Carrier dynamics at semiconductor surfaces

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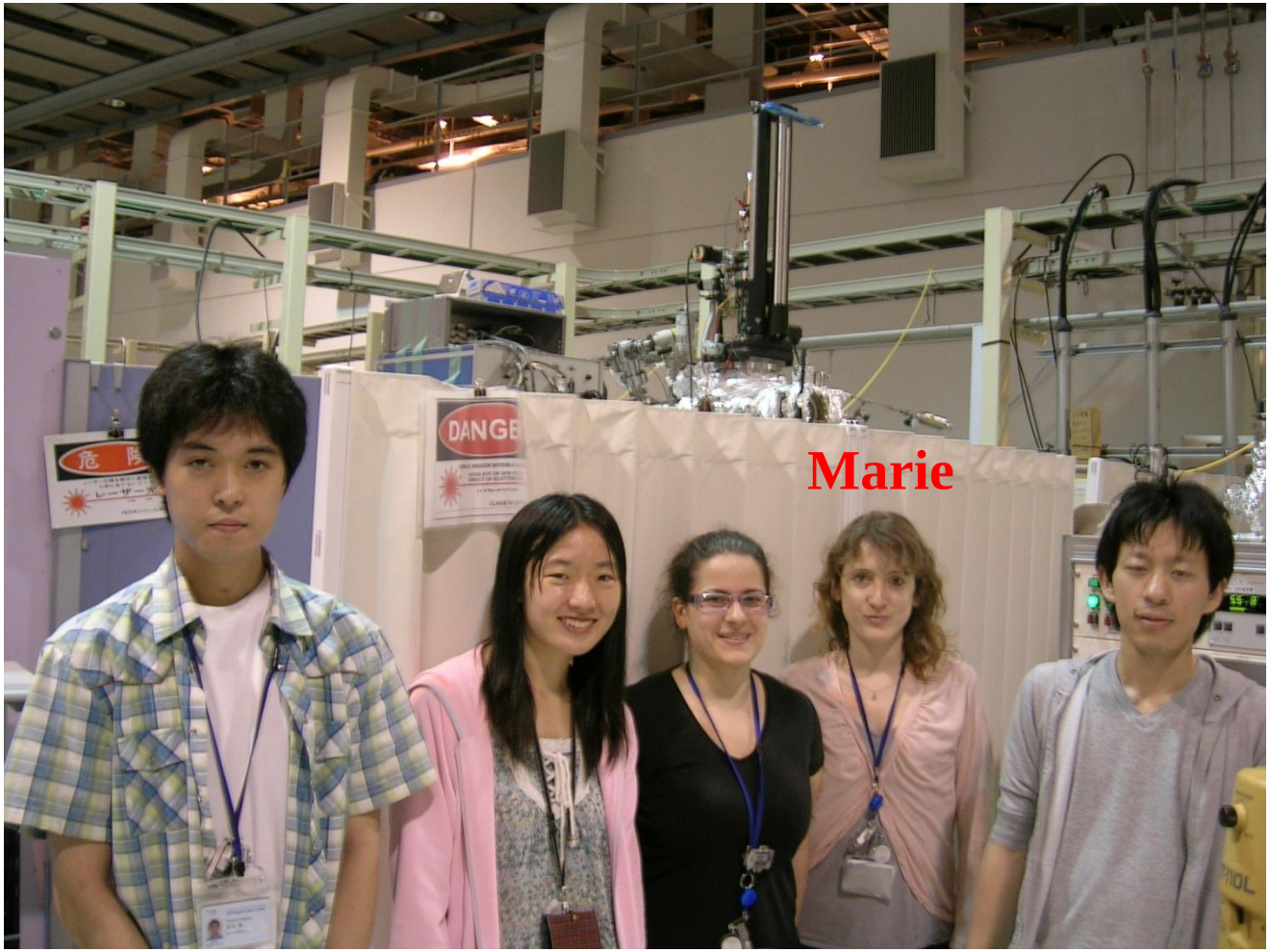
Acknowledgements



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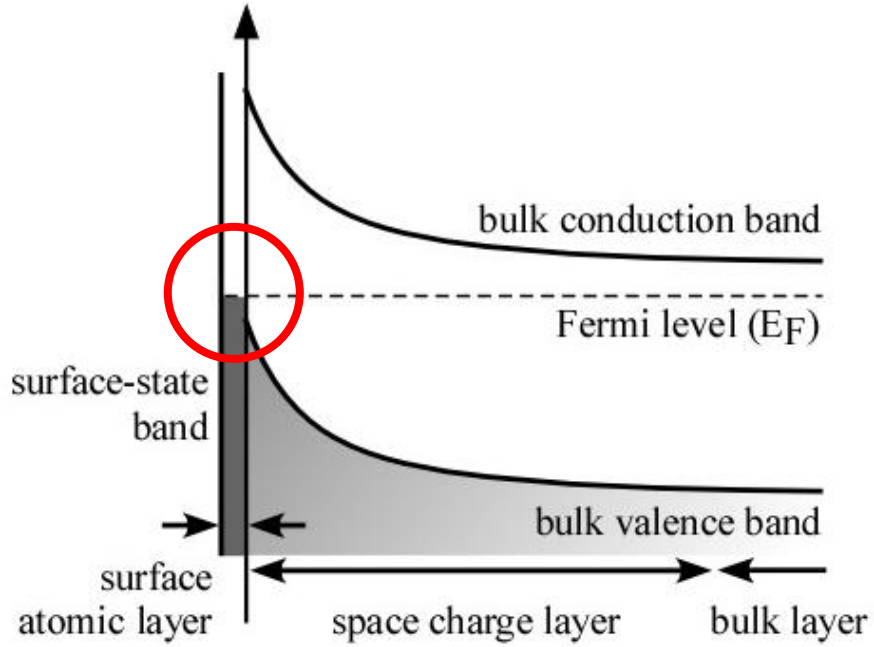
Low-dimensional physics at a surface

