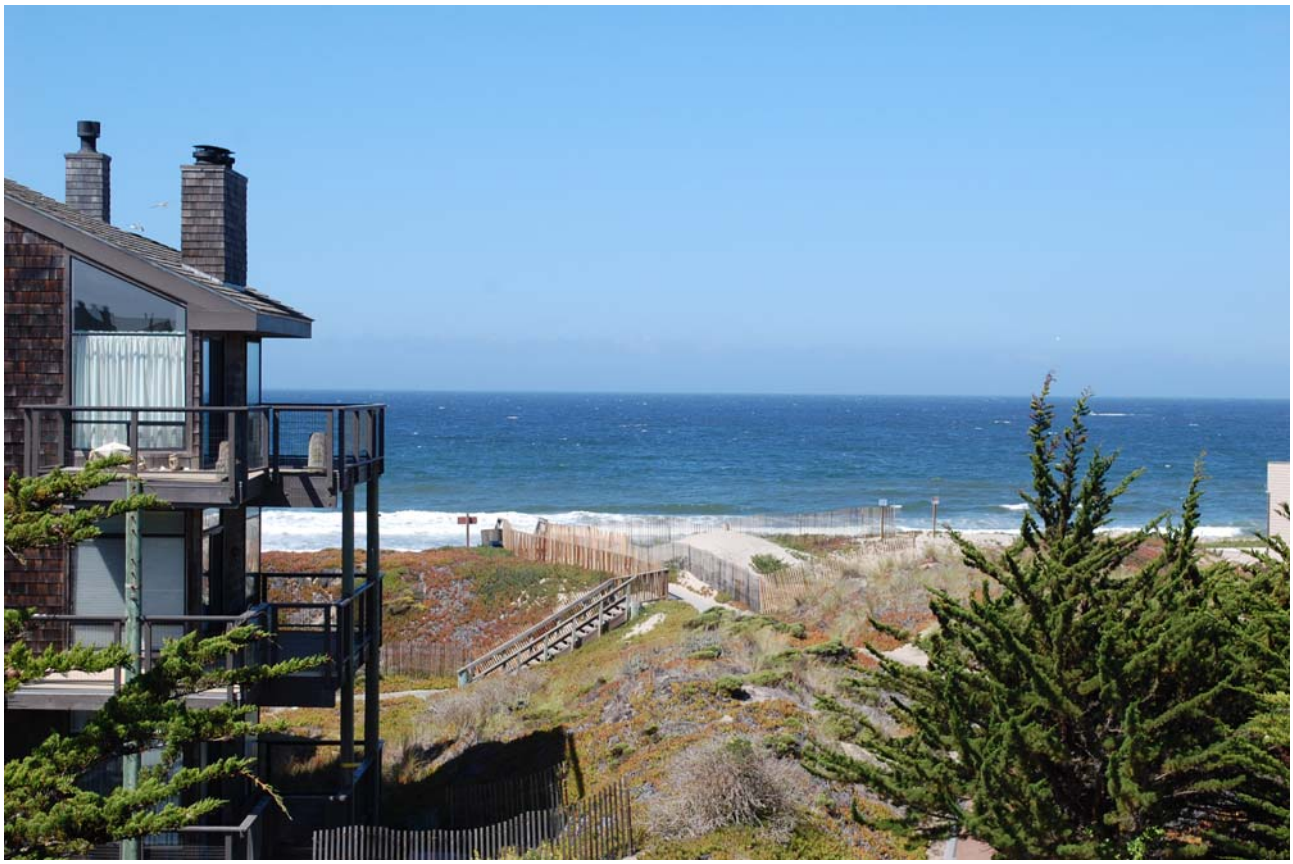


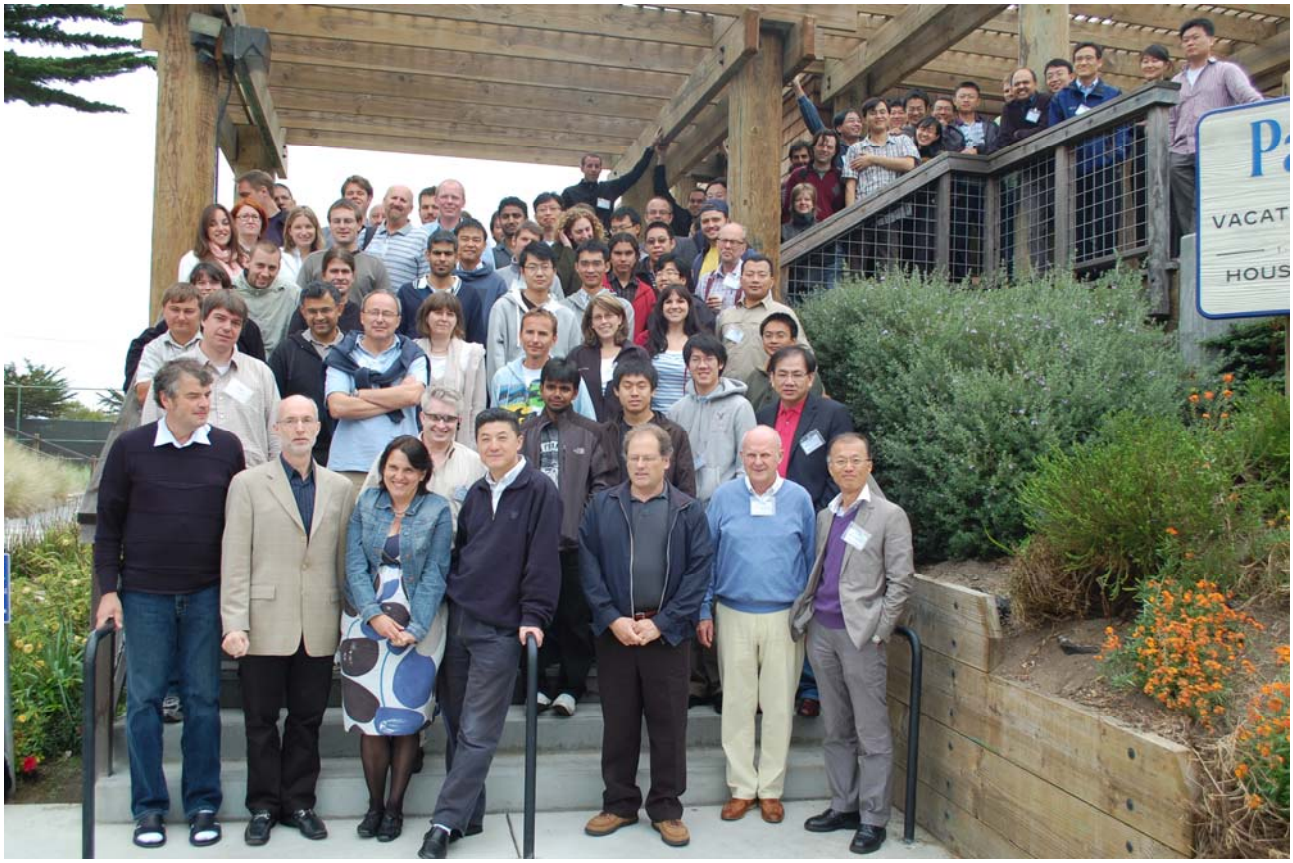
Report on Summer School
"Emerging Materials for Spintronics"

