Silicon nitride as graphene substrate in device design

Shaohua Xiang [1], Stefano Colonna [2], Fabio Ronci [2], Stefan Heun [1], **Roberto Flammini*** [2]

[1] NEST, Istituto Nanoscienze-CNR and Scuola Normale Superiore, 56127 Pisa, Italy

[2] CNR-Istituto di Struttura della Materia, via Fosso del Cavaliere 100, 00133 Rome, Italy

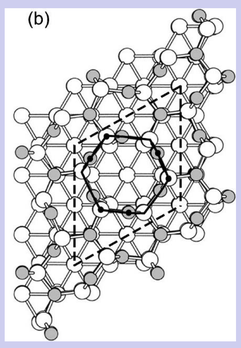
ABSTRACT: One of the most severe limits in future design of graphene-based electronic devices is that, when supported on a substrate, the carrier mobility of graphene (G) is often reduced by an order of magnitude or more. Ultra-thin β-Si_3N_4 can be used as high-K dielectric to overcome this problem. In this work we present the results of the first experimental characterization of the G/β-Si_3N_4 (0001)/Si(111) interface. First, the β-Si_3N_4 film was grown on Si(111) under UHV conditions and thoroughly investigated by scanning tunneling microscopy (STM). Subsequently, a G flake has been transferred on top of it by a PMMA-based transfer technique. The structural and electronic investigation of this prototypical interface has been conducted by STM and μ-Raman spectroscopy showing a high quality of the graphene layer with a low number of defects. This study demonstrates that β--Si_3N_4 (0001)/Si(111) has strong potential as platform for future graphene-based electronic device applications.

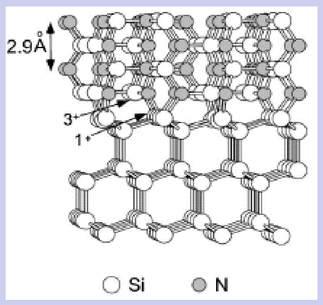
β-Si_3N_4/Si(111)-(8x8) XPS, LEED, STM

THERMAL NITRIDATION :
- step 1 : Si(111)-7x7 preparation
- step 2 : Sample held at 750° C in ammonia

atmosphere for 15' (pressure 10^{-5} mbar)

THE MODEL : structure of the interface and the 8x8 reconstruction



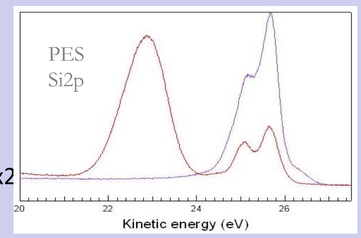


Kim et al. PRB **67** (2003) 035304

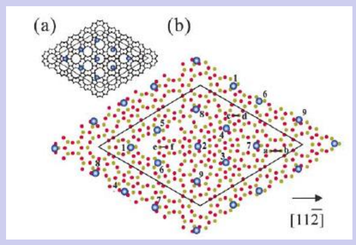
low lattice mismatch: 1.2 % (between the 2x2 cell of the Si(111) and (1x1) cell of the β-Si_3N_4(001))

bilayer of about 6 Å

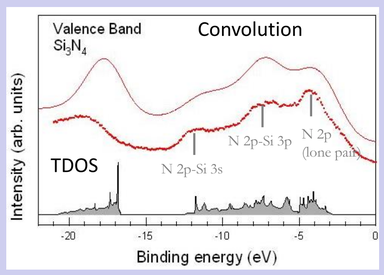
No definitive model exists for the (8x8) recontruction

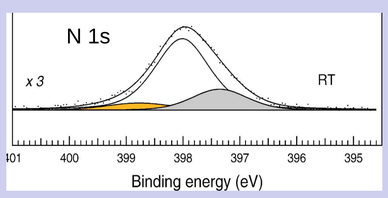


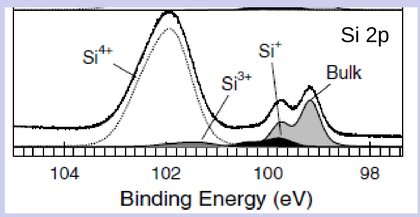
Model proposed by Ahn et al. PRL **86**(2001)2818



CHARACTERIZATION : core-level and valence band photoemission



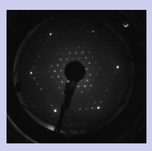


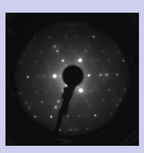


author ref.	Si^{1+} *(eV)*	Si^{3+} *(eV)*	Si^{4+} *(eV)*
theory[39,40]	0.7	2.1	2.8
this work	0.62	2.13	2.79
Dufour[22]	0.60	/	2.59
Stesmans[41]	/	/	3.15
Kim[23]	0.64	2.21	2.74