governed by surface electrons at the Fermi level

The regulation

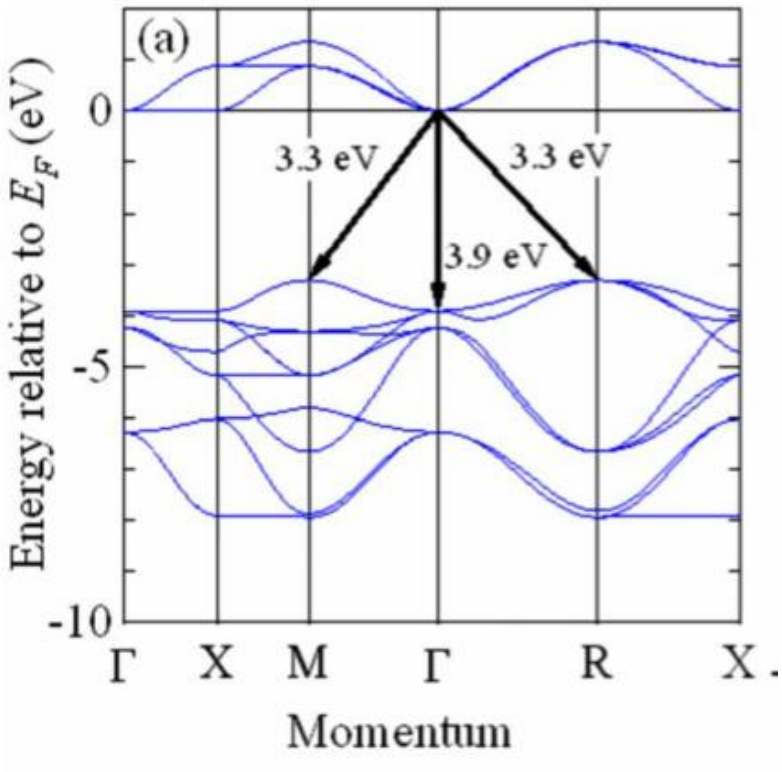


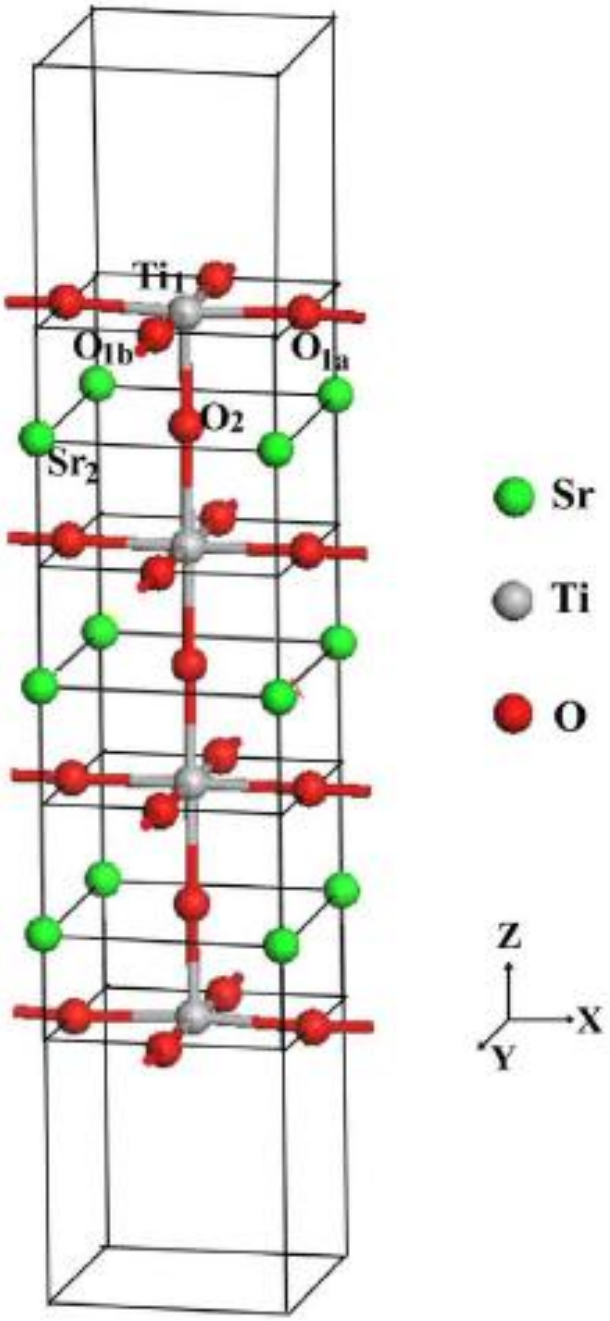
Induction of intriguing electronic states at a surface

- Formation of long-ranged ordered phase (surface superstructure)
- Insulator-to-metal surface phase transition
- Etc

$SrTiO_3$ (001)

a playground for studying correlated electrons
a model for catalytic reaction
a candidate of future device (oxide electronics)





H/$SrTiO_3$(001)

Hydrogen-induced metallicity of SrTiO3 (001) surfaces

Feng Lin *et al*, Phys. Rev. B **79**, 035311 (2009).

- $SrTiO_3$: d^0 configuration.

  Electron filling into the Ti 3d band

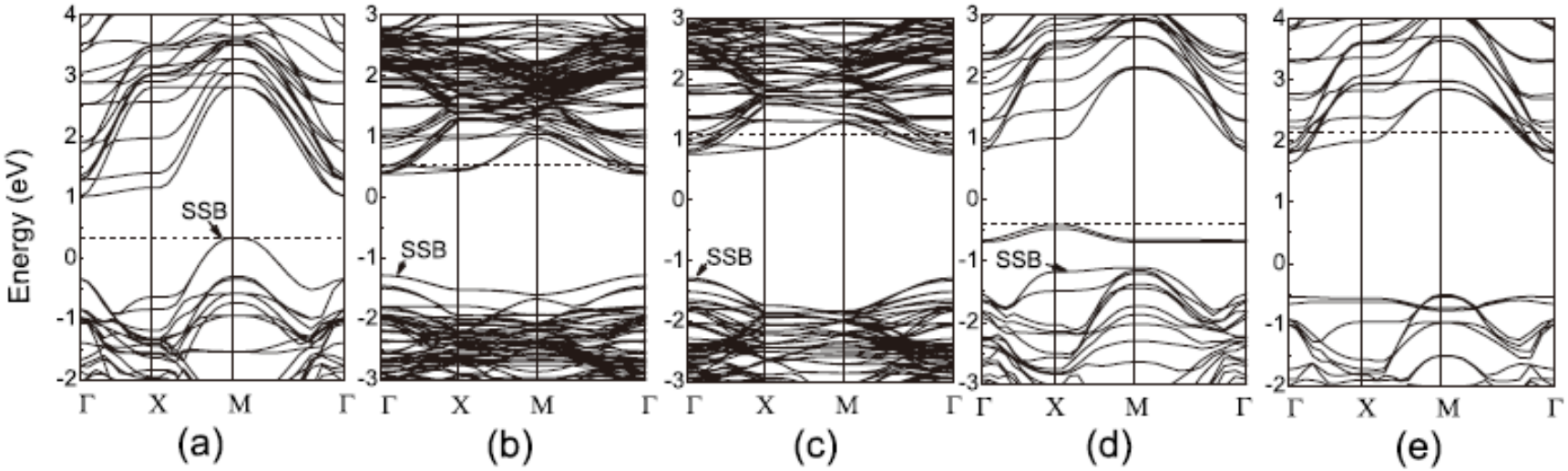
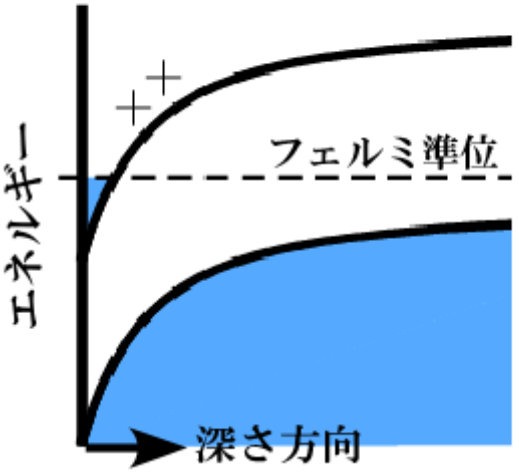


