Growth and Characterization of Graphene-like 2D Nanolattices of Silicene and AlN

A. Dimoulas[1], E. Xenogiannopoulou[1], P. Tsipas[1], D. Tsoutsou[1], S. Kassavetis[1], E. Golias[1], S.A. Giamini[1], C. Grazianetti[2,3], D. Chiappe[2], A. Molle[2], M. Fanciulli[2,3]

[1]National Center for ScientificResearch "Demokritos", 15310, Athens, Greece
[2]Laboratorio MDM, IMM-CNR, I-20864, Agrate Brianza (MB), Italy
[3]Dipartimento di Scienza dei Materiali, Università degli Studi di Milano Bicocca, I-20126, Milano, Italy
Contact@E-mail: dimoulas@ims.demokritos.gr

Abstract (Arial 10)
The outstanding properties of graphene have opened the way to search for other two-dimensional (2D) sp2 hybridized materials. The graphene's "cousins" silicene and germanene, the 2D semiconductor MoS2 and the insulating hexagonal BN are considered to be the main "ingredients" complementing semi-metallic graphene in new electronic devices. The main idea is that 2D graphite-like materials could couple weakly between each other through Van der Waals forces maintaining the integrity of each layer and preserving their good physical properties near ideal, normally obtained in their free standing form.

Silicene, has recently attracted intense attention, mainly due its compatibility with current Si-based nanoelectronic devices. As free-standing silicene does not exist in nature, there is an increasing effort to realize it on suitable substrates. Remarkably, silicon wets the Ag(111) surface forming a 2D honeycomb network topology with a variety of superstructures and buckling configuration [1].

In the present work the electronic band structure of monolayer (4x4) silicene on Ag(111) (Fig. 1) is imaged by angle resolved photoelectron spectroscopy [2]. A dominant hybrid surface metallic band is observed to be located near the bulk Ag sp-band which is also faintly visible. The two-dimensional character of the hybrid band has been distinguished against the bulk character of the Ag(111) sp-band by means of photon energy dependence experiments (Fig. 2). The surface band exhibits a steep linear dispersion around the K_{Ag} point and has a saddle point near the M_{Ag} point of Ag(111) resembling the p-band dispersion in graphene (Fig. 3).

To integrate silicene on suitable electronic devices, there is a need to be developed on dielectric substrates. It is predicted that silicene is stable when encapsulated between two thin graphite-like hexagonal AlN layers [3]. The possibility to grow stable silicene on insulating substrates such as hexagonal AlN could be a major technological breakthrough.

Ultrathin (sub-monolayer to 12 monolayers) AlN nanosheets are grown epitaxially by plasma assisted molecular beam epitaxy on Ag(111) single crystals [4]. Electron diffraction (Fig. 4) and scanning tunneling microscopy (Fig. 5) provide evidence that AlN on Ag adopts a graphite-like hexagonal structure with a larger lattice constant compared to bulk-like wurtzite AlN. This claim is further supported by ultraviolet photoelectron spectroscopy (Fig. 6) indicating a reduced energy bandgap as expected for hexagonal AlN.

This work was supported by the 2D-NANOLATTICES (Grant No. 270749) of the Future and Emerging Technologies (FET) program of the European Commission 7th Framework Program.

References

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Figures

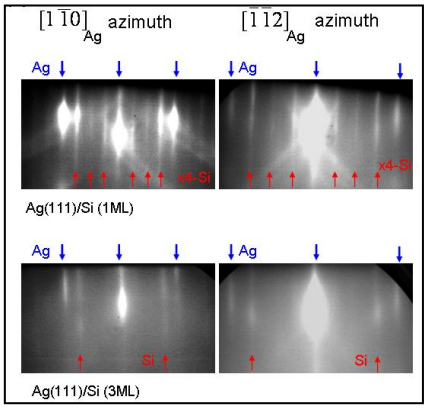

Figure 1: (a) RHEED diffraction patterns of the clean and Ag(111)/Si (1ML) and Ag(111)/Si (3ML) samples obtained along the $[\bar{1}\,\bar{1}\,2]$ and $[1\,\bar{1}\,0]$ azimuth of Ag(111) surface. Blue and red arrows indicate the diffraction streaks of Ag(111) and Ag(111)/Si superstructure, respectively.

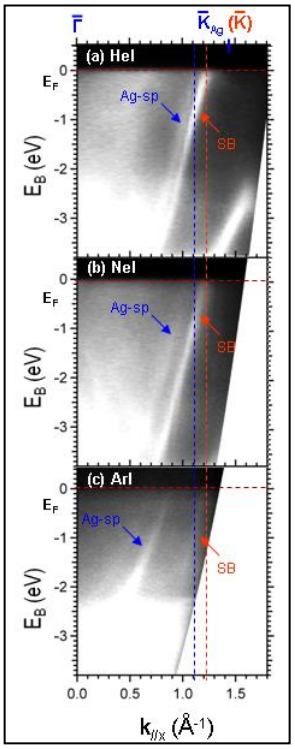

Figure 2: Energy vs. $k_{//x}$ dispersion for $k_{//y}$=0 for the Ag(111)/Si (1ML) structure acquired by ARPES along the $\bar{\Gamma}\bar{K}_{Ag}$ with different excitation energies hv: (a) HeI 21.22eV, (b) NeI 16.67eV and (c) ArI 11.62eV. The dispersing bulk Ag *sp*-band is indicated by blue line, while the invariant surface band *SB* is marked by red line.