August 27-31, 2010

Pajaro Dunes, Watsonville (California, USA)

by Lukas Müchler

In recent years much work has been done on a new quantum state of matter, the Quantum Spin Hall (QSH) state. This new state does no break any additional symmetries compared to a regular insulator, thus does not fit the model of regular phase transitions, such as the transition from the liquid to the solid state (broken translational symmetry). Being deeply related to the well known Quantum Hall Effect, the QSH state has an insulating bulk and conducting edge states and is described by a topological invariant. Because the counter propagating edge states are fully spinpolarised and protected against nonmagnetic impurity scattering by time reversal symmetry, materials in the QSH state are ideal candidates for future applications in Spintronics. This new state can be realised in 2D systems such as quantum wells structures as well as in 3D materials. Recently, a joint paper about this new state of matter in the well known Heusler compounds has been published in collaboration of Stanford University and J.-G. University of Mainz and further publications are in preparation. Thus students from the University of Mainz and Kaiserslautern travelled to Watsonville (CA, USA) to participate in ''Emerging Materials for Spintronics'' which was organised by Stuart Parkin (IBM), Shoucheng Zhang (Stanford University) and Claudia Felser (Graduate School MAINZ, University of Mainz).



Participants of “Emerging Materials in Spintronics” with S. Parkin, C. Felser and S. Zhang (front row, second to fourth from left)

The workshop had several main topics, the main focus being on recent developments in theory and experimental work on topological insulators (TI), the 3D QSH-state. Several talks were given on oxide structures and the properties that arise at interfaces, such as the conducting behaviour of an interface of two insulating oxides. After a nice dinner the opening session was given by Arthur Ramirez (UCSC, USA) on the exotic properties of oxides, which was followed by an introduction to the field of topological insulators by Xiaolang Qi (Stanford University, USA). On the following day Steve Conradson from the Los Alamos National Laboratory gave a tutorial on advanced structural characterisation during which he especially pointed out the importance of EXAFS measurements

to get deeper insight in the local ordering, which could explain various phenomena such as the magnetic behaviour of Pt-Co alloys.

Afterwards, Jürgen Kübler (TU Darmstadt, Germany) gave an overview on the theory of Heusler compounds by presenting calculational details on the computation of Curie temperatures of half metallic ferromagnets in the Heusler family with remarkable accuracy.
A very detailed and accurate introduction to ARPES measurements on topological insulators was given by Yulin Chen. This method is a very powerful tool, since it is capable of proving the existence of the TI-state, i.e. the linear dispersion relation on the surface of a TI can be observed.
Later on Warren Pickett (UC Davis, USA) reported on new developments in electronic structure methods, especially pointing out the existing differences in the scale of research done on this topic in the US and Europe.
New progress on the topic of MBE growth and properties of thin films of the TI Bi_2Se_3 and Bi_2Te_3 has been presented by Xi Chen from Tsinghua University (Peking, China) with the experimental confirmation of the time reversal symmetry protection of the surface states. In this context Yi Cui from Stanford University talked about nanoribbons of TI with tuneable layer thickness and large surface-to-volume ratios.

Later, Naoto Nagaosa from the University of Tokyo (Japan) proposed a new conserved quantity in systems with spin orbit coupling resulting in a new prediction of spin conservation in systems with strong spin orbit coupling. In the evening session, Shoucheng Zhang from Stanford University predicted the quantized Anomalous Hall Effect during his talk about recent developments in the theory of TI and also proposed an experimental setup to test his predictions.

On the next day Gerrit Bauer from the Kavli Institute of Nanoscience (Delft, the Netherlands) explained the model behind the Spin wave Seebeck Effect and difficulties in calculating qualitative results. Afterwards, Sadamici Maekawa from the Advanced Science Research Center (Tokai, Japan) talked about spin-wave spin currents, its usage as a transmission tool of heat in the context of the Spin Seebeck Effect and as the transmitter of current using the Spin Hall Effect.


Typical flora at Pajaro Dunes

Turning the attention to a more applied topic in racetrack memory, Mi-Young Im from the Lawrence Berkley Nat. Lab. (USA) presented the stochastic nature in magnetisation reversal and domain wall motion. The method of choice was magnetic transmission soft X-ray microscopy which led to the result that the degree of stochasticity depends on the geometry of the nanostructures and can thus be controlled by choosing an appropriate setup.

