, cost efficiency for the production of that foil type has been taken into account. In parallel to these efforts, A4 large graphene sheets have successfully been transferred to these barrier foils using (poly)vinylalcohol as supporting transfer polymer.
• Integration into organic electronics: succeeded in fabricating UV-sensitive organic pho-todiodes (OPDs) demonstrating the high UV transmissivity of graphene combined with low dark current. One of the OPDs have been integrated into a smoke detector. Fully flexible and semi-transparent OLED of the size of 1.5×2 (cm)2 and a large area rigid OLED with a supporting grid of 42.3 (cm)2 using graphene as anode have been built.

Description of work performed and main results

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been driven by the vision of developing an approach to the production of high quality graphene (transmittance ≥ 90%, sheet resistance ≤ 10 Ohm/sq.) on a large scale and at low cost. This will make this type of graphene (produced by chemical vapour deposition - CVD) a compete¬tive alternative to electrode materials currently used in (flexible) organic electronics, such as indium tin oxide (ITO).
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Expected final results and potential impacts

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Project public website address:	www.graphene-gladiator.eu

2. Core of the report

Project objectives, Work progress and achievements, and project management during the period

The Project Summary Pdf document contains the core of the report.