FIG. 4. Band structures of (a) clean and (b)–(e) hydrogen-adsorbed TiO_2-terminated $SrTiO_3$ surface. Herein, (b) and (c), respectively, correspond to the adsorption coverages of 1/12 and 1/6 ML, which are calculated using 2×2 supercell, while, (a), (d), and (e), respectively, correspond to the clean surface, Ti-2/3 ML adsorption, and 1 ML adsorption, which are calculated using 1×1 supercell. The Fermi level is denoted by the dashed line. Surface-state bands (SSBs) are denoted by arrows.

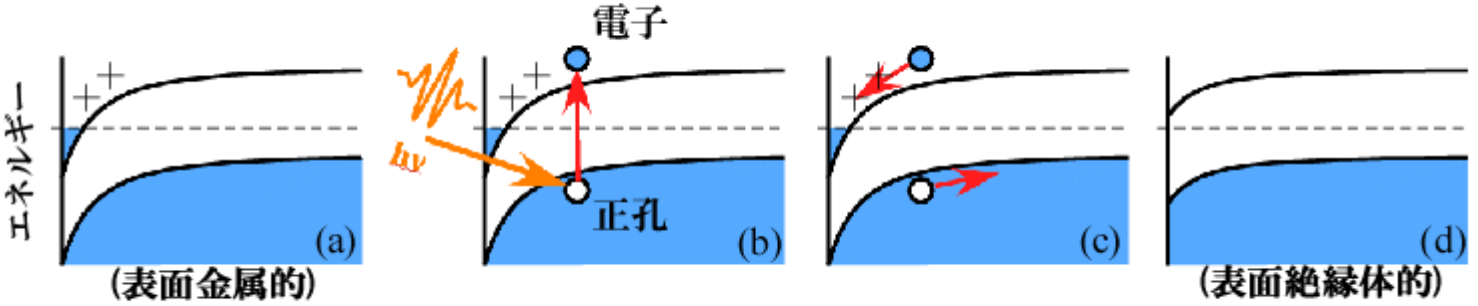
$H/SrTiO_3(001)$

Motivation

Surface metallization?

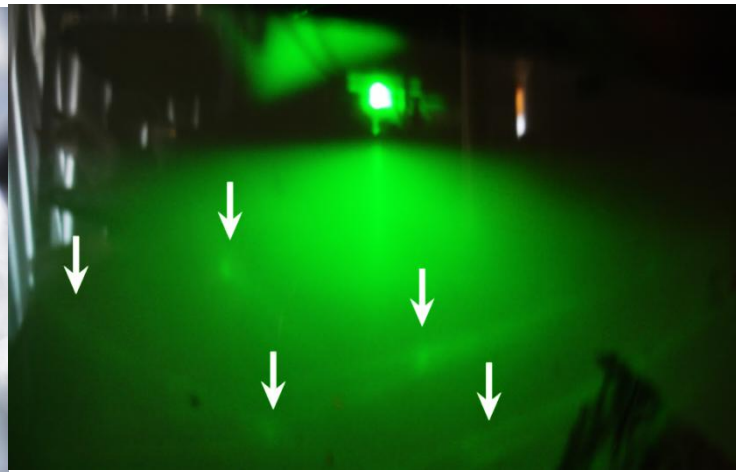


Optically-induced surface metal-to-insulator transition?



