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Adsorption of Organic Layers on the $BiAg_2$ Surface Alloy Exhibiting a Giant Spin Orbit Splitting

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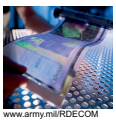
Motivation

Merging spintronics and organic electronics

- organic molecules become building blocks of more and more electronic devices: low cost, easy to process, etc.
- the electronic properties of the organic molecules can easily be tuned, e.g., by the choice of the central atom of Pc molecules
- spintronics: spin dependent transport phenomena are used as an additional information channel besides the regular electric currents to construct, e.g. smaller devices with larger storage capacities
- combination of both fields paves the way to future high performance electronic devices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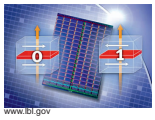
Ronald Sastrawan, Fraunhofer ISE



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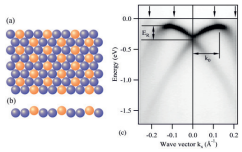
Giant Spin Orbit Splitting

Splitting due to an in-plane gradient

- in surface alloys such as $BiAg_2$, $PbAg_2$, and $BiCu_2$ the larger atomic species (Bi, Pb, etc.) buckles out of the surface plane
- due to the buckling, these alloys exhibit an in-plane potential gradient that leads to a spin splitting of the surface bands ("giant spin splitting") apart from and even bigger than the Rashba type spin splitting (which is due to a potential gradient in z-direction found, eg., for Au(111), Bi(111))
- giant spin splitting is about 3 times larger than the Rashba type splitting observed for Bi(111), about 10 times larger than for Au(111)
- the surface state of the original metal (Ag, Cu, ...) vanishes upon formation of the giant spin split alloy surface state



Material	E_R (meV)	k_0 (Å^{-1})	α_R (eV Å)	Reference
InGaAs/InAlAs heterostructure	<1	0.028	0.07	[4]
Ag(111) surface state	<0.2	0.004	0.03	[5,6]
Au(111) surface state	2.1	0.012	0.33	[6,7]
Bi(111) surface state	~ 14	~ 0.05	~ 0.56	[8]
Bi/Ag(111) surface alloy	200	0.13	3.05	This work

E_R: Rashba energy of split states
k_0: wave number offset
α_R: Rashba parameter

C.R. Ast et al., PRL **98**, 186807(2007)

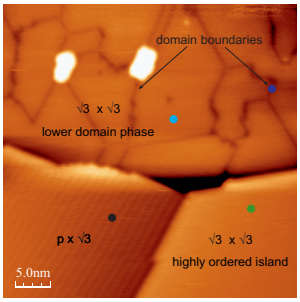
$BiAg_2$ Surface Alloy / $BiAg_2$ Mixed Structures

Preparation

- evaporation of Bi from a Knudsen cell onto a pre-heated Ag(111) single crystal
- post annealing step to about 100°C
- formation of $BiAg_2$ surface alloy checked via LEED

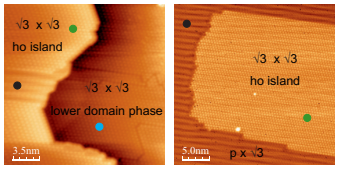
General sample structure

- sample covered with √3 x √3 highly ordered $BiAg_2$ islands / domains
- lower $BiAg_2$ √3 x √3 ordered areas exhibit numerous domain boundaries
- slight excess of Bi leads to a gradual dealloying of the√3 x √3 highly ordered $BiAg_2$ islands into p x √3 structures
- p x √3 islands: √3 periodicity in Ag[11$\bar{2}$] direction (lower, striped appearance)



V_{sample} = 0.7 V, I_T = 30 pA, T = 80 K

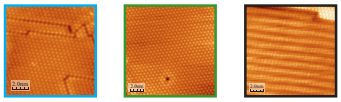
√3 x √3 $BiAg_2$ surface alloy | **p x √3 dealloyed phase**



left: V_{sample} = 0.7 V, I_T = 30 pA, T = 80 K
right: V_{sample} = 0.1V, I_T = 55 pA, T = 80 K

- upon landing, the Bi atoms embed into the Ag(111) substrate
- to relieve surface stress this dillute surface alloy becomes a more and more dense √3 x √3 structure
- displaced Ag atoms diffuse around the surface and form highly ordered √3 x √3 islands with incoming Bi atoms
- after the entire surface is covered with the $BiAg_2$ surface alloy further Bi leads to a dealloying of the sample by transforming √3 x √3 ordered islands into p x √3 ordered islands

