Beam test results of prototype silicon sensors manufactured by Infineon Technologies Austria AG

Presented at the International Workshop on Semiconductor Pixel Detectors for Particles and Imaging, Niagara Falls, Canada, 2014

W. Treberspurg*[1], U. Bartl[2], T. Bergauer[1], M. Dragicevic[1], J. Hacker[2], A. König[1], T. Wübben[2]

1) Institute of High Energy Physics, Austrian Academy of Sciences, Vienna (Austria)

2) Infineon Technologies Austria AG, Villach (Austria)

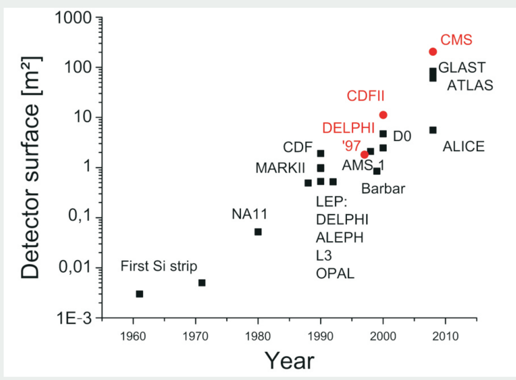
ABSTRACT

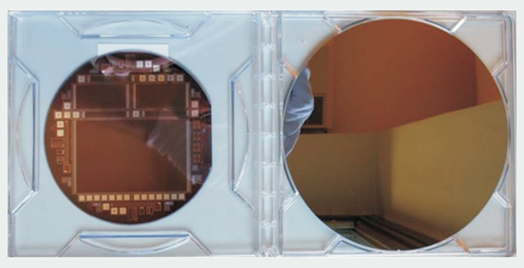
The demand for silicon sensors of modern particle physics experiments has continuously increased since their development in the late 1980ties. Nowadays, the outer tracking systems of the ATLAS and CMS experiments will have to be replaced by utilizing the same technology of standard planar silicon sensors. By then the required number of sensors might exceed the production capabilities of the existing companies and institutes. Therefore the Institute of High Energy Physics in Vienna (HEPHY) has engaged in a cooperation with the European semiconductor manufacturer Infineon Technologies Austria AG to develop a production process for silicon sensors. The project has been triggered by the upgrade of the CMS outer tracker, which will combine short strip sensors with macro pixel ones.
Since 2012 three prototype batches of silicon strip sensors have been produced and electrically characterized. The overall results have shown a promising quality. Nevertheless, out of the small number of weak strips almost all are located at distinctive areas on the wafers and feature a similar behavior. To investigate the final detector performance, a number of representative sensors has been used to build modules, which were operated at beam tests. At the first hadron beam test the modules were read out with the analogue APV25 chip, before and after gamma irradiation. During the other tests with an electron beam the data were not only taken with the APV25 chip but in addition with the binary CBC2 chip, which has been developed to be used at the CMS tracker upgrade.

Introduction

The Infineon project

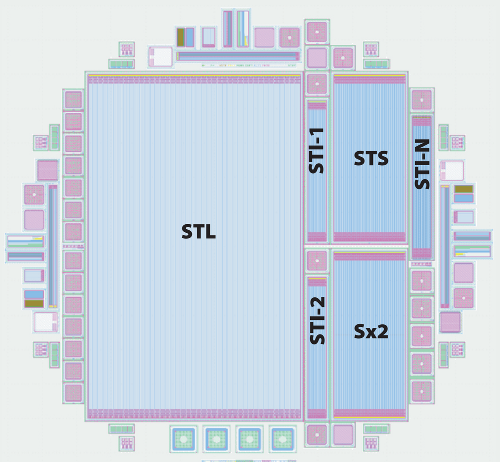
After the high luminosity upgrade of the LHC (HL-LHC), expected to take place at the beginning of the next decade, the detectors have to withstand an increased level of radiation. To cope with these tightened demands and the higher density of particle tracks new systems and sensors have to be built. The upgrades of the outer tracking detectors for the ATLAS and CMS experiments will both be realized by silicon sensors, produced in a standard planar production process. A sensitive surface of several 100 m^2, which by then has to be covered with silicon sensors, represents the top of a continuously increased development. To facilitate the production of sufficient sensors the Institute of High Energy Physics in Vienna (HEPHY) has engaged in a cooperation with Infineon Technologies Austria AG in the late 2009.
The first prototype batch of silicon strip sensors has been designed at HEPHY and produced 2012 at Infineon's production site in Villach. It is intended to recreate a commonly used silicon strip sensor, as it can be found for instance in the outer tracker of the CMS experiment. Therefore 300 µm thin, high resistivity, 6 inch float zone wafers have been selected to produce p-on-n, AC-coupled strip sensors with poly silicon resistor biasing and a coupling dielectric made of SiO_2-Si_3N_4.
After the quality of these sensors has been proven, the preparation of 200 µm thin, n-in-p sensors, produced on 8 inch wafers is ongoing.