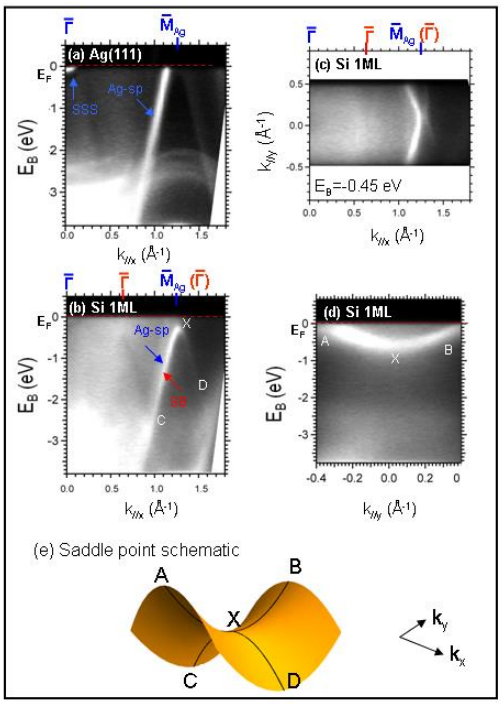

Figure 3: (a) and (b) Energy vs. $k_{//x}$ dispersion for $k_{//y}$=0, recorded along the $\bar{\Gamma}\bar{M}_{Ag}$ direction of the Ag(111) SBZ for the clean Ag(111) and Ag(111)/Si (1ML) samples, respectively; (c) constant energy contours k_x-k_y (E_B=-0.45eV) for the Ag(111)/Si (1ML) sample; (d) Energy vs. $k_{//y}$ dispersion for $k_{//x}$=1.2 Å^{-1} along the $\bar{\Gamma}\bar{M}_{Ag}$ for Ag(111)/Si (1ML) sample and (e) Saddle point schematic.

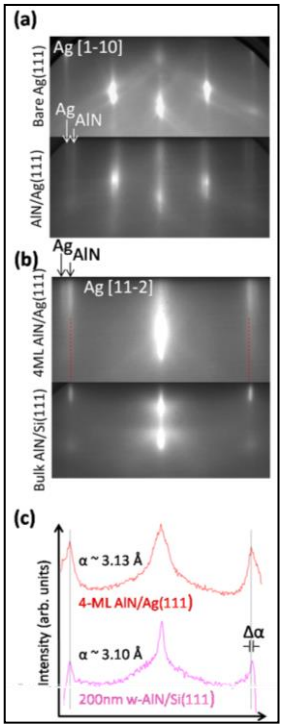

Figure 4: (a) RHEED patterns of bare Ag(111) and AlN/Ag(111) structures along [1-10] azimuth of silver. The overall streaky pattern shows that AlN grows epitaxially on the Ag(111) substrates. (b) RHEED and (c) intensity patterns of 4 ML-thickAlN/Ag(111) and wurtzite 200nm-AlN/Si(111) structures along [11-2] azimuth of silver. For illustration purposes, in fig. 4(b) and (c) we have shifted the pictures in order for the first order left streaks to be aligned. A slightly larger lattice constant is determined for the ultrathin layer which is characteristic of its graphitic structure.

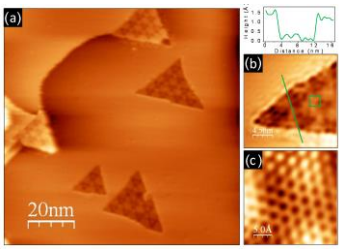

Figure 5: (a) STM topography (100x100 nm^2) of 2D triangle-shaped islands epitaxially grown on Ag(111) substrates, V_{tip}=0.8 V, I=1 nA; (b) magnification (20.5x20.5 nm^2) of a single AlN island and line profile along the green line; (c) atomic resolution (2.5x2.5 nm^2) STM topography inside an island (see green contour in panel (b)).

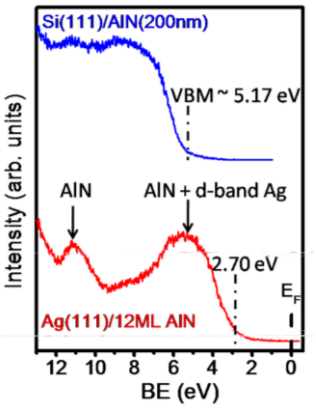

Figure 6: HeI valence band spectra of the AlN(bulk)/Si(111) and AlN(12ML)/Ag(111) samples. The smaller VBM of the 12ML-AlN/Ag comparing to the bulk w-AlN/Si sample could be an indication of the smaller energy bandgap, which is expected for a graphite-like hexagonal AlN phase.