

Scientific Report

Workshop on New Trends in Topological Insulators

Organizers:

Stephan Roche (ICN2, ICREA)
Sergio Valenzuela (ICN2, ICREA)
David Soriano (ICN2)

Venue:

Sant Feliu de Guixols (Girona), Spain
3 – 6 June 2013

➤ **Scope of the Workshop**

This *New Trends in Topological Insulators* workshop gathered world leaders in the emerging field of topological insulators and related topics. Topological insulators stand as a new class of materials in which spin-orbit interaction produces topologically nontrivial insulating bulk electronic phases and associated conducting gapless states at the material boundaries. These boundary states are described by Dirac-fermion physics and show complex spin textures. They have properties that are unlike any other known one or two dimensional electronic system with foreseen applications ranging from spintronics to quantum computation. Theory also predicts the existence of many other possible topological electronic phases, ranging from topological superconductors to fractional topological insulators. This fast developing field is being driven by a combination of experiment and theory. This workshop brought together leading researchers with broad backgrounds to explore all aspects of topological insulators, topological superconductors, and related materials and phases. Participants of this workshop addressed the most important theoretical and experimental issues associated with this new state of quantum matter and discussed possible uses of topological insulators in future practical applications. The main topics included: electronic transport properties of topological insulator boundary states, materials science for predicting and observing topological phases in real materials, topological insulator devices that incorporate magnetism and/or superconductivity, quantum anomalous Hall effect and Majorana fermion states, disorder effects, localization phenomena, topological superconductors and related phases.

➤ **General Organization Aspects**

The workshop, partially funded by ESF, took place in San Feliu de Guixols (June 3-6, 2013), and gathered about 90 participants from all over the world. The scientific workshop has been a true success in many respects. First, the great interest generated by the event has been clearly demonstrated by large number of applications, made through the workshop website designed for the event. The website has been also a platform to inform the participants about practical details, transportation and accommodation, scientific program, sponsors and so forth.

<http://www.icn.cat/index.php/en/events/past-events/2013-past-events/workshop-on-topological-insulators>

The workshop took place in the Hotel Eden Roc, which offered a complete ensemble of services (conference rooms, accommodations, etc...) and have greatly facilitated the organization. Being far from Barcelona downtown a special transportation was required to reach the venue, although other transportation means were available to the participants. The isolated nature of the venue however was very beneficial to favor the interaction of the participants and to generate exciting scientific discussions.

The scientific program has covered most of the new trends in the development of the field of topological insulators as detailed below, including most recent aspects of Mercury Telluride and Bismuth-based TI-alloys. The list of scientific speakers was jointly established by the local organizing committee, David Soriano (ICN2), Stephan Roche (ICREA and ICN2) and Sergio O. Valenzuela (ICREA and ICN2), and the scientific committee composed by Laurens Molenkamp (Würzburg University), Zahid Hasan (Princeton University) and Eugene Chulkov (DIPC, San Sebastian).

A balanced choice of speakers was made, covering most debated issues from material growth, to characterization, novel classes of materials with topological properties, or the search for Majorana fermions, a challenging scientific topic which has raised great interest in recent years. On the other hand, the selection of participants, who submitted their contributions, was made giving priorities to young European researchers (Ph.D. students or postdoc), already engaged in the field of topological insulators and that requested to present their results through posters or contributed oral talks. Posters were installed the first day of the workshop and remained all throughout its duration, allowing participants to exchange and discuss during coffee breaks and specially designed poster sessions.

➤ Program Overview

Progress has been reported in the field of first-principles modeling of TI-materials, which is fundamental for a realistic exploration of defects, impurities, and interfaces. Predictions of new materials have been presented that exhibit topological insulating properties, but in many cases, the poor quality of produced materials obscure the topological fingerprints. The report of optical, STM, or transport characterizations of TI-materials has been in that respect a key contribution to the workshop, with advance in the description of spin-related properties.

