**Supporting information**

**Undercooling driven growth of Q-carbon, diamond, and graphite**

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**Finite-element simulations:** To understand the laser-solid interactions carbon melting on Si and Sapphire substrates, finite-element simulations are performed using laser-solid melt interactions (SLIM) for surface temperature profiles and COMSOL *Multiphysics* for depth dependent temperature maps. **Fig. S1a** reveals the temperature *vs.* time profiles for PLA (at 0.8 J cm-2) of DLC thin films grown on silicon and sapphire wafers respectively. As sapphire has much lower thermal conductivity, it traps the heat increasing melt lifetime upto 100 ns. Due to the higher thermal conductivity of Si, upon PLA only the surface overlayer of DLC melts as revealed in **Fig. S1b**, while the film/substrate interface remains in solid phase attaining maximum temperature ~2000 K. **Fig. S1c** reveals that complete melting of carbon film occurs for DLC grown on sapphire as the film/substrate interface achieves temperature over 4000 K. Increased heat trapping at the substrate leads to faster regrowth rates triggering formation of Q-carbon for DLC films grown on substrates with low thermal conductivity.

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**FIG. S1** (a) Temperature *vs*. time profile after PLA using 0.8 J/cm2 laser energy density simulated using SLIM programming for DLC deposited on silicon and sapphire substrates. Fig. (b) and (c) highlight the depth-dependent temperature profiles at 10 ns, calculated using COMSOL *Multiphysics* for DLC grown on silicon and sapphire, respectively.