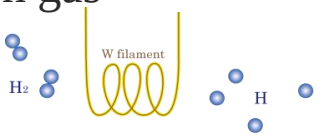
$H/SrTiO_3(001)$

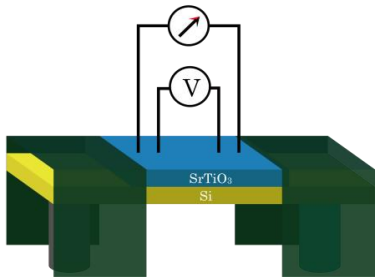
Surface transport measurements



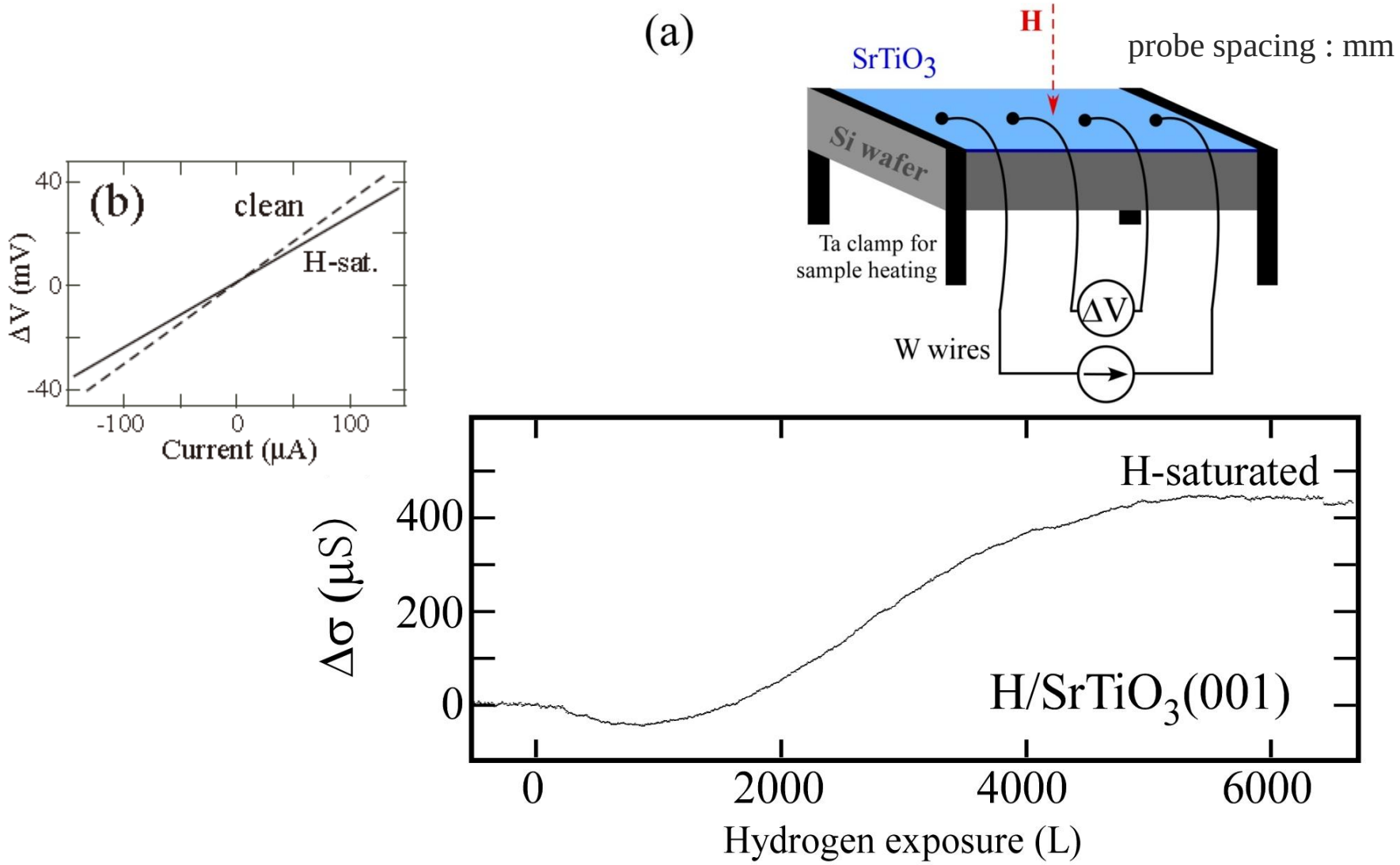
SrTiO3(001)

- 0.05wt %Nb-doped (n-type)
- TiO_2-terminated (HF treatment)
- Heat treatment in oxygen gas (free-oxygen vacancy)
- H atoms by a hot filament in hydrogen gas