Top: The demand for silicon sensors is still increasing
Bottom: The 6 inch wafer with the recent design and a 200 µm thin 8 inch wafer

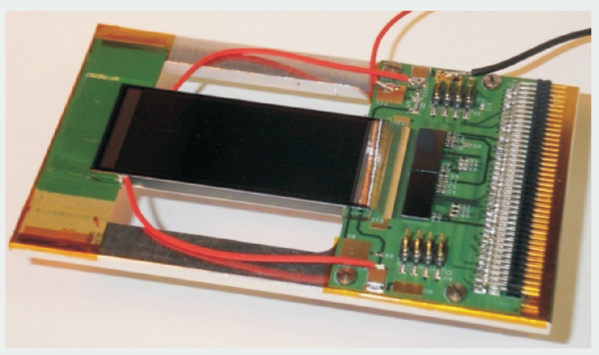
Sensor	Size [mm²]	# of strips	Pitch [µm]	Width [µm]	Length [mm]
STL	102 x 64	512	120	20	99.5
STS	50 x 22.5	256	80	20	48.1
Sx2	50 x 22.5	512	80	20	24
STI	42.7 x 7.5	64	80	20	40.6

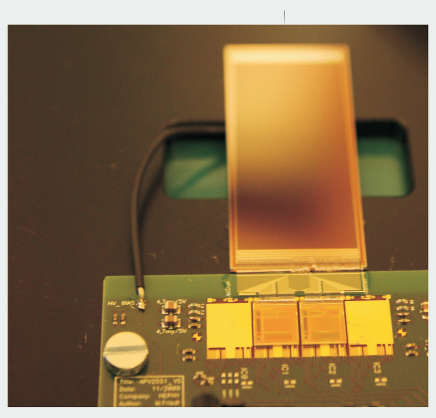


Top: Table of different sensor parameter
Left: The wafer design with the 4 different strip sensors

Wafer design and production

The wafer layout features a set of different AC-coupled strip sensors designed for different purposes. The large STL sensor has been used to investigate the quality of the production process, the three small STI sensors for irradiation experiments at various facilities and the STS sensor to build modules.
Since 2012 three different batches of wafers have been produced on the equipment used for the commercial production of the factory. Each batch can be seperated into split groups, in which the production process slightly differs





Left: The CBC2 module containing two closely arranged STS sensors
Bottom: An APV25 module containing one STS sensor

The modules

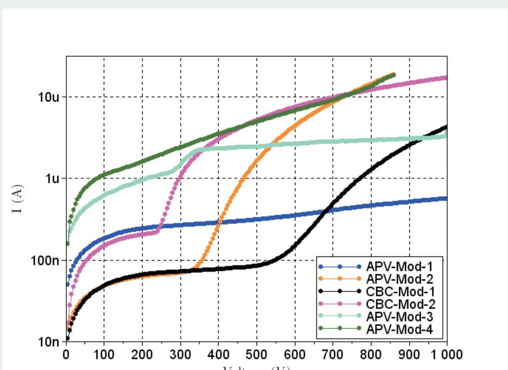
Two different kinds of modules, built with Infineon sensors have already been operated at beam tests. Four analogue read out modules have been manufactured at HEPHY. They are composed of a STS sensor, mounted on a plastic material carrier together with a PCB. On the PCB two APV25 readout chips are attached to a small pitch adapter, a glass substrate with aluminum traces. The strips of the sensor are electrically connected to the readout chips through the pitch adapter by wire bonds, while the high voltage is applied to the backside of the sensor by an isolated wire.
A binary read out CBC2 module has been manufactured by the CERN bonding laboratory. Its basic elements are two STS sensors and two CBC2 chips. Both chips are bonded on a carbon fiber pitch adapter, which is bent around the hybrid in order to connect the top sensor as well as the bottom one to one single chip. This way the direction of passing particles can be measured on a low level [2]. Again wire bonds are used to connect the strips, while the high voltage is applied by an isolated wire.

