FuelGems Nanotechnology Characterization

Figures 1 and 2 present TEM images of typical particles in sample N1 and N2, respectively. Low magnification images of both samples (top row images) show aggregates of interconnected round particles. They have diameters of about 20-30 nm in sample N1 and about 40-50 nm in sample N2. The detailed structure of these particles can be seen in high-resolution (HR) TEM images shown in middle and bottom rows of Figures 1 and 2. In both samples, the particles have the structure of turbostratic carbon. They are composed of graphitic planes of sp^2 carbon. In many places, planes are concentric and parallel one to another forming onion-like carbon (OLC) structures. However, the particles show also high degree of disorder and some amorphous carbon. Furthermore, many particles show some empty spherical cavities in their cores. All these observed morphological features, i.e., aggregates of interconnected spherical particles with disordered OLC structure and empty core cavities. The additional feature present in most of the HRTEM images of sample N1 are small iron-containing nanoparticles (< 5 nm) appearing as darker spherical spots.

Figure 3 shows Raman spectrum from a sample containing these carbon particle aggregates. The spectrum consists of four peaks located at about 1340, 1590, 2680, 2930 cm^{-1}, respectively. The G band at about 1590 cm^{-1} corresponds to the E_{2g} phonon mode. The D peak at about 1340 cm^{-1}, is a phonon mode often assigned to tetrahedrally-bonded (sp^3) carbon atoms in diamond-like structures [7,8]. In graphitic structures, the D peak originates from high degree of disorder and defects. All Raman lines are relatively broad, which indicates the strong disorder of this carbon material, which is consistent with HRTEM images. The 2D peak at around 2680 cm^{-1} is a second order phonon mode, which is an overtone of the D band and its appearance indicates the presence of sp^2 carbon planes. However, the relatively low intensity and significant broadening of this peak indicates strong disorder. The D + G peak at around 2930 cm^{-1} has been assigned to the sp^2 and sp^3 C-H stretching vibrations. Its broadening is yet another indication of the disorder. In agreement with TEM and HRTEM images.

Figure 4 shows Raman spectra from sample N1 (left) and N2 (right). The strong broad band visible in both samples across the region characteristic for carbon peaks is a strong luminescence peak. The only Raman signal that can be detected is the low-energy structure measured for sample N1 (see inset in left panel).

