6^{TH} ROSE WORKSHOP CERN 23-24 OCT 2000 – MINUTES –

These notes are a summary of the discussion session that was held at the end of the 6th ROSE Workshop, 23-24 October 2000. Some additional remarks are added for elaborating on specific topics in view of possible future activities.

Contents:

A) TECHNICAL ISSUES

1) VARIATION OF β IN STANDARD MATERIAL

Remark as to β (CERN scenario) and g_C(Hamburg scenario):

The β-value is defined as the slope of N_{eff} as function of fluence Φ as measured in a CERN-scenario experiment (consecutive irradiation and annealing for 4 min at 80 ^{0}C). It should be remembered that this value is not identical to g_C (the parameter for generation of stable defects as analysed in complete annealing experiments using the Hamburg scenario). Attention should be given to the fact, that the 4min/80^{0}C values in the CERN scenarios include an incomplete beneficial annealing and an onset of reverse annealing, while in g_C both these contributions are selected out! As larger fluences are only to be obtained with larger irradiation times (becoming increasingly larger than the beneficial annealing time constant) that component included in the N_{eff}(4min/80^{0}C) measurements for obtaining the β-value is not proportional to fluence anymore and could therefore distort the results. However similar problems are also unavoidable in the Hamburg analysis. For large fluences (appreciably above 10^{14}cm^{-2}) the beneficial annealing becomes very small as compared to the other effects. Additional uncertainties could then force someone to neglect it completely since otherwise no good fit could be obtained. The fit in this case would just consist of a constant plus second order annealing, resulting again in errors for the "real" g_C. These complications could lead to systematic errors for low flux irradiations (e.g. with 24 GeV/c protons at the CERN-PS or pions at PSI) while they are avoided for high flux irradiations (e.g. with neutrons at the TRIGA in Ljubljana). In the latter case large fluences are obtained in short times and hence the beneficial annealing component would always be fluence proportional.

Part of the following unexpected behaviour may be due to these problems. They are only valid for the p-irradiation (PS) resp. pion irradiation (PSI) but not for the neutron damage (TRIGA).

<u>Wide range of β found:</u>
Oxygenated silicon is always found to give the best (i.e. minimum) beta compared to untreated material. Wide variations are seen in diodes processed on standard material - material with low [O]. Moreover, some manufacturers often obtain good results on standard material - e.g. SINTEF, who use a proprietary gettering process. Various ideas were suggested for further investigation;

a) How important is the oxygen profile. Often the oxygen concentration is large at the surface, even in standard material. What effect does a non-uniform distribution of radiation induced space-charge have on the properties of the diode? Modelling could answer this question. Improvements in the SIMS technique of [O] versus depth may be helpful.

b) How important is the chemical nature of the oxygen, i.e. if it is O_i, O_{2i}, O_{3i} etc. Normally oxygen is in the form of isolated interstitials. Some processing may affect this.

c) Hydrogen may be important. Hydgrogen is extremely difficult to identify in silicon. A technique used at Brunel might find a way to quantify the hydrogen content If so, then correlations between the hydrogen content and β could be made.

d) Is there a correlation between the material resistivity, the processed resistivity and beta? There is a large amount of old data which could be re-analysed to find such a correlation. Data in which the same material was processed at different manufacturers should be looked at again.

2) IS THERE AN $\alpha_{INFINITY}$?

The leakage current anneals with time. No saturation value exists at or below room temperature. According to Michael Molls annealing function (see PhD thesis) a saturation of α at room temperature annealing would be reached after more than 1000 years. Values should be quoted therefore after a standard anneal - e.g. 4 min/80 Centigrade, or 80 min at 60 Centigrade.
There is general consensus that α should be measured using guard rings and that the volume must be well defined. The analysis of I/V-curves is delicate, a minimum of I may be reached sometimes well beyond depletion voltage (pinch off) after type inversion and especially after longer annealing times, which can lead to substantial variations. This is also linked to the definition of V_{depl} and QA (quality assurance) issues, see next section.

3) WHAT IS THE DEPLETION VOLTAGE ?

Various techniques exist - laser (mip), mip, alpha, x-ray, CV. These mostly agree. The CV technique is the one most widely available. A frequency of 10 kHz at room temperature is reliable. Gunnar Lindström and Alexander Chilingarov will write a document defining best practice. CV technique works over the temperature range -20 to +20 Centigrade. Gunnar will investigate the possibility of measuring the capacitance using a charging capacitor and charge sensitive amplifier.
Technical notes on the ROSE Webpage are a good way to distribute best practice.

4) BEHAVIOUR OF N_{EFF} VERSUS TEMPERATURE

The various techniques tried - laser(mip), mip and x-rays need to be checked for consistency.

5) QUALITY ASSURANCE DURING PRODUCTION

Renate Wunstorf gave a presentation on this issue at the Workshop. It was agreed that there should be a special session at the next meeting.
The two techniques for obtaining consistent data from irradiated diodes were the "Hamburg scenario " (HS) and "CERN scenario" (CS).
HS gives all the parameters required to make damage predictions, but is very time consuming; it needs several diodes, each irradiated to a different fluence. The CS is good for comparing materials/diodes and is less time consuming; one diode is irradiated and tested at different fluences. However, it is harder to extract parameters for damage predictions. As to differences see also top remark in 1).
Is there another scenario which is both efficient and gives key parameters for damage predictions ?