Electrical characterization

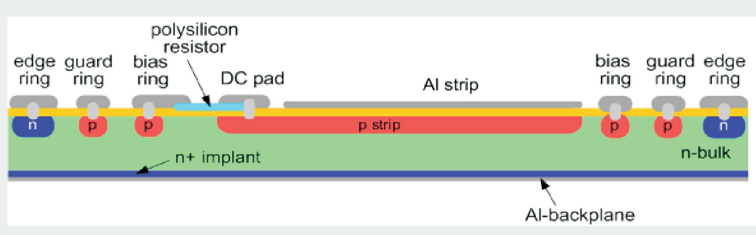
Overview of the sensors

All operated modules have been assembled with six different sensors. The first two modules, which are read out with APV chips (1, 2) as well as the CBC module used sensors of the first batch. The later manufactured APV modules (3, 4) are built of sensors of the second batch. Hence the APV module 1 and 2 could be operated at both beam tests.
The sensors deplete at a voltage of about 250 V and are operated at 300 V. Although the sensors of the second batch feature higher leakage currents, they are still well below 10 µA. Some of the sensors of batch one tend to break down earlier, which is understood, since it has only been seen for sensors of one distinctive split group.

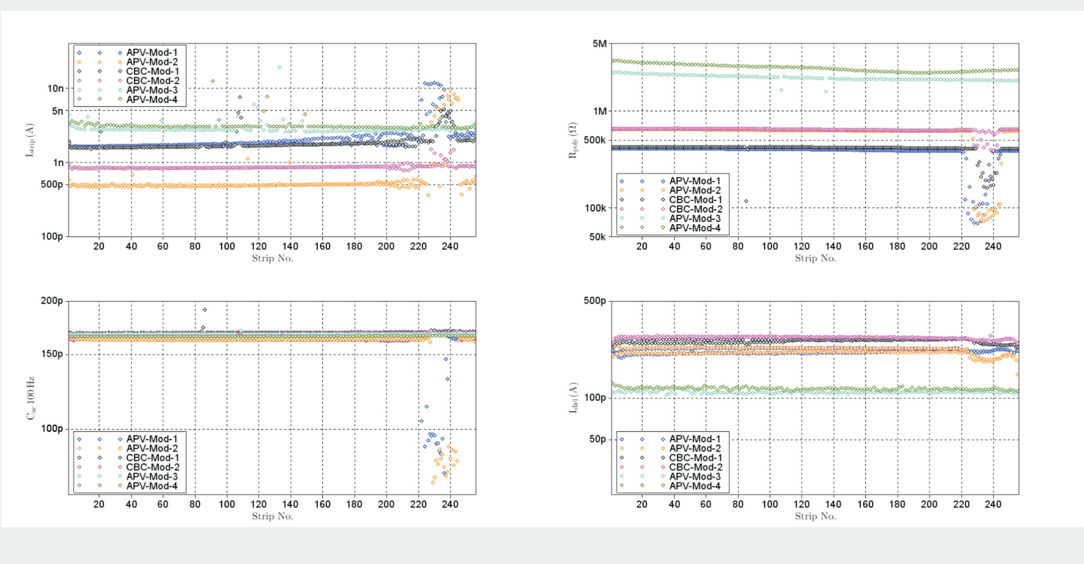
Module	Batch	Chip	Beam
APV-Mod-1	1	APV	SPS, DESY
APV-Mod-2	1	APV	SPS, DESY
CBC-Mod-1	1	CBC	DESY
CBC-Mod-2	1	CBC	DESY
APV-Mod-1	2	APV	DESY
APV-Mod-2	2	APV	DESY



Left: Overview of module and beam tests **Right:** The leakage current of all sensors



Left: The structure of an AC-coupled sensor
Bottom: Different parameter measured on each strip



Strip measurements

In the course of the electrical characterization of the sensors, at least four basic parameters have been measured on each strip. They are the current flowing through each strip, the poly silicon bias resistance and the current and capacitance between the metallic read out strip and the strip implant.
Thereby a systematic accumulation of weak strips near the right edge of the sensor has been observed on sensors of the first batch. This effect could be lead back to the existence of local surface charge carrier, which results in a poor strip isolation. After the sensors of the second batch have shown the same behavior, different methods have been investigated to remove the surface charge [3]. Finally, the sensors of the second batch have been cured, before mounting them on the latter built APV modules 3 and 4.