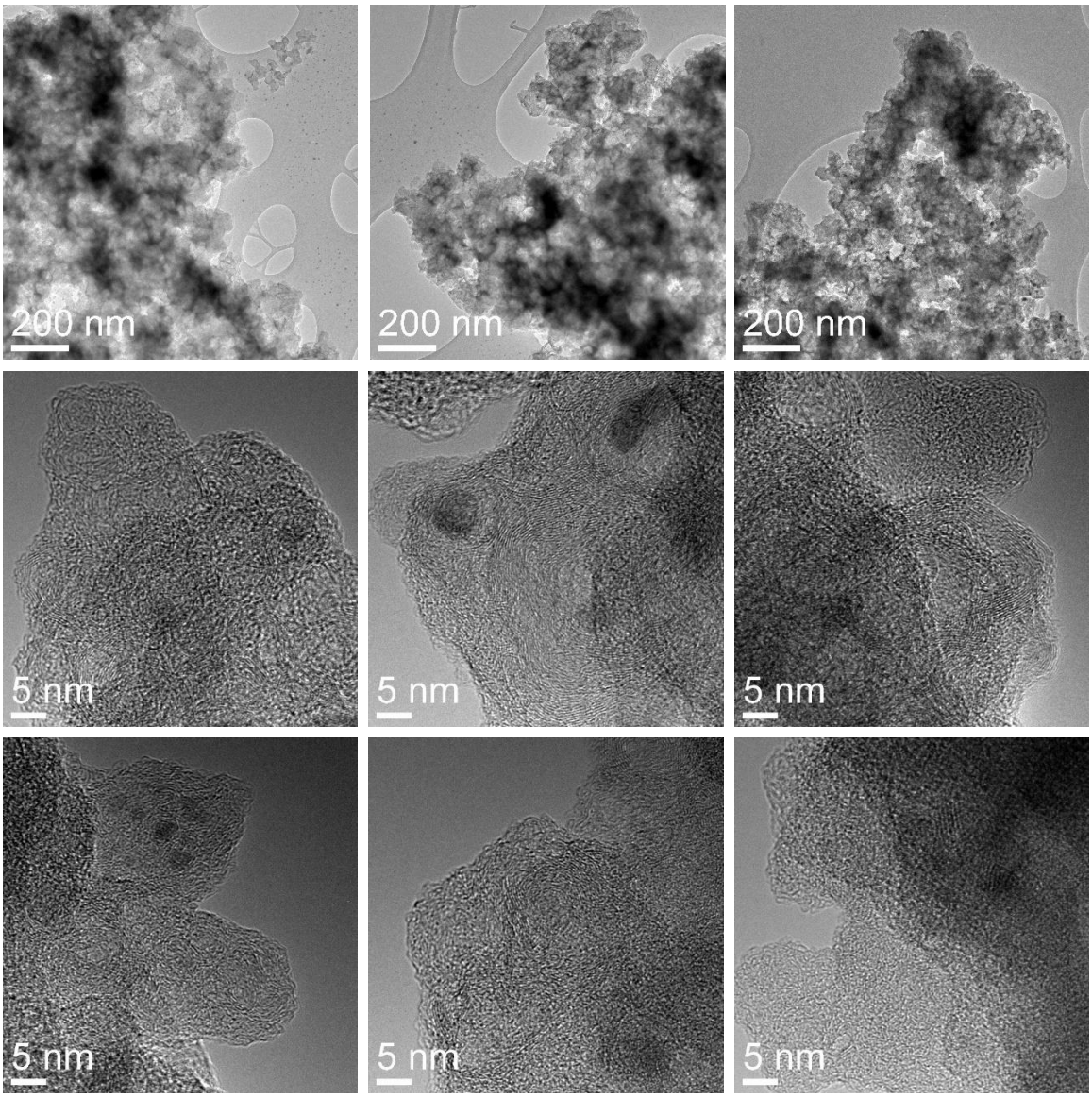

Figure 1. Low- (top) and high-magnification (middle and bottom) TEM images of carbon aggregate particles in sample N1.