The **first session** was devoted to HgTe. Transport data obtained from (Hg,Cd)Te quantum wells by the group of prof. Molenkamp in 2007 at university of Würzburg [**König et al., Science, 318, 766 (2207)**] led the first observation of the quantum spin Hall effect in a 2-dimensional material, which now is seen as the prime manifestation of a 2-dimensional topological insulator. Prof. Molenkamp, awarded with the Oliver E. Buckley prize in 2012 by his contribution to the field of topological insulators, started the Workshop by giving an introductory talk on 2-dimensional topological insulators together with an overview of topological effects in strained HgTe and HgTe quantum wells, from the first measurements to current understanding of proximity effects with superconductors. Prof. Laurent Levy, from Institut Néel (Grenoble), discussed the surface states in 3-dimensional HgTe and gave a very nice introduction to ARPES spectroscopy, the main experimental tool to unveil the

physical properties of these exciting materials. To conclude session I, prof. Nicholas Kioussis (California State University) introduced a new topological insulator based on elemental tellurium under strain.

Session II was started by prof. M. Zahid Hasan (Princeton University) who gave an introductory talk on 3-dimensional topological insulators and presented new and exciting spectroscopic results of the surface states in established topological insulator materials such as bismuth chalcogenides and candidates as samarium hexaboride. Prof. Hasan is an expert on ARPES and also one of the pioneers in this field together with prof. Molenkamp and prof. Shouchen Zhang (Stanford University). Prof. Eugene V. Chulkov from DIPC (San Sebastian), introduced first-principles calculations, including spin-orbit interactions, of complex topological insulators, Rashba-type systems and magnetic proximity effects. To conclude this session, Liang Wu, a PhD student from Johns Hopkins university, gave a very nice talk regarding a new spectroscopic technique used to investigate low frequency conductivity and to detect the topological phase transition in Indium-doped Bi₂Se₃ topological insulators.

Session III was the first one devoted to review the theoretical advances on topological insulators. Prof. Shun-Qing Shen from the Hong-Kong university, gave a unified description of topological insulators and superconductors from one to three dimensions based on the Dirac equation. Prof. Shuichi Murakami from Tokyo Institute of Technology, gave a nice talk concerning the interesting phenomena taking place at the interface between two topological insulators. Prof. Gustav Bihlmayer from Jülich (Germany) closed the session by focusing on the implications and specific characteristics of edge states in 2-dimensional topological insulators explored by DFT.

On **session IV**, the speakers showed topological insulating phases appearing in low dimensional materials: quantized spin Hall effect in Graphene/hBN heterostructures in the absence of time reversal symmetry (Pablo Jarillo-Herrero, MIT); topological boundary states in Graphene nanoribbons containing tellurium-terminated edges (Oleg Yazyev, EPFL); conductance quantization in exfoliated Bismuth at room temperature using a STM (Juan José Palacios, UAM); and coherent transport of Dirac fermions in mesoscopic Bi₂Se₃ nanowires (J. Dufouleur, Dresden).

Session V was also theoretical and was devoted to the magnetoelectric effect in topological insulators and Weyl semimetals. Prof. Joel Moore (Berkeley University) gave a brilliant introduction to topological insulators, including the theoretical prediction and discovery, and presented recent work on magnetoelectric effects. Prof. Marcel Franz (British Columbia) provided new intriguing phenomena related to the existence of the anomalous Hall effect in Weyl semimetals and Ivo Souza (DIPC) reviewed some recent development in the theory of linear magnetoelectric effect in topological insulators.

Sessions VI and IX were devoted to discuss the effect of magnetic impurities on the surface of topological insulators. In session VI, Nitin Samarth (PennState University) showed experimental data of Iron-doped topological insulators in which a gap is observed at the surface states due to time-reversal symmetry breaking. The discussion was followed by Oliver Rader (Helmholtz-Zentrum) who combined theoretical and experimental results to demonstrate in which cases it is possible to open such a gap in a topological insulator by

varying between surface and bulk magnetic doping. This is a hot topic in this field and, as expected, gave rise to several discussions during the dinner and coffee breaks. The discussions continue the day after in **session IX** where Jan Honolka (Czech Republic) showed the results obtained by X-ray absorption spectroscopy (XAS) technique in the group of prof. Roland Wiesendanger regarding the effect of magnetic impurities in the bulk of topological insulators. Hyoung Joon Choi (Yonsei University) closed the session showing the theoretical results obtained using first-principles calculation on the same hot topic.