CHARACTERIZATION : LEED

7x7





8x8

Before After

CHARACTERIZATION : STM

R. Flammini et al. PRB **91**, 075303 (2015)

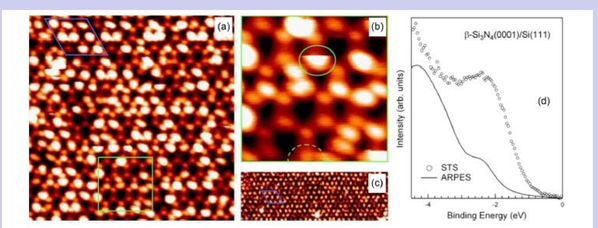


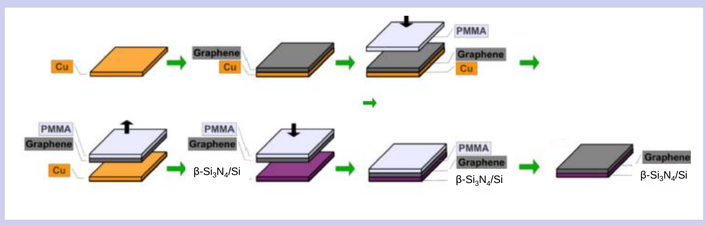
FIG. 5. (Color online) (a) 15 × 15 nm² STM image ($V_S = -4$ V, $I_T = 2$ nA) of a β-Si_3N_4/Si(111) sample. (b) High resolution 4 × 4 nm² STM image ($V_S = -4$ V, $I_T = 2$ nA) collected immediately after the one in panel (a) on the sample area highlighted by a green square. Green ovals highlight mobility of nitrogen adatoms (see text for discussion). (c) 10 × 30 nm² STM image ($V_S = -4$ V, $I_T = 2$ nA) showing the almost complete 8 × 8 reconstruction. The blue lozenge highlights the 8 × 8 unit cell. (d) Comparison between the STS spectrum and the ARPES line profile at Γ, taken from the rough data corresponding to Fig. 2(a). The STS spectrum is obtained from the image in panel (c); see text. The STS and ARPES profiles are not in scale.

The surface reconstruction is still debated:
Wang et al PRB **60** (1999) R2146 and Ahn et al. PRL **86** (2001) 2818

as well as the interface:
Yang et al. J. of Appl. Phys. **105**, 024108 2009 and Kim et al. PRB **67** (2003) 035304

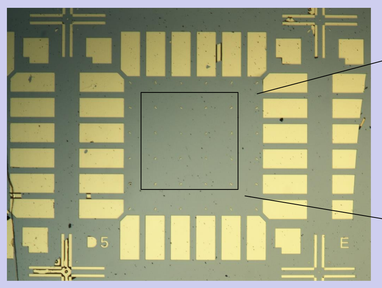
G/β-Si_3N_4/Si(111)-(8x8) G transfer

1. G is grown by CVD on a Cu substrate
2. PMMA (poly(methyl methacrylate)) spin coated on G

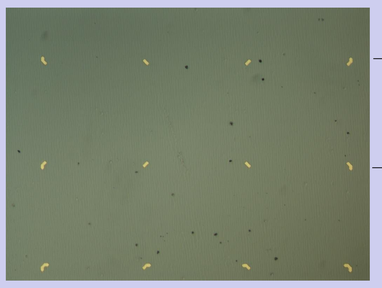


3. Metal etching
4. transferred on SiN
5. Dissolution of PMMA

Contacts made on the silicon nitride surface



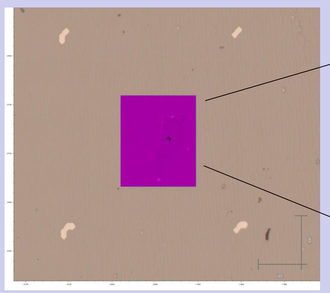
Gold markers for spatial reference



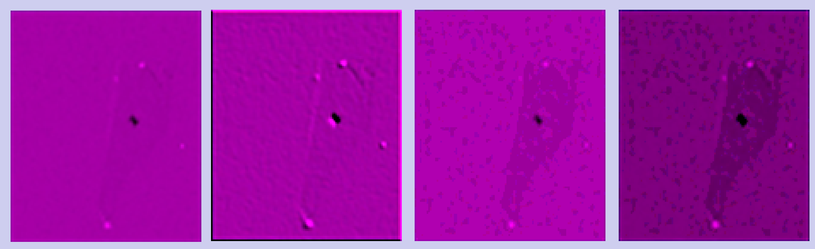
μ-Raman

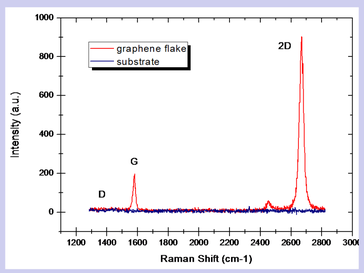
on SiO_2 and Si_3N_4 G difficult to identify by optical microscope: they show almost the same diffraction index as of G