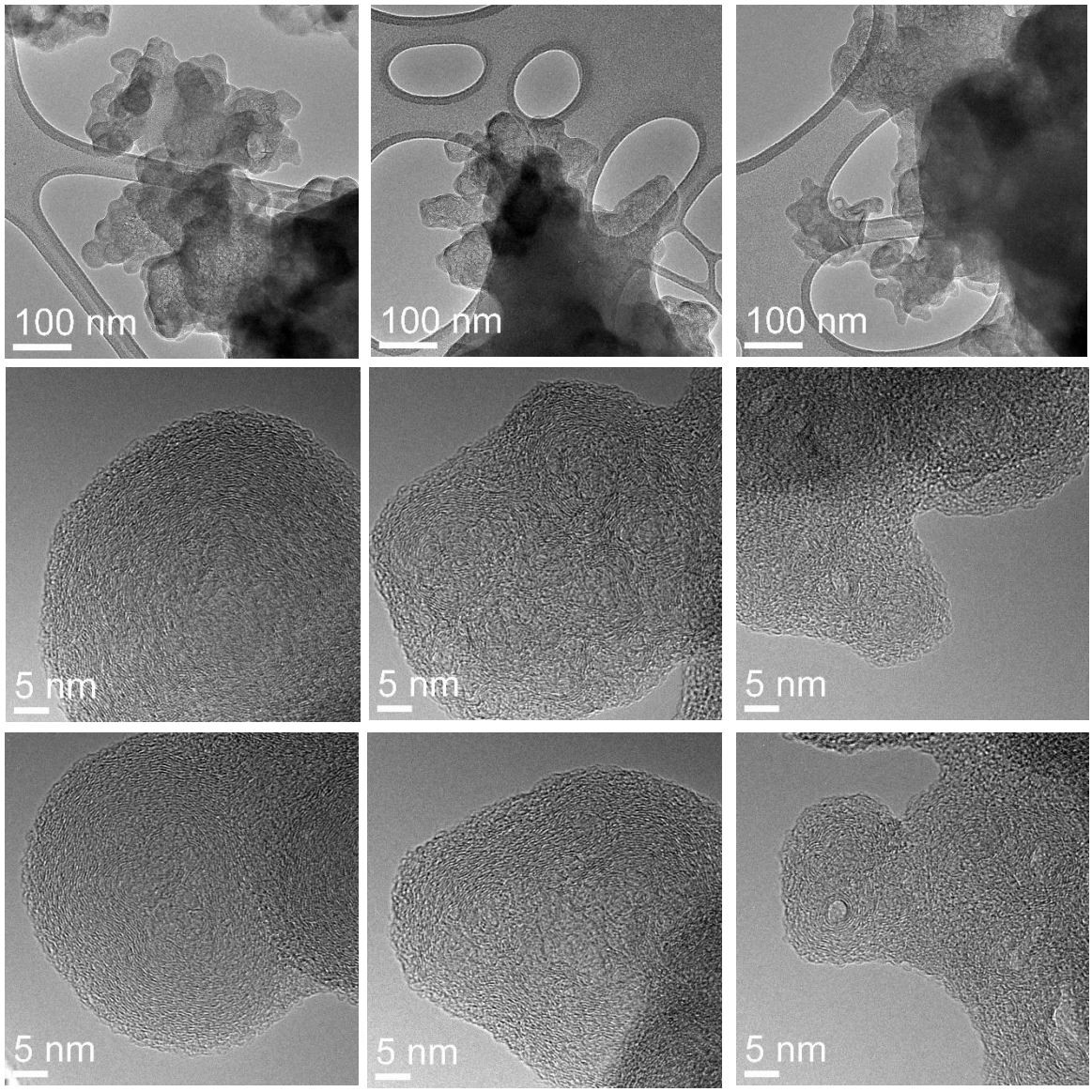

Figure 2. Low- (top) and high-magnification (middle and bottom) TEM images of carbon aggregate particles in sample N2.

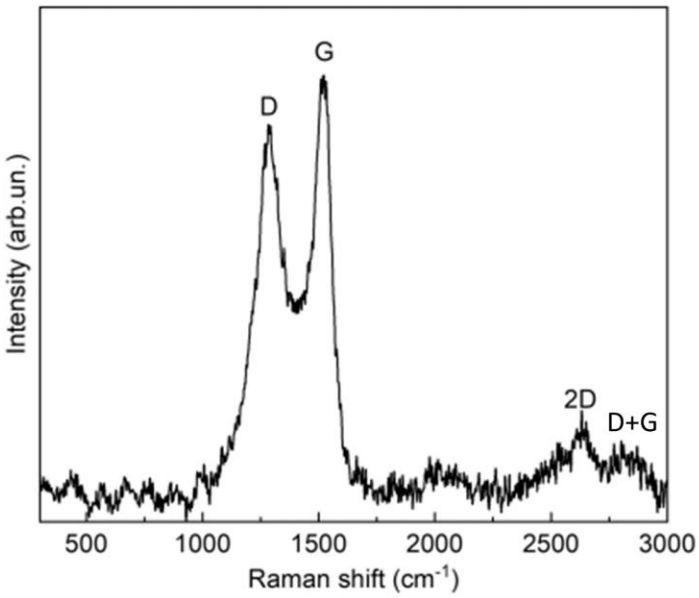

Figure 3. Raman spectrum of sample containing carbon aggregate particles.

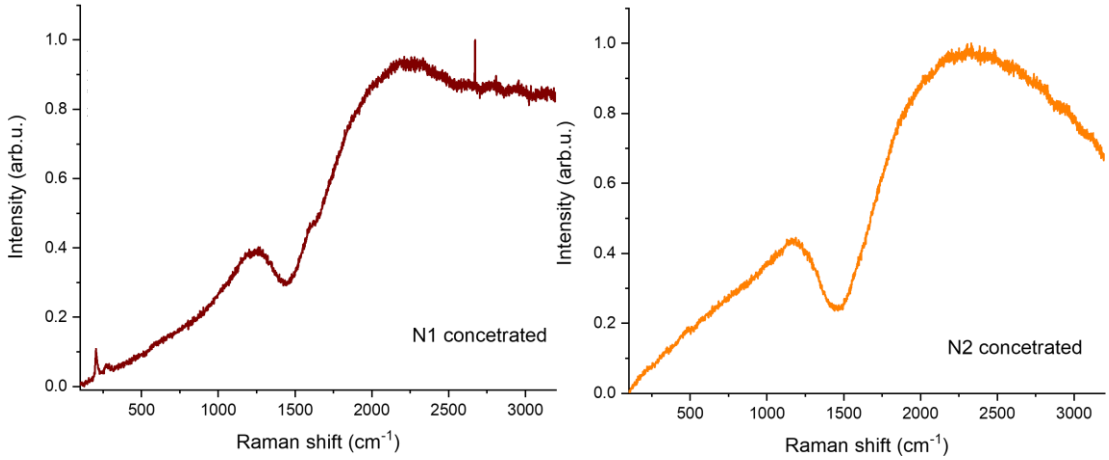

Figure 4. Raman spectra of sample N1 (left) and N2 (right). Inset shows background-subtracted low-energy region of sample 1.