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Three-Dimensional Spatial-Topology Effects, Magnetoresistance in Three-Dimensional Porous Graphene

Spatial topology is a critical factor for graphene due to its spatial symmetry arranged in hexagonal lattice. Actually, many studies on spatial-topology modification have been reported, such as 1D or 0D graphene (graphene nanoribbon [1,2] and quantum dot [3], respectively), antidot system [4,5], and strained graphene inducing gauge field [19, 20]. As a new platform, upsizing 2D graphene into 3D architectures is also interesting for exploring new physics. Many theoretical studies on such 3D graphene systems has been reported on viewpoints of 3D-topology effects [6-8]. Particularly topological defects which are geometrically required to form 3D architecture with negative Gaussian curvatures. Since such 3D-topologyccal effects are expected to bring intriguing physics, experimentally exploration is strongly demanded.

Recently high-quality 3D graphene which has open porous structure smoothly interconnected graphene network without edge and fringes [9] have been developed with chemical vapor deposition (CVD) method,. This 3D porous graphene preserves the properties of Dirac fermion well, allowing us to explore interesting phenomenon only observed in 3D graphene system. Additionally, the 3D-spatial topology such as pore size can be tune by CVD conditions, providing pore size dependence of curvatures and topological defects. It will provide a platform for investigating the topological effect. In this report, we experimentally investigated 3D spatial-topology effects through the electrical transport measurements.

We synthesized open and smoothly inter-connected 3D graphene with different pore size of 100–300 nm and ~1 μm (Figs. 1(a,b)).Raman spectra of these samples demonstrated that the 3D graphene is composed by single-layer graphene due to the high 2D/G intensity ratios (Fig. 1(c)). We performed magnetoresistance (MR) measurements at 3.8 K with a standard four probe method in Fig. 2(a). The large pore-sized (~1 μm) sample shows a conventional positive MR, whereas the small pore-sized (100–300 nm) sample exhibits negative MR (weak localization). These comparation are a clear indication of the spatial-topology effects on the magnetic-field correction, showing the strong dependence on spatial topology of the pore size.

According to the theoretical report [10], several scattering rates including elastic scattering events can be deduced owing to the nature of quasiparticle chirality in graphene. Figure 2(b) plots the T dependence of the ratio $\tau_i^{-1}/\tau_\varphi^{-1}$, where τ_i^{-1} and τ_φ^{-1} are the intervalley and dephasing scattering rate, respectively. It is found that intervalley scattering event prevails in the sample with small pores at low temperature, and that inelastic scattering event is dominant regardless of the pore size at high temperature. These results show that the curvature of graphene surface is strongly related with intervalley scattering events.

Through purely geometrical considerations, 3D graphene structures with high curvature require much topological defects according to the Euler's theorem. At topological defects, especially odd-number carbon ring, when the momentum vector k of carriers revolves around the singularity $k = 0$ (Γ point), K point reverses to K' one. It is the main reason of intervalley scattering events. Our findings provide not only deeper understanding of 3D graphene systems but also pave a new way to realize a spatial-topology controllability of valleys.

References

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Figures

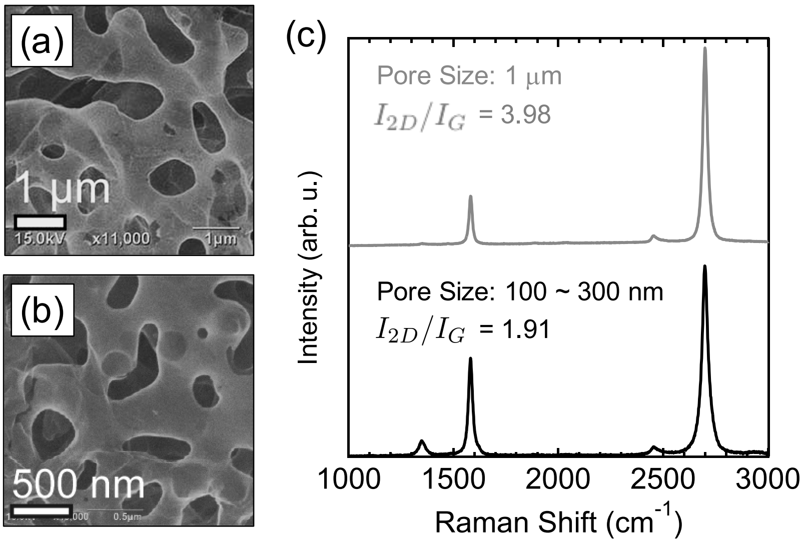

Figure 1: (a,b) Scanning electron microscopy images of the 3D porous graphene with 1 μm (a) and 100–300 nm (b) in a diameter.

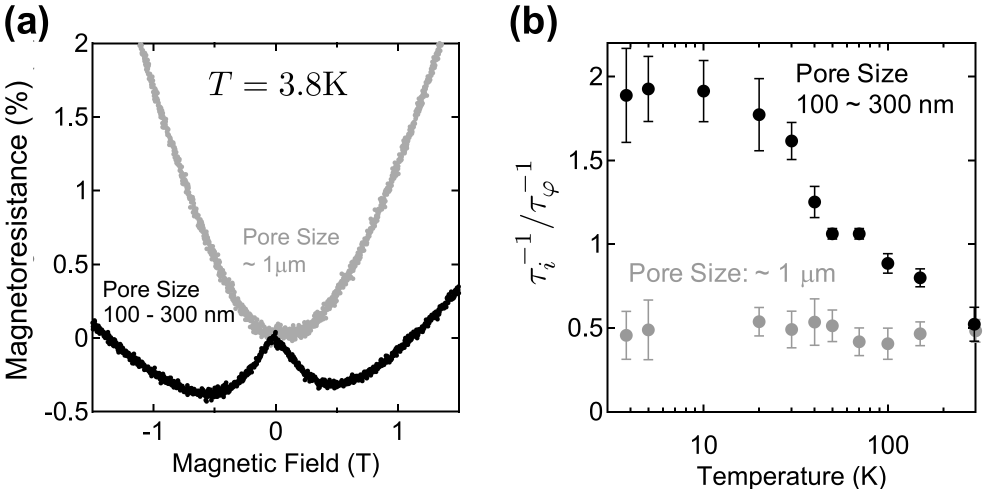

Figure 2: (a) Pore-sized dependence of the normalized magnetoresistance at 3.8 K. (b) Temperature dependence of the ratio $\tau_i^{-1}/\tau_\varphi^{-1}$.