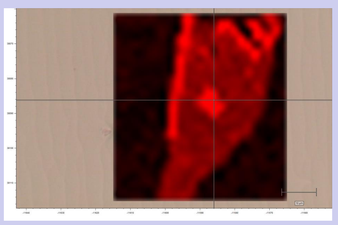
Graphene Transfer



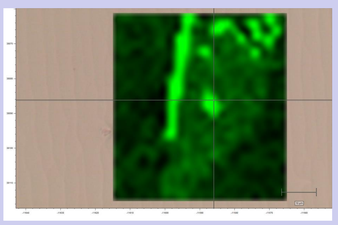
Raw data Filtered data



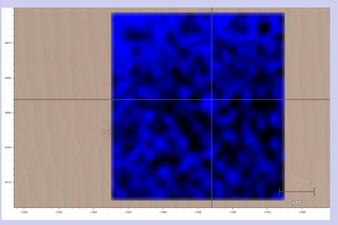




2D peak intensity map



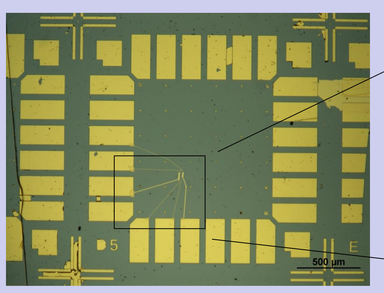
G peak intensity map



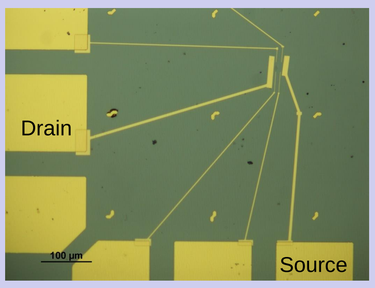
D peak intensity map

Gold leads

Hall bar device

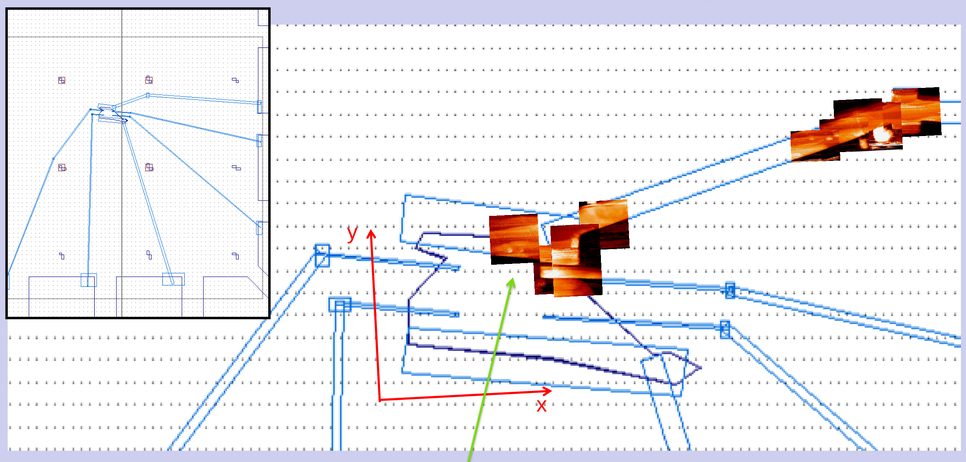


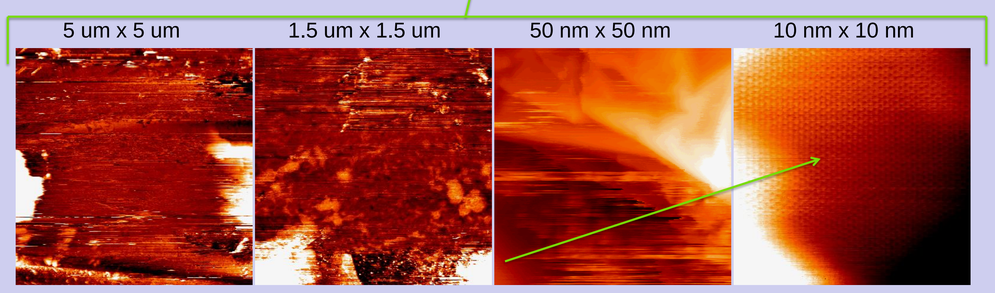
Gold leads to contact the graphene flake



G/β-Si_3N_4/Si(111)-(8x8) STM

Images taken at 0.05 V, 10 nA





Graphene !

SUMMARY : a thin, flat and homogeneous layer of silicon nitride has been grown by thermal nitridation on Si(111). The β-Si_3N_4/Si(111)-(8x8) interface has been studied by photoelectron spectroscopy at the italian and french synchrotron radiation sources, by Low Energy Electron Diffraction (LEED) and Scanning Tunnelling Spectroscopy (STM). Once characterised in UHV the surface has been exposed to air and then a Graphene (G) flake has been deposited on it by PMMA-based transfer technique. A Raman study has been performed in order to ascertain the presence of the G flake and its quality. Gold leads and contacts have been then lithographed on the surface in order to build a Hall bar device. The sample then has been inserted again in UHV. STM images show the high quality of the graphene flake. This preliminary and promising work demonstrates that the G transfer procedure on β-Si_3N_4/Si(111) is reliable and ready for further studies.