√3 x √3 lower domain phase | **√3 x √3 highly ordered islands** | **p x √3 dealloyed islands**

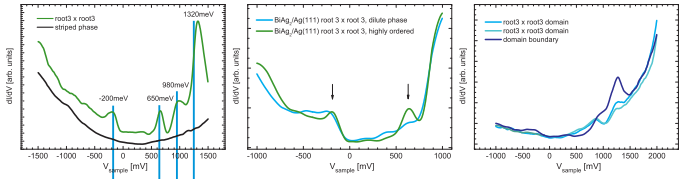

left: V_{sample} = 0.7 V, I_T = 30 pA, T = 80 K
center: V_{sample} = 1.0 V, I_T = 100 pA, T = 80 K
right: V_{sample} = 0.6 V, I_T = 55 pA, T = 80 K

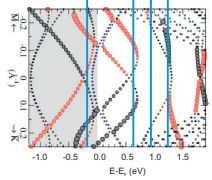
Literature

C. Kato, Y. Aoki, and H. Hirayama, PRB **82**, 165407 (2010)
K.H.L. Zhang et al., PRB **83**, 235418 (2011)
C. R. Ast et al., PRB 75, 201401(R) (2007)

Spectroscopy

Pure $BiAg_2$ structures

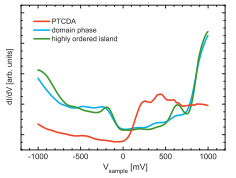




G. Bihlmayer, S. Blügel, E.V. Chulkow, PRB **75**,195414 (2007)

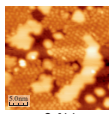
- the $BiAg_2$ spectra exhibit a peak which can be assigned to the giant spin split alloy surface state as well as several peaks corresponding to empty states
- all empty state peaks are in good agreement with DFT calculations (G. Bihlmayer et al., PRB **75**,195414 (2007)) and earlier STS data (C.R. Ast et al., PRB **75**, 201401(R) (2007))
- slight differences in the spectra of $BiAg_2$ islands and lower structures are observed
- domain boundaries within the lower level $BiAg_2$ structures show a different spectroscopic behavior than the inner part of the domains (C.R. Ast et al., PRB **75**, 201401(R) (2007))
- spectra of the p x √3 structure remains almost featureless within an energy range of ± 1.5 V around the Fermi level

PTCDA on $BiAg_2$

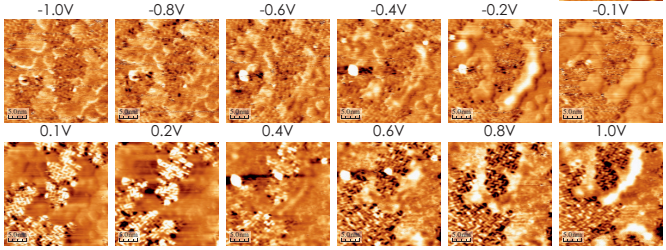


- no features observed at the energy of the $BiAg_2$ surface state in spectra taken on PTCDA layers
- pronounced onset of PTCDA molecular levels close to E_F for empty states

Topography

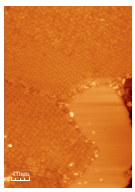


dI/dV



I_T = 100 pA, T = 80 K, Topography image recorded at V_{sample} = -0.8 V

Outlook: Interaction of PTCDA with the Bi-Ag surface structures



Is the disorder induced by the substrate?

Is the interaction with the substrate stronger at the √3 x √3 domain boundaries?

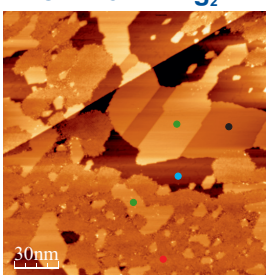
Do the molecules contribute to relieve/ build up surface stress?

Is there any interaction between the molecular overlayer and the giant spin orbit split surface state?

→ Laterally resolved STS in combination with ARPES measurements

V_{sample} = 1 V, I_T = 100 pA, T = 80 K

PTCDA on $BiAg_2$



V_{sample} = 1.2 V, I_T = 10 pA, T = 80 K

General sample structure

- at submonolayer coverage PTCDA seems to grow exclusively on lower $BiAg_2$ covered areas
- as on several other metallic substrates, PTCDA forms ordered island where the molecules assume a herrigbone like arrangement
- PTCDA forms large islands surrounding the highly ordered √3 x √3 islands
- several domain boundaries can be found within the molecular layers
- while some PTCDA covered areas exhibit almost perfect order, large areas exhibit a certain disorder in their herringbone arragement

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