$H/SrTiO_3(001)$



$\Delta\sigma=\sigma_{H/STO}$ = 440 μS > 39 μS （2-D Ioffe-Regel limit）

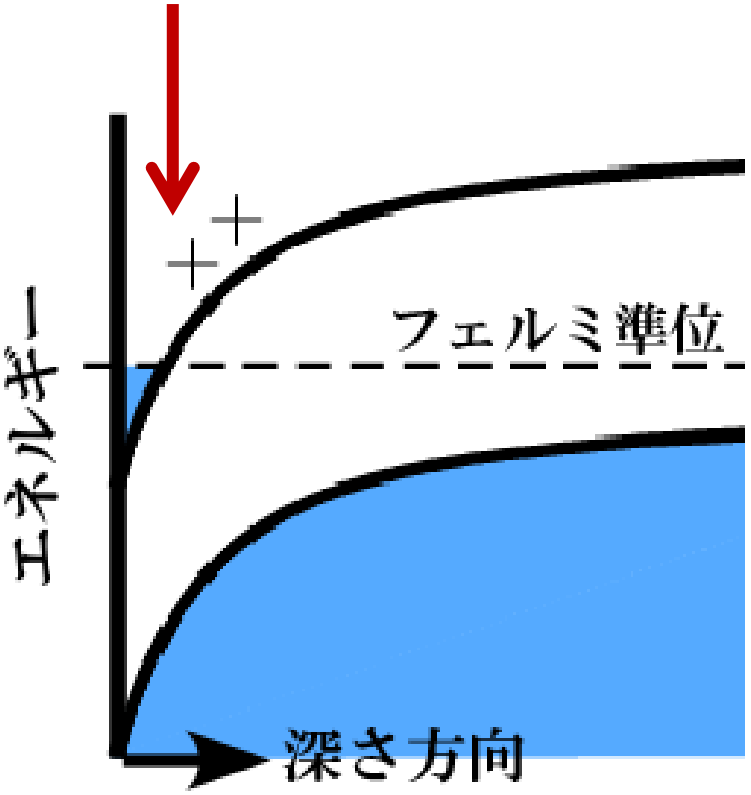
Band transport regime

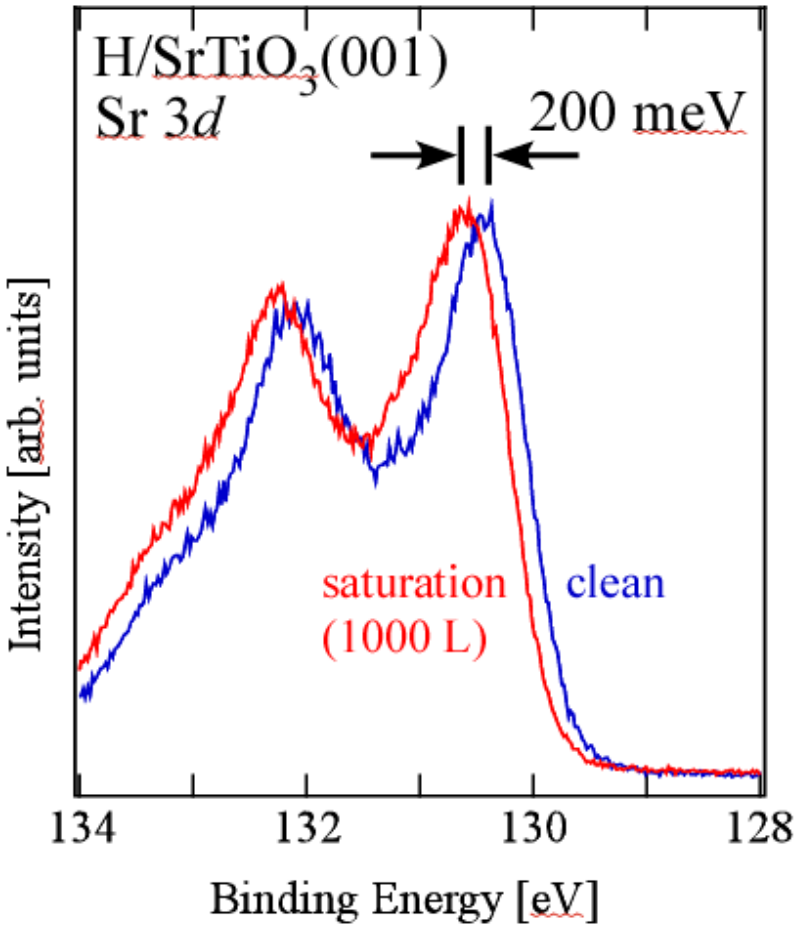
$H/SrTiO_3(001)$

Photoemission Experiments

- SPring-8 BL07LSU

Downward energy shift for the surface metallization





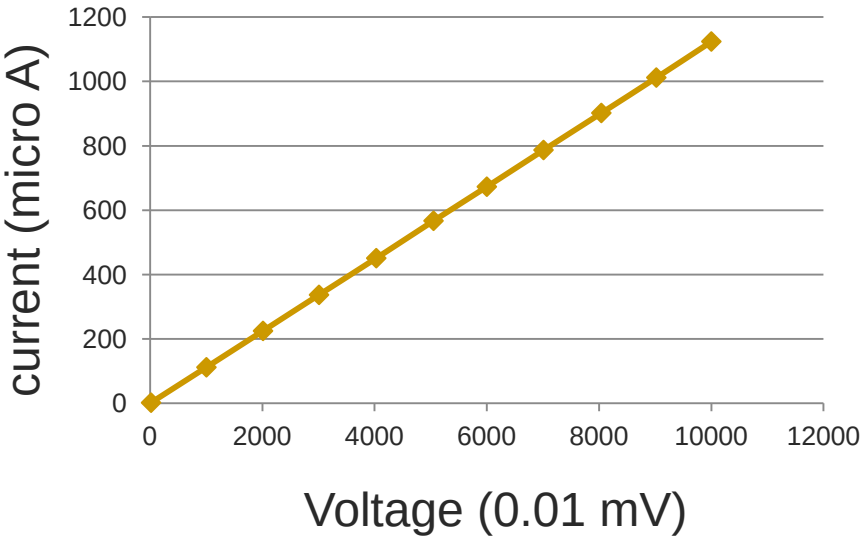
$H/SrTiO_3(001)$

Note:

