LETTER OF INTENT

POST ACCELERATION OF RARE EARTH ISOTOPE BEAMS FOR RADIOTRACER- DLTS ON SiC

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Summary

Due to its thermal stability and radiation insusceptibility the semiconductor SiC is going to become the material of choice for high voltage and high power devices. Publications about rare earth ions diluted in semiconductors and insulators report on emitted light by intra 4f-shell transitions at wavelengths which are fairly independent of the characteristics of the host lattice. Therefore, they attract considerable interest as possible emitters in a variety of materials. Er\textsuperscript{3+} ions in quartz fibres serve as an optical amplifier for fibre communication systems operating near 1.5\textmu m, which is the minimum of the absorption of these fibres [1,2].
It is our goal to investigate the electrical properties of rare earth-related defects in SiC to characterize induced band gap states. The used methods are standard spectroscopic methods in semiconductor physics which are improved by using radioactive isotopes. The radioactive decay of \textsuperscript{140}Nd to \textsuperscript{140}Ce via the short lived \textsuperscript{140}Pr is used to clearly correlate different signals with Nd or Ce related defects. We intend to use the spectroscopic techniques Deep Level Transient Spectroscopy (DLTS), Thermal Admittance Spectroscopy (TAS) and capacitance-voltage (CV) profiling.
1. Introduction

The electrical and optical properties of semiconductors are extremely sensitive to defects and impurities. Even extremely diluted concentrations will determine the type and magnitude of electronic conductivity, luminescence properties or the mean life time of charge carriers if the impurity or defect in question gives rise to a localized electron state having an energy within the band gap of the semiconductor. Because of this sensitivity, a precise knowledge of impurity related band gap states is highly desirable to understand electronic behavior of rare earth doped semiconductors.

Because of its outstanding physical properties, SiC is one of the most attractive semiconductor for high voltage and high power devices today. A characteristic emission of light by intra 4f-shell transitions at wavelengths near $1.5\mu m$ is also observable as nearly temperature-independent on Er implanted Silicon Carbide (SiC) [3]. Thus, the investigation of the behavior of rare earths in that material becomes interesting.

The advantage of doping semiconductors by ion implantation is the control of concentration, depth and lateral distribution of the dopants. However, ion implantation is always accompanied by structural damage to the crystal requiring thermal annealing to achieve electrical activation of the dopants. The reconstruction of the SiC lattice with a melting point of about $3100K$ requires annealing temperatures up to $1900K$. Using standard spectroscopic techniques to characterize the electronic and optical properties achieved by the doping, it is essential to discriminate between states created by the dopant and states due to remaining implantation defects or defects introduced by the annealing procedure itself.

The production of pure radioactive beams of rare earth- isotopes is therefore of large interest for the further investigation of the behaviour of these materials implanted in SiC.

2. Experimental methods

Most spectroscopic techniques in semiconductor physics which are able to detect and characterize band gap states do not reveal information about their microscopic origin. On the other hand, structurally or chemically sensitive methods, like magnetic resonance techniques, PAC, or Mossbauer effect, generally do not reveal the energetic position of a state within the band gap. To overcome the chemical “blindness”, radioactive isotopes are being used as “tracers”, i.e. a doping experiment is done with a radioactive isotope instead of a stable isotope of the element of interest. Because of its characteristic concentration change according to the nuclear decay law, the involvement of a radioisotope in an experimentally observed band gap state can be confirmed or denied definitely by several subsequent spectroscopic measurements during the elemental transmutation. Band gap states related to either the parent or the daughter isotope are uniquely identified by their decreasing or increasing concentration, respectively.

To detect band gap states or, more generally speaking, impurity related effects, standard techniques of semiconductor physics are used in these radiotracer studies: spectroscopic techniques like Deep Level Transient Spectroscopy (DLTS) and Thermal Admittance Spectroscopy (TAS) as well as capacitance-voltage (CV) profiling. These electrical techniques directly yield absolute concentrations. Hence, the observable signal change is
expected to be precisely proportional to the concentration, i.e. it directly reflects the nuclear decay law. [4]

3. Proposed Experiments

The electrical activation of implanted dopants in SiC needs due to the strong interatomic bonding high annealing temperatures. An imperative prerequisite for these implantation studies is therefore the unambiguous identification of the optical and electrical signals related to rare earth atoms in SiC.

We intend to make use of the radioactive decay of $^{140}$Nd ($T_{1/2} = 3.37\ d$) into $^{140}$Ce via the short lived $^{140}$Pr ($T_{1/2} = 3.4\ min$). The concentration of $^{140}$Pr is negligible compared to the concentration of $^