Session VII was devoted to ARPES and spin-polarized ARPES spectroscopy. The session was driven by two experts on this technique: prof. Philip Hofmann (Arhus University) showed a way to engineer the number of topologically protected Dirac cones at the surface of a topological insulator via its surface orientation; prof. Akio Kimura (Hiroshima university) introduced the last and more advanced techniques to unveil the spin texture at the surface of a topological insulator. To conclude, Dr. Yoshiyuki Ohtsubo from Synchrotron SOLEIL, showed recent ARPES images and spin texture of surface states in Sn ultrathin films.

Session VIII was devoted to growing procedures and the chemical properties of topological insulators. The session was started by prof. Klaus Kern from Max-Planck Institute for Solid State Research who gave an overview of new growing techniques to synthesize high quality topological insulators. Prof. Kern also introduced natural topological insulators. Prof. Jiannong Wang (Hong-Kong university) showed recent result on MBE (Molecular Beam Epitaxy) grown high-index Bi₂Se₃ (221). Dr. Ana Isaeva (TU Dresden) and Dr. Ana Akrap (University of Geneva) discussed about the possibility of obtaining new topological insulators by chemical exfoliation of Bismuth or by applying high pressure to BiTeI respectively.

Session XI was devoted to the field of Majorana fermions which is becoming a hot topic in recent years and are expected to exist at the interface between a superconductor and a topological insulator. The session was opened by prof. Carlo Beenakker, who gave a very nice overview of this hot topic and propose several ways to detect such Majorana fermions in superconductors. Indeed, several talks have addressed the possible observations of Majorana excitations in systems based on topological insulators or materials with strong spin-orbit coupling. Some signatures of Majorana fermions have been published in the recent literature but interpretation is controversial, since many other alternative explanations of the experimental data have been simultaneously proposed. During the workshop, several theoretical talks (including the invited talk by Carlo Beenakker) have proposed new directions of exploration for such signature, based on different design and alternative device geometries. The session was complemented by prof. Alfredo Levy (UAM) and prof. Ramon Aguado (ICMM-CSIC) who are active spanish researchers in this field and gave nice talks combining the theoretical description of such exotic particles with novel experiments designed to detect Majorana fermions.

Last **session XII** was started by Benoit Fauque (CNRS) who showed very nice experimental results regarding thermopower and Nernst effect in topological insulators. To conclude the Workshop, prof. Maciej Lewenstein (ICFO), an expert on ultracold atoms, gave some new ideas and explained the problems related to the design of topological insulators using ultracold atoms.

➤ **Post-Workshop Dissemination**

Two initiatives were taken for dissemination after the completion of the workshop: 1) The publication of a Book on topological insulators and of conference proceedings. Discussions between the Book's editors (F. Ortmann, S. O. Valenzuela and S. Roche) and 2) Proceedings' editors (E. Chulkov, A. Kimura and D. Soriano) have been engaged with the participants and both projects are undergoing.

➤ **Future Editions of the Workshop**

The workshop, originally planned as a one-time event, has raised the interest of many participants for follow-up editions with the same format in the coming years. The 2014 edition will be organized in Germany, under the responsibility of Laurens Molenkamp from Würzburg University and Oliver Rader from Helmholtz-Zentrum Berlin. The 2015 edition is foreseen to take place in San Sebastian, Spain. Perhaps more than anything else, the interest in organizing new editions is a testament of the success of the workshop, which has thus sparked a new series on this topic, offering a chance for Europe to establish a reference meeting on topological insulators in the next years. The impact on the European scientific community will thus continue increasing, gathering recent advances and offering a platform for further networking, collaboration, including international exchanges.