6) THE PHYSICAL BASIS FOR NIEL VIOLATION

Calculations which split the NIEL into two parts – isolated vacancy/interstitial production and clustered vacancy/interstitial production - have been started by Mika Huhtinen. More work is required.

7) MOBILITY AFTER IRRADIATION.

The Lancaster group has shown that there are no changes in the mobilty up to 2×10^{14} ncm^{-2}.
Lorentz angle measurements (Karlsruhe) seem to show changes. However, the Hall mobility and drift mobility are not always identical. This problem needs further study.

B) COMMON PAPERS

The R48 publications policy has always been that each group would publish with authors who had contributed to a particular piece of work, but that the RD48/ROSE Collaboration would be acknowledged under the author list. At the last meeting in March it had been felt that one common publication at the end of the project would be a good idea. G. Lindström had presented an invited talk in Hiroshima and at the LEB. Responding to feedback, these were made into common publications. M. Moll played a key role in organising this process. Meanwhile the LEB paper had been also submitted to NIM in the pixel2000 conference proceedings.
It was agreed that the common publications that had already been written were sufficient given that RD48 would finish officially at the end of 2000.

C) FUTURE OF RD48/ROSE

RD48 is approved until the end of 2000. The successful transfer of the oxygenated technology to the detector manufacturers, and its acceptance for use in many systems - e.g. ATLAS Pixel detector, means that RD48 has achieved its objectives. Many people have expressed a desire for the Collaboration to continue - e.g. ATLAS and CMS Pixel detector projects.
Gunnar Lindstrom and Steve Watts wrote to Dietrich Schinzel in July this year with a suggestion for a Common Project. The need for a central irradiation facility was stressed in this letter. The current status is that RD48 will finish at the end of 2000. The only Si related R&D

project that will continue is RD39 (cryogenic silicon) due to the needs of experiments such as TOTEM and NA60. A common "silicon detector facility" is favoured by D. Schinzel. The need to support the radiation facilities has been accepted.

In principle, the ROSE Collaboration could continue in some form after RD48 is finished. However, there should be a need from the experiments, a common programme should exist, and its formal status with CERN needs to be defined and agreed. Comments on these issues are given below.

1) NEED FROM THE EXPERIMENTS

Both the ATLAS and CMS Pixel projects are keen for continuing work on radiation effects. The LHC experiments have been asked to comment on the consequences should the LHC be upgraded to run at a luminosity of 1E35. This will require more radiation tolerant tracking systems, requiring an ongoing R&D in this field. Also as to the production phase of present LHC experiments advice to quality assurance would be welcomed, as outlined by Renate Wunstorf. Finally present knowledge of the DOFZ advantages has to be secured in order to be safe against any surprises during operation (details see in 2)).

2) ISSUES FOR A COMMON PROGRAMME.

A list of issues that need further study, that would form a common programme follows; it is subdivided into

a) issues for securing the present DOFZ results wrt applications in LHC experiments
b) offering advice for quality assurance during the acquisition phase of segmented detectors
c) issues for ongoing long term R&D

a) Securing present DOFZ results for LHC applications

- Correlation between manufacturing process and radiation hardness:
  Although the beneficial effect of O-enrichment for the radiation tolerance had been conclusively established in all experiments and independently of the manufacturers there are open questions wrt the quantitative correlation. E.g. the reverse annealing for CiS diodes (16h/1150C) is lower than that for the SINTEF process (80h/1150C), although as expected the O-concentration for SINTEF is much larger than that for CiS. Another unexplained result is that in some cases the β-value for standard and oxygenated silicon processed by the same manufacturer seems to be identical (both low!) while a process by another manufacturer shows the expected difference (see also above). For the production phase of present applications the clarification of these questions is regarded to be very important.

- Optimisation of DOFZ process, O-concentration by SIMS
  So far the DOFZ process had been done in a range between 16h/1150C and 8d/1200C. SIMS measurements have shown that for the low in-diffusion process one gets a quite inhomogeneous O-distribution while in the latter case the depth profile is almost constant. However the SIMS measurements have to be improved since they have not given the expected symmetric (wrt the front-rear side) distribution. Presently a modified technique is studied measuring the depth profile on a bevelled sample. It is believed that the new technique (preliminary results ok) will be routinely available early next year. Only then and in connection with the point made in the previous paragraph a proper optimisation of the DOFZ process could be completed.