In the framework of infrared spectroscopy, D.N. Basov (UCSD, USA) talked about the recent investigation on the TI Bi_2Se_3 with this method. Unfortunately the predicted gapless surface states could not be observed, which is probably due to impurities in the samples and the intrinsic n-doping that has also been pointed out by Yulin Chen in his talk. Turning the attention to superconductivity and suprafluids, Hans Hilgenkamp (University of Twente, the Netherlands) proposed a Bose Einstein condensate of exitons in oxide heterostructures such as $LaAlO_3/SrTiO_3$. After these interesting ideas, Christian Pfleiderer (TU München, Germany) gave a report about some very exiting and prior to that not observed magnetic ordering, which is connect to the theory of TI by the Berry Phase of the electrons in real space. In a very pedagogical introduction the complex phenomenology was presented together with a theoretical explanation after which a very fruitful discussion emerged .\

MAINZ doctoral students with S. Parkin (left) and C. Felser (right)

On the next day Susanne Stemmer presented the work of her group on complex oxide heterostructures by MBE and the very high electron mobilities that can be achieved with this method. After these experimental talks, Warren Pickett (UCD) gave a very detailed talk about the appearance of Dirac cone-like dispersion relations in the metallic spin channel of a VO_2/TiO_2 interface, which shows a metal-insulator transition depending on the thickness of the VO_2-layer.
Later on, Jean Marc Triscone (University of Geneva) discussed the unusual transport properties at

the $LaAlO_3/SrTiO_3$ interface, which is a conductor that becomes superconducting at 200 mK.

Coming back to TI, Jürgen Kübler presented the theory of time reversal polarisation in TI, which is connected to the charge polarisation proposed by Zak and can be used to determine the value of the topological invariant in periodic systems.

Having made some comments on this topic before, Alex Zunger (National Lab of Renewable Energies, Boulder, USA) criticised the work that has been done on the 2-D Quantum Spin Hall Effect in HgTe/CdTe quantum wells and proposed some corrections. His main point was the observation, that the gapless edge states are not topological protected edge states, but regular interface states, an error that can be attributed to a wrong $\textbf k \cdot \textbf p$-model in the literature. This talk was surely the most discussed one and no clarification has been given during the conference, which maybe can be attributed to the intense discussions even during the talk.

Poster session

After a short break, Robert de Groot, who discovered halfmetallic ferromagnets, talked about the magnitude of the electron correlation in those materials and pointed out, that no correlated methods such as LDA+U are needed to describe such materials in a correct way.The following talk was a about a very sophisticated study on Landau-level spectroscopy of Dirac surface states in TI by Tetsuo Hanaguri (Riken, Japan), which the linear dispersion relation of the surface states and the strong connection to graphene. A similar study has also been presented by Aharon Kapitulnik from Stanford University in which the effect of a step on the surface of a TI has been examined. Both studies agreed well with each other and an interesting model for the DOS at the steps has been proposed.

Christoph Brüne from the University of Würzburg (Germany) gave an overview of the discovery of the QSHE in HgTe/CdTe quantum wells and some recent measurements that confirmed the edge state nature of the conducting electrons. The last talk from Macel Franz (UBC, USA) was about a very theoretical topic. His group simulated the effect of a magnetic monopole in a simple cubic topological insulator in the framework of axion electrodynamics and found a dragging of charge from the conducting surface into the bulk, which has been called the Wormhole Effect.

Besides the lectures, there has also been a poster session with a lot of discussions as well as plenty of time and possibilities to discuss things between the talks or in the evenings. It really has to be stressed out that the atmosphere was very relaxed and the possibility to play some volleyball or other games in the free time helped to stay concentrated in the lectures.

The location, Pajaro Dunes, has to be mentioned as well. Living in beautiful apartments near the beach with the possibility to have an ingle with some nice people every evening really was a beautiful experience.