➤ **Program of the Workshop**

3 de Junio

SESSION I

15:30 – 16:15

HgTe as a topological insulator

Laurens W. Molenkamp

16:15 – 16:50

Mercury Telluride, a topological insulator with helical spin texture

Laurent Lévy

16:50 – 17:15

A novel family of chiral-based topological insulators: elemental tellurium under strain

Nicholas Kioussis

17:25 – 18:00

Coffe Break/ Poster Session

SESSION II

18:00 – 18:45

Topological surface states: discovery and recent results

M. Zahid Hasan

18:45 – 19:20

Electronic structure of complex topological insulators and Rashba-type systems

E. V. Chulkov

19:20 – 19:45

A sudden collapse in the transport lifetime across the topological phase transition in $(\text{Bi}_{1-x}\text{In}_x)_2\text{Se}_3$

Liang Wu

4 de Junio

SESSION III

9:00 – 9:45

Dirac equation in topological insulators and superconductors

Shun-Qing Shen

9:45 – 10:20

Surface and interface states of topological insulators

S. Murakami

10:20 – 10:45

Edge states of 2D topological insulators explored by density-functional theory

G. Bihlmayer

10:55 – 11:30

Coffe Break/ Poster Session

SESSION IV

11:30 – 12:05

Tuning the many body ground state of a system of Dirac quasiparticles

Pablo Jarillo-Herrero

12:05 – 12:40

Engineering topological boundary states in topological insulators

Oleg V. Yazyev

12:40 – 13:05

Topologically protected quantum transport in locally exfoliated bismuth at room temperature

J. J. Palacios

13:05 – 13:30

Quasi-ballistic transport of Dirac fermions in Bi₂Se₃ nanowire

J. Dufouleur

13:30 – 15:30

Lunch

SESSION V

15:30 – 16:15

Topological insulators and their implications for electronic order

Joel E. Moore

16:15 – 16:50

Electromagnetic response of Weyl semimetals

M. Franz

16:50 – 17:25

Magnetoelectric coupling and surface anomalous Hall effect

Ivo Souza

17:25 – 18:00

Coffe Break/ Poster Session

SESSION VI

18:00 – 18:35

Interfacing 3D topological insulators with magnetism

Nitin Samarth

18:35 – 19:00

Band gap opening and lifetime broadening of topological surface states with and without magnetic moments

Oliver Rader

5 de Junio

SESSION VII

9:00 – 9:45

Tailoring the electronic texture of a topological insulator via its surface orientation

Philip Hofmann

9:45 – 10:20

Probing spin textures of topological surface states in ternary chalcogenides

Akio Kimura

10:20 – 10:45

Surface states of Sn ultrathin films with Dirac-like dispersion and helical spin polarizations

Yoshiyuki Ohtsubo

10:55 – 11:30

Coffe Break/ Poster Session

SESSION VIII

11:30 – 12:05

High quality synthetic and natural topological insulators

Klaus Kern

12:05 – 12:40

Some recent results on MBE grown 3D topological insulators

Jiannong Wang

12:40 – 13:05

A 2D TI in various crystal-chemical surroundings: a study on the bismuth bilayer

A. Isaeva

13:05 – 13:30

BiTeI: a high-pressure topological insulator?

A. Akrap

13:30 – 15:30

Lunch

SESSION IX

15:30 – 16:05

X-ray absorption spectroscopy of magnetic atoms coupled to TI surface states

J. Honolka

16:05 – 16:40

Effects of magnetic impurities on topological surface states

Hyoung Joon Choi

17:25 – 18:00

Coffee Break/ Poster Session

21:00

GALA DINNER

6 de Junio

SESSION X

9:00 – 9:45

How to detect and braid Majorana fermions in a quantum spin Hall insulator

Carlo Beenakker

9:45 – 10:20

Majorana Single Charge Transistors

A. Levy-Yeyati

10:20 – 10:45

AC Josephson effect and multiple Andreev reflection currents in nanowire junctions with Majorana fermions

Ramón Aguado

10:55 – 11:30

Coffee Break/ Poster Session

SESSION XI

11:30 – 12:05

Entropy transport in Bi_2Se_3 and Bi_2Te_3

Benoît Fauque

12:05 – 12:40

Topological insulators – What can we do with ultracold atoms

Maciej Lewenstein