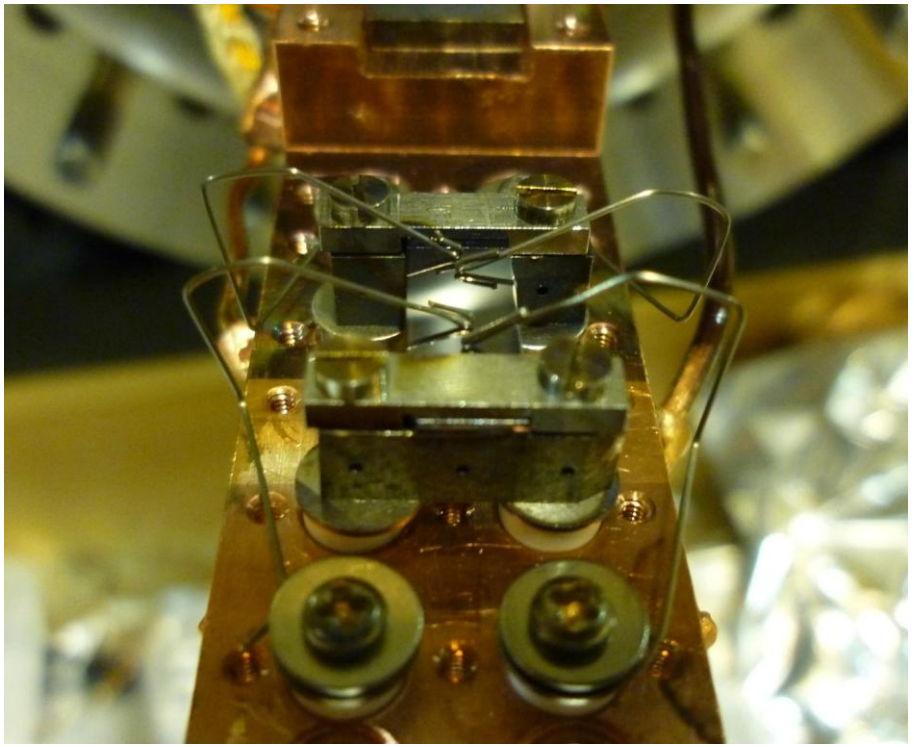
Photoemission and Transport Experiments

- SPring-8 BL07LSU

異なる手法の同時測定が可能に



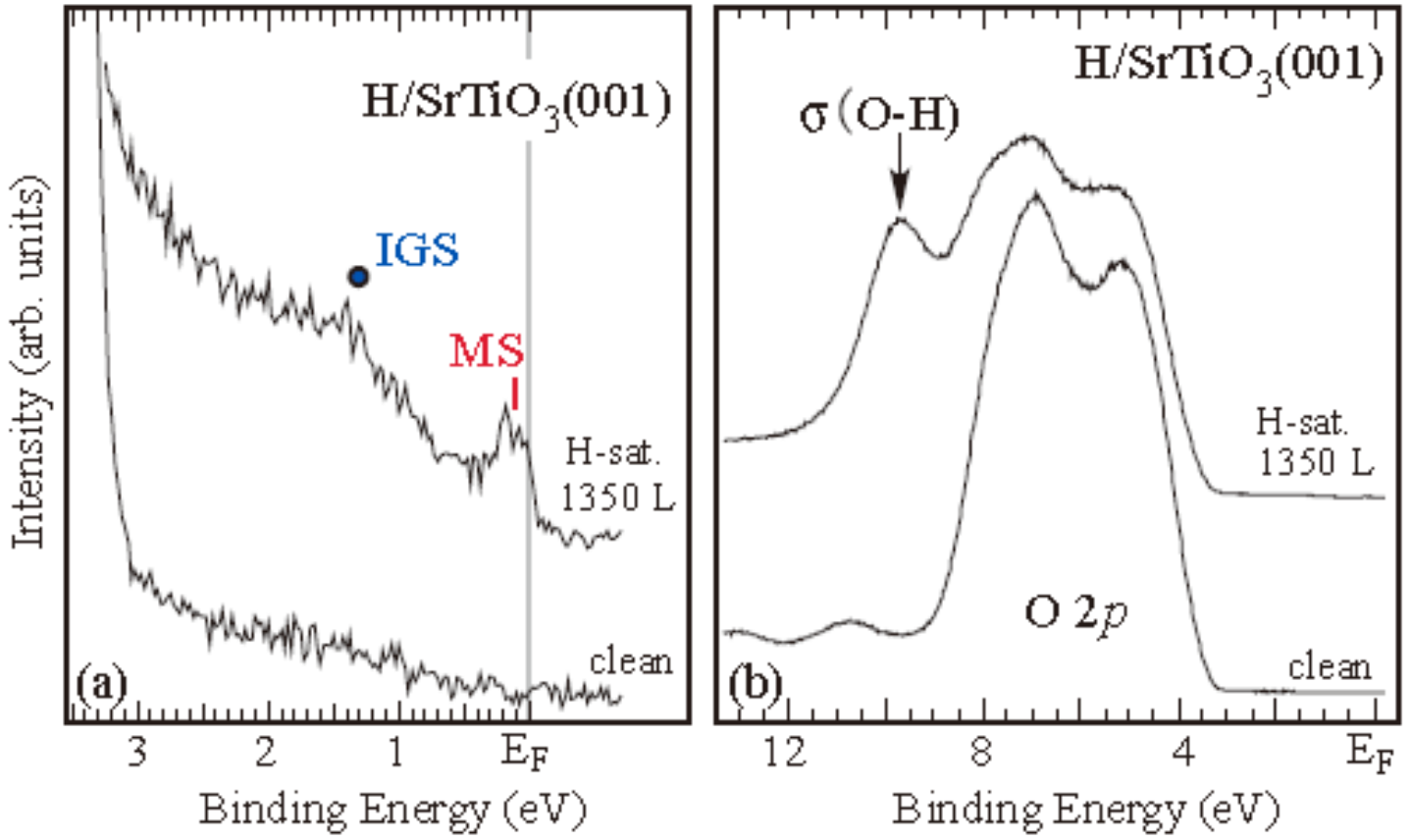
Photoemission and transport measurements on the same sample