- DOFZ benefits for segmented detectors
  The vast majority of damage studies done so far in our collaboration had been performed with test pad diodes. Comparisons between damage effects in segmented detectors (pixel and strip) and test pad diodes (same wafer) need to be studied in order to guarantee that the effects seen so far are likewise to be expected in the real devices. This has often been asked for by LEB and we should comply with this request. One of the major differences between segmented and test pad structures is the high surface coverage of oxide in the segmented ones. Also with respect to our normal test pad diodes the process of segmented structures involves a generally much more complex process (e.g. nitride). Surface effects cannot be excluded as being important also for the overall detector properties.

b) Offering advice for quality assurance methods during acquisition phase for LHC

- General aspect
  Tests on segmented detectors being delivered by the manufacturers are needed not only to check the guaranteed performance (leakage current, break down voltage,...) before irradiation but also for securing the radiation hardness. This has to be done regardless of whether the DOFZ or a standard process is used. With respect to the huge number of detectors only selected measurements can be performed however securing performance for the total lifetime. Selection of a set of such tests will largely profit from the experience and know how available in the ROSE collaboration and should therefor be discussed between ROSE and the involved LHC groups in close collaboration. A number of different issues have to be addressed, among them:

- Results from damage studies (HS, CS) needed
  The knowledge of the connection between damage results for test pad diodes and those for segmented detectors is vital (see a) above). Only then we could draft a limited test recipe which would be both feasible and sufficient to guarantee the long term behaviour of devices.

- Advice for actual tests
  A number of specific knowledge present within the ROSE community could and should be used: enhanced temperature annealing and projection to LHC operation, actual measurement of current, depletion voltage and charge collection. Some of the tests would be best performed on pad diodes processed on the same wafer (see above).

- Unexpected effects
  Even in cases where unexpected effects in the behaviour of as processed detectors or after their irradiation would occur, the LHC groups could profitably draw from the wide experience and know how available in ROSE.

c) Issues for ongoing long term R&D

- The oxygen story is not over! Normally oxygen is in the form of O_i (interstitial O). The performance of the material with the oxygen in the form of O_i, O_{2i} and O_{3i} needs further study.
- The role of hydrogen has yet to be understood. Ideas to study this now exist. Other impurities may play a role which are yet undiscovered.
- Reverse annealing is significantly suppressed by the oxygenation process. This needs to be understood as more improvement may be possible (see also above).
- The defect kinetics of cluster formation needs further study.
- NIEL Violation needs further calculation.

- The V2-/V2= mystery and inter-centre charge transfer needs further study.
- Defect kinetics at 100K is a completely new subject and needs study due to the use of cryogenic silicon.
- Simulation tools for 2D and 3D irradiated devices need further work. For example, the behaviour of the E-field in irradiated detectors is an interesting topic for study. In addition, one could combine both surface and bulk effects if a suitable package was available.

3) OPTIONS FOR A CONTINUATION OF ROSE

There are four options for ROSE (may be only selected groups who decide so) to continue;

a) To join with RD39
b) To only hold a workshop annually to exchange results and ideas.
c) To obtain "recognised experiment status", and have an organised common programme.
d) To include ROSE activities within a CERN approved common project.

Institutes will be asked for their view as to the best option.

a) Joining with RD39
At a joint meeting with RD39, common research issues were defined as;

- Study of cold oxygenated Si detectors
- Understand defect kinetics at 130K.
- Understand charge trapping.
- Understand N_{eff} and CCE versus temperature.
- Simulation of cold detectors.

Many of the ROSE groups are also members of RD39.
There was no final consensus on a joint collaboration between RD48 and RD39.

b) loose collaboration between interested groups
This option would be the least formal one with the only exchange of results and ideas during an annual meeting hopefully to be held at CERN.

c) status as a new CERN experiment
Although not impossible, experiments on issues not directly dealing with HEP projects exist at CERN, this option would involve a lengthy and well based applicational process and its outcome will largely depend on the CERN policy.

d) common project supported by CERN common project supported by CERN
Interested groups would combine to write a letter of intent for a common project, on the basis of what has been outlined above. It is understood that these groups would not necessarily apply for any CERN money but in exchange of the benefits apparent for CERN they would ask the CERN authority for support in the following way: establish ROSE* (could be given a new name) as an official CERN project, providing the possibility for a team account at CERN, allowing the access to and use of existing irradiation facilities (personnel for performing the experiments to be supplied by the external groups) and providing the necessary infrastructure for annual workshops at CERN. In such a case it would be understood that such a collaboration is not just a continuation of the present one but forms anew. In case this option is favoured a meeting should be held soon and a letter of intent would have to be submitted as best before the end of the year.

IMPORTANT: DEADLINE FOR RESPONSE TO OPTIONS A)-D):
the following questionnaire should be answered by 1-December-2000 (deadline).

Best regards to everybody,
25-Nov-2000
Gunnar Lindstroem, Stephen Watts, Michael Moll

QUESTIONNAIRE ABOUT ROSE FUTURE

For a possible ongoing R&D in the field of radiation tolerant silicon detectors our group favours a participation in (click one only):

a) joining with RD39
b) loose collaboration (no official CERN status)
c) status as a new "CERN experiment"
d) common project supported by CERN
e) none of these options (explain!)

DATE:
GROUP NAME:
LEADER:
INSTITUTE:

ATTENTION: PLEASE SEND YOUR REPLY TILL FRIDAY, 1-DECEMBER-2000
TO: Gunnar.Lindstroem@desy.de
Michael.Moll@cern.ch
Stephen.Watts@brunel.ac.uk