Beam test at SPS with APV

Beam test and irradiation facility

During the first beam test at the SPS accelerator at CERN the modules were exposed to a 120 GeV/c hadron beam, wide enough to illuminate the full width of the sensors. The beam arrived always perpendicular to the sensor planes and the trigger signal was provided by a single photomultiplier [4].
To investigate the effect of gamma irradiation, one module (APV-Mod-1) was taken to SCK CEN in Mol, Belgium and exposed to a dose of 700 kGy from a ^{60}Co source at a dose rate of 25 kGy/h. Subsequently it has been shipped back to CERN to record another run.

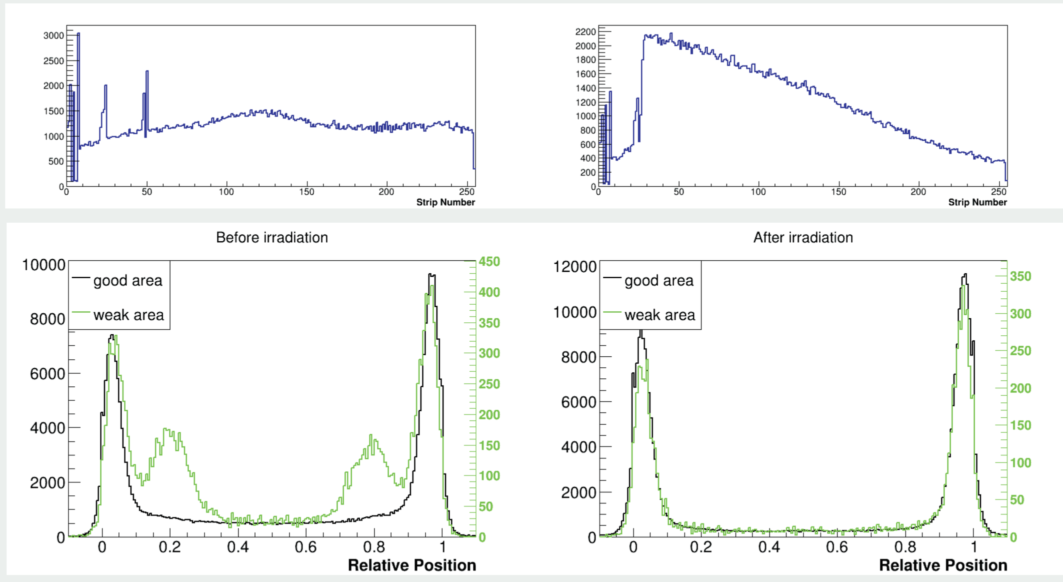


Figure 1: The beam profile (top) and eta distribution (bottom) for runs before and after gamma irradiation. Data of weak strips between strip 221 and 239 are plotted green

Results

The analysis of the APV-Mod-1 module has been performed on two different regions of the sensor. Thereby it turned out that the area of weak strips between strip 221 and 239 features a different behavior, concerning the cluster distribution.
At the upper part of figure 1 it can be seen that both areas of the sensor are hit at the runs before and after gamma irradiation. The signal sharing between two strips is determined by the existence of local charges and can be investigated with the eta distribution. For both runs the distribution is plotted, using data of the weak area (green) and the remaining good one (black).
While the distribution of both areas crucially differs before gamma irradiation, it is very similar afterwards. This indicates the existence of surface charges, which have been over compensated by irradiation.

Beam test at DESY with APV

Beam test facility

At the second beam test at DESY all four APV modules have been exposed to a 4 GeV/c positron beam. The data acquisition has been done with the same system used at the previous beam test at the SPS accelerator, described in [5].