$H/SrTiO_3(001)$

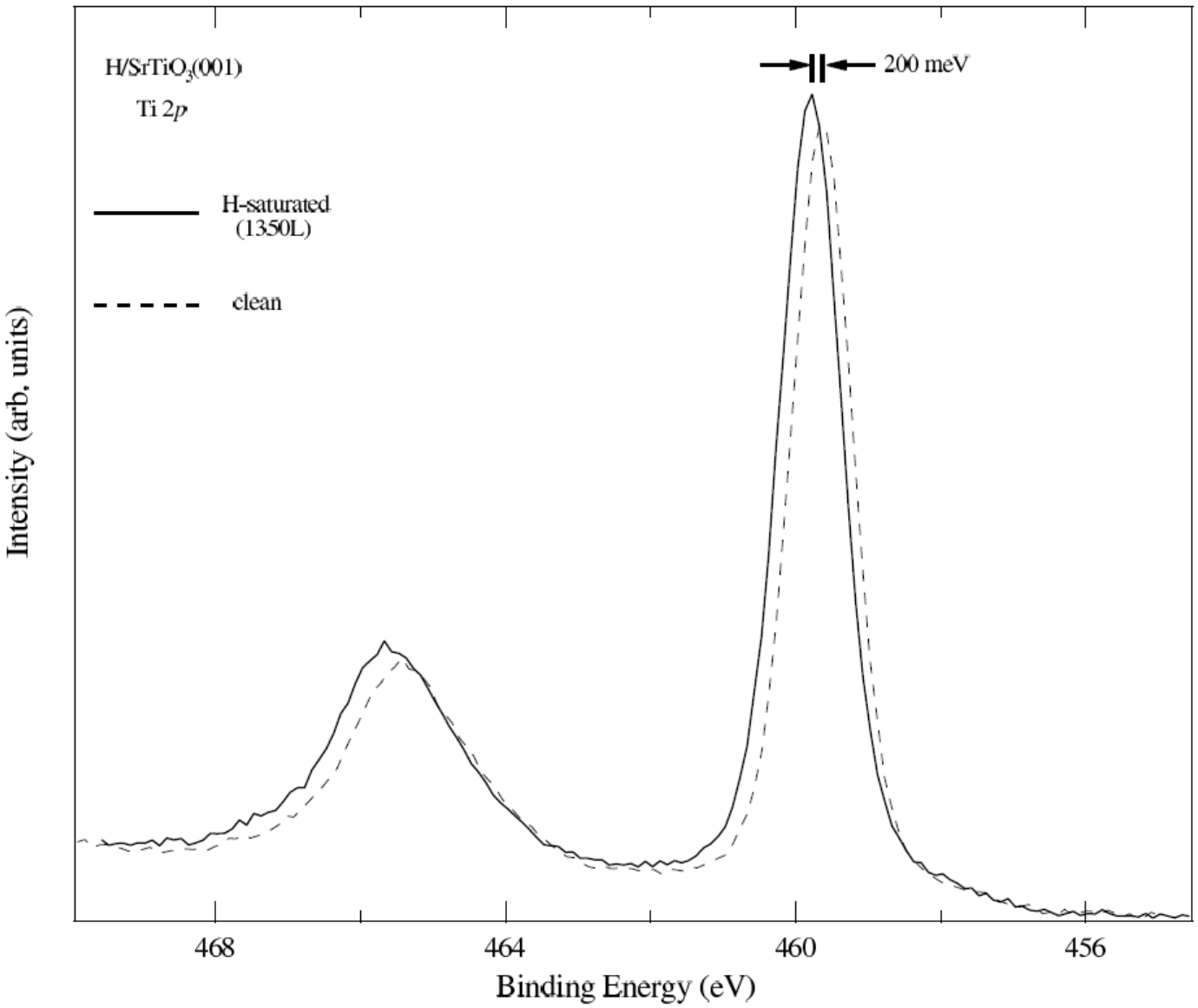
Photoemission Experiments

- SOLEIL TEMPO

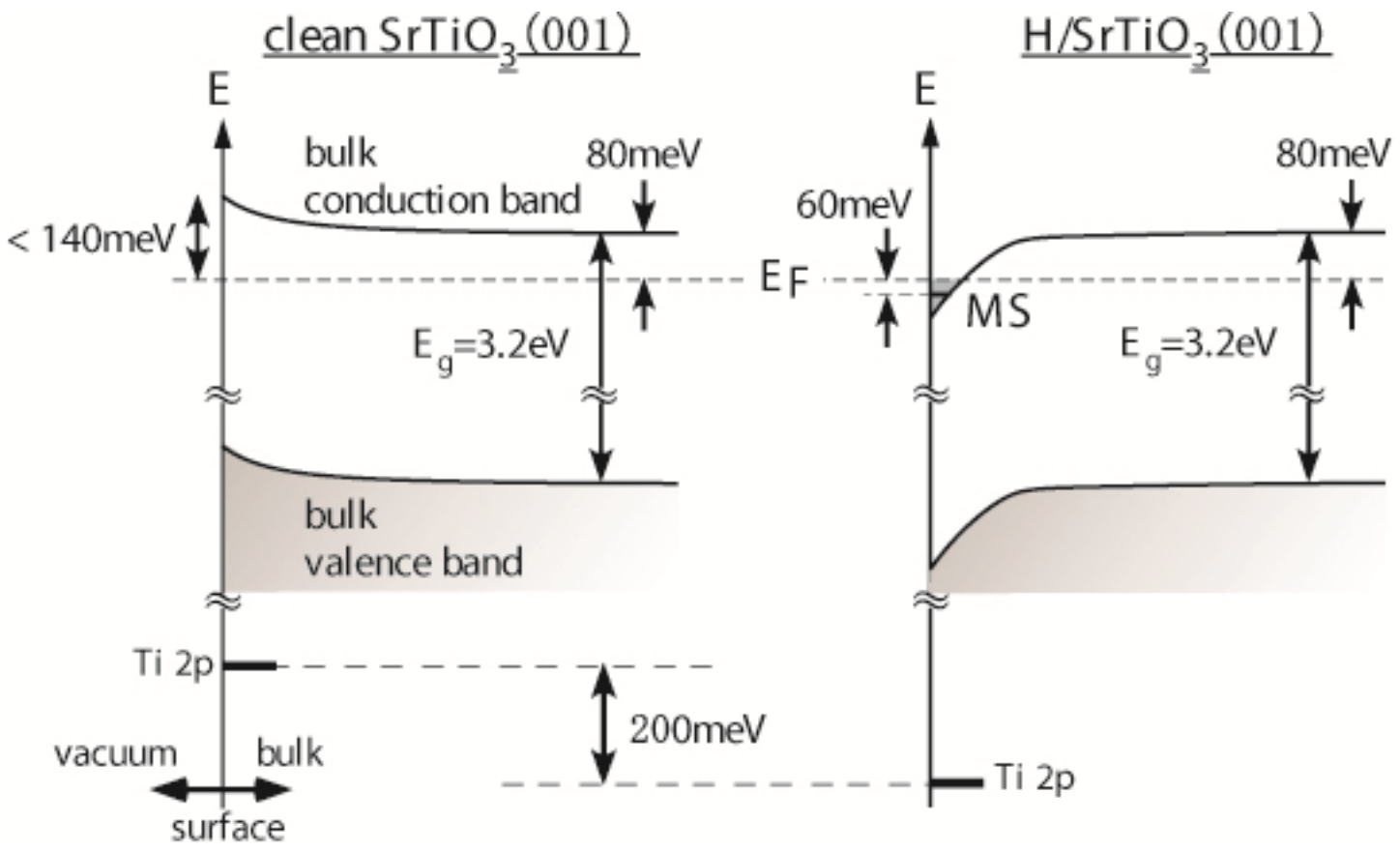


hv=81 eV, tuned to match with the minimum of Ti 3d bulk conduction band

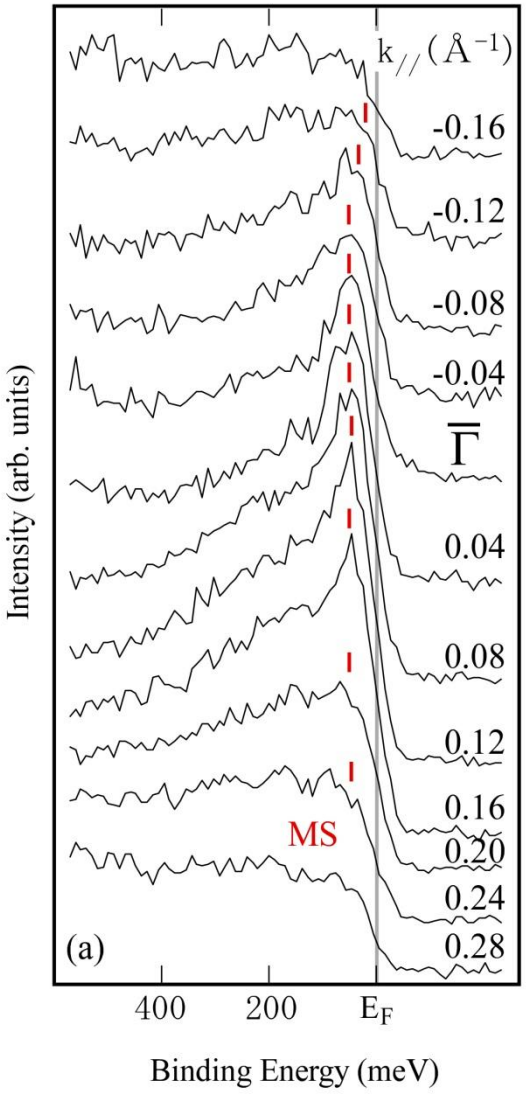
$H/SrTiO_3(001)$


H/SrTiO3(001)
Ti 2p
H-saturated
(1350L)
clean
200 meV
Intensity (arb. units)
468
464
460
456
Binding Energy (eV)