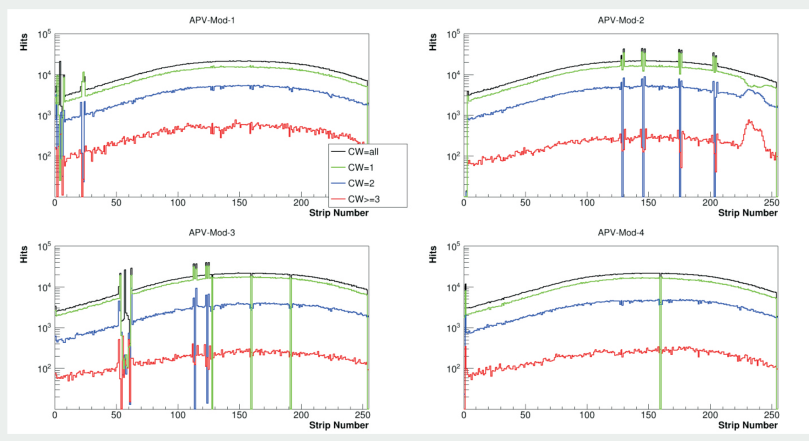


Figure 2: Hit distribution for all modules, including the sum of all cluster widths (CW, black), the center of gravity of CW1 (green), CW2 (blue) and CW3 (red) events

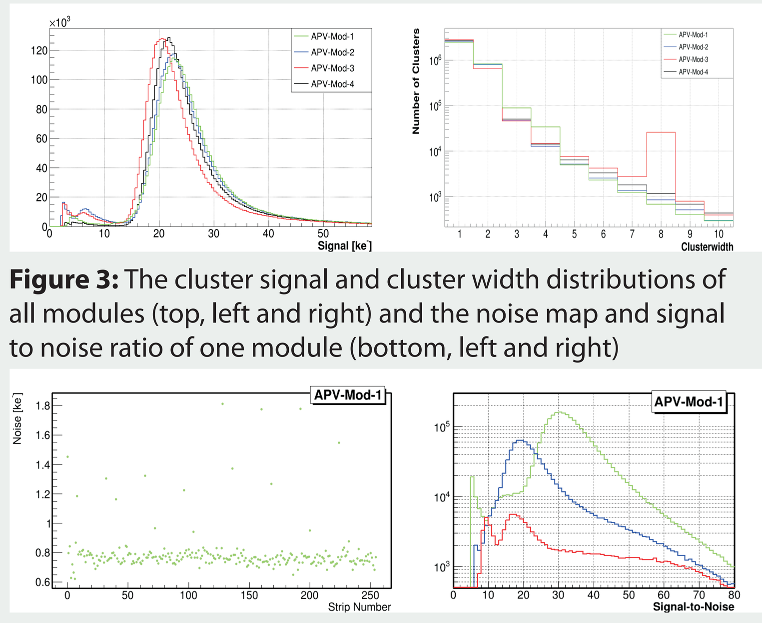


Figure 3: The cluster signal and cluster width distributions of all modules (top, left and right) and the noise map and signal to noise ratio of one module (bottom, left and right)

Results of different samples and areas

To investigate local changes of the strip isolation, the hit map of each sensor, with separated events of different cluster sizes is plotted in figure 2. It can be observed that APV-Mod-1 has been permanently cured after the gamma irradiation, while APV-Mod-2 still features an accumulation of weak strips around strip number 230. The effect only appears in a leak of CW1 (cluster width 1) events and its compensation by events with larger cluster sizes. In contrast, the distribution of different cluster sizes is similar to the overall sum of CWs for APV-Mod-2 and -3.
The signals of all modules are well above 20 ke, which is expected for 300 µm thin sensors. The distribution of cluster widths is dominated by CW1 due to the perpendicular incident angle of the beam. The noise of all modules is below one ke and a little heightened for APV-Mod-1, due to the gamma irradiation. Nevertheless, the signal to noise ratio (SNR) of this module is still above 30 for CW1 and around 20 for larger CWs (figure 3).

Bias scan

In addition the bias voltage has been varied between 100 and 290 V during 12 different runs. The active area inside the bulk expands with an increasing voltage, which results in a higher signal and a smaller noise. The dependence of the signal to noise ratio (SNR) of all four modules on the applied bias voltage for CW1 (cluster width 1) events is plotted in figure 4. All modules behave very similar and stabilize at a value around 36. Only APV-Mod-1 features a smaller SNR due to the higher noise.