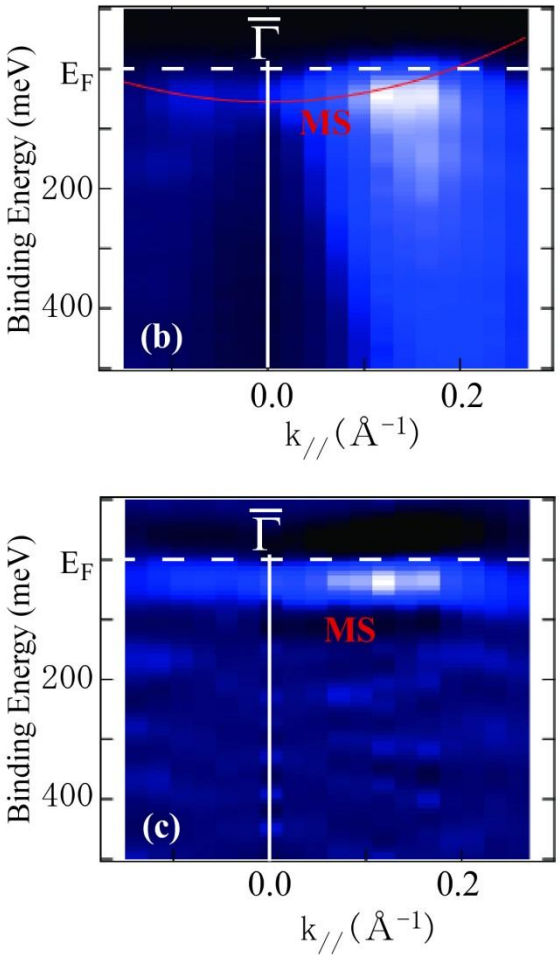
$H/SrTiO_3(001)$


clean SrTiO3(001)
H/SrTiO3(001)
E
bulk
conduction band
80meV
< 140meV
Eg=3.2eV
bulk
valence band
Ti 2p
vacuum
bulk
surface
200meV
E
60meV
EF
MS
80meV
Eg=3.2eV
Ti 2p

$H/SrTiO_3(001)$



Intensity diagram



The second derivative

k_F=0.2 Å^{-1}

Mean free path
l = 2 nm (RT)

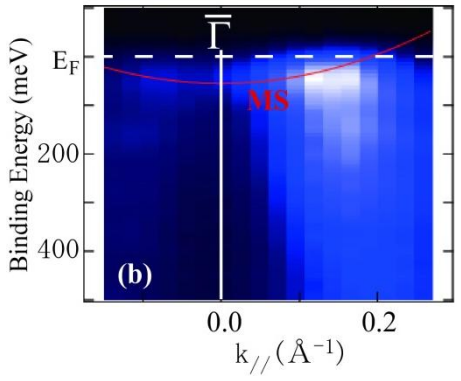
Broad spectral feature,
appeared at high binding energy

H/$SrTiO_3$(001)

As expected, not only the MS peak but also peaks, IGS and "broad feature", were found.

"broad feature"

- Polaron formation due to the electron-phonon interaction
  [Y.J.Chang *et al*., PRB 81, 235109(2010).]
- Electron correlation effect (Fermi liquid)
  [W. Meevasana *et al*., Nature Materials, **10**, 114 (2011).]



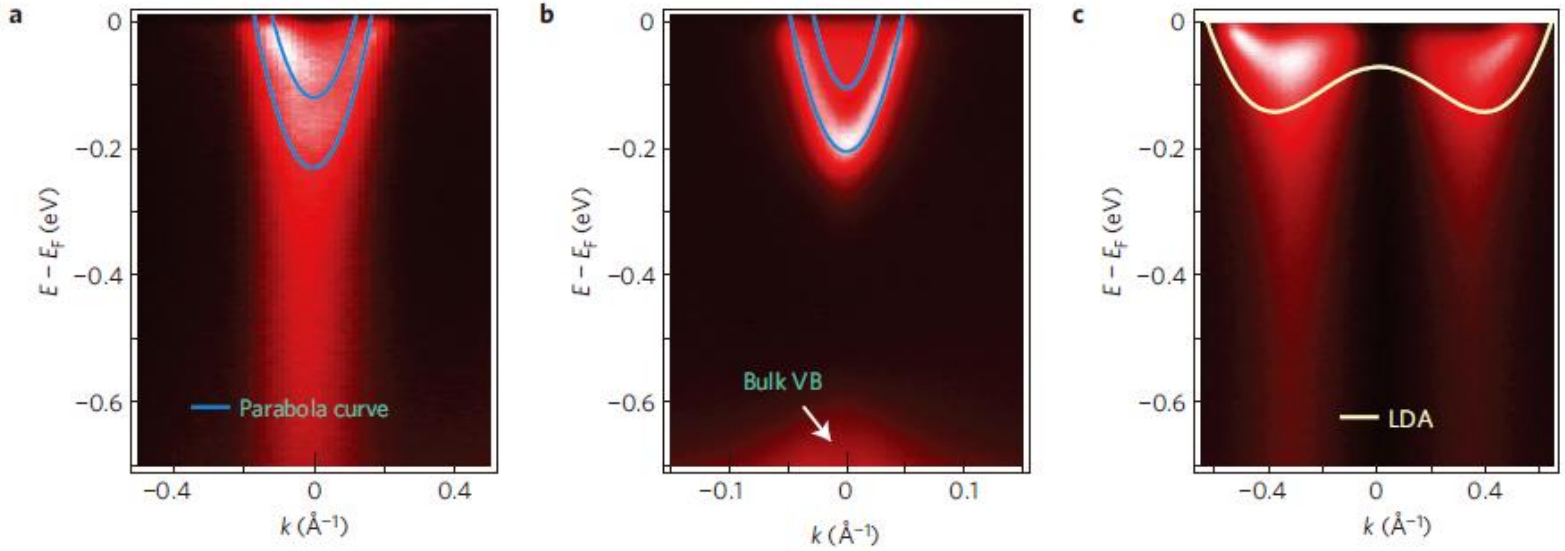


Figure 4 | Comparison of ARPES data from $SrTiO_3$, InAs and $Bi_2Sr_2CuO_6$ samples. a,b, 2DEG states at the surface of $SrTiO_3$ (**a**) and InAs (**b**). **c**, ARPES data from the single-layer cuprate $Bi_2Sr_2CuO_6$ (Bi2201) along $(\pi, 0)$ to $(0, \pi)$. The lines in **a** and **b** are parabolic dispersion relations, to guide the eye, and the result of a local density approximation band-structure calculation in **c**.

Summary

- A solid surface is an interesting playground to study low-dimensional electronic system.

- Surface insulator-to-metal transition or surface metallization was found by hydrogen adsorption on a $SrTiO_3$ surface.

  Spectral features, likely related to the many body effects, were observed.

  M. D'angelo *et al.*, Phys. Rev. Lett. accepted

- The VUV-soft X-ray photoemission research is now extending to the time-resolved measurement.

  - **The optically-induced surface metal-to-insulator transition**
  - fs-ns time: dynamics of the correlated carriers
  - ps- ms time: a model for photo-chemistry