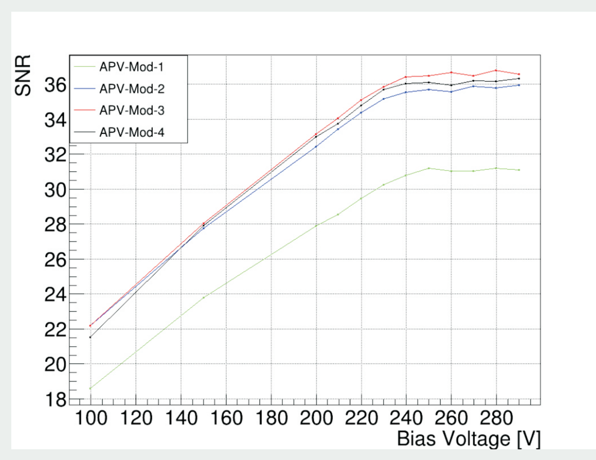


Figure 4: Dependence of the signal to noise ratio on the bias voltage of all modules

Beam test at DESY with CBC

Beam test with CBC2 chip

The binary read out CBC module has been operated during a beam test, organized by the CMS collaboration at the same accelerator facility at DESY, as the APV modules. Details concerning the chip performance and read out can be found in [2].

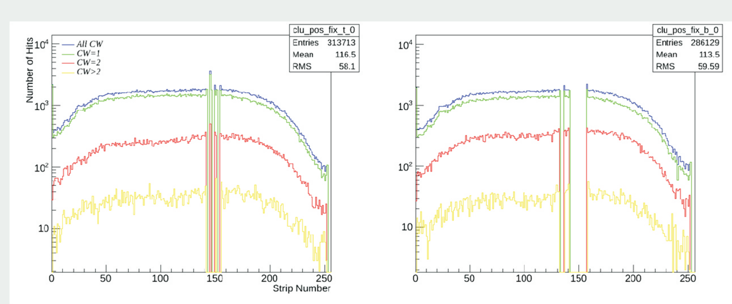


Figure 5: Hit distribution on the sensors of the CBC module, separated per cluster widths

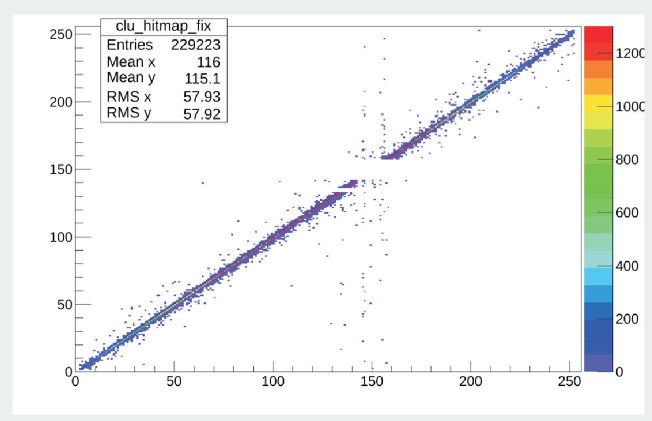


Figure 6: Hit correlation for both sensors of the CBC module

Results

To investigate the local strip isolation, again the hit map is plotted for events of different cluster widths (CW) and their sum in figure 5. Although both sensors feature masked and non connected strips around strip number 150, the overall performance is fine.
Both sensors of the module are arranged very close the each other (2-4 mm) with parallel strips. Hence a strong correlation of events of one sensor to events on the other is expected. Figure 6 shows that almost all hits are located at the same strip number on both sensors.

[1] M. Dragicevic et al., Qualification of a new supplier for silicon particle detectors, Nucl. Instrum. Meth A 732 (2013) 74.
[2] W. Furgerson et al., The CBC microstrip readout chip for CMS at the High Luminosity LHC, JINST 7 C08006 (2012).
[3] W. Treberspurg et al., Optimizing the quality of silicon strip sensors produced by Infineon Technologies Austria AG, JINST 9 C0105 (2014).
[4] M. Dragicevic et al., Results from a beam test of silicon strip sensors manufactured by Infineon Technologies AG, Nucl. Instrum. Meth A (2014).
[5] M. Friedl et al., Readout and data processing electronics for the Belle-II silicon vertex detector, in: Proceedings of the TWEPP 2009, vol. 6, (2009) 417.

* Email: wolfgang.treberspurg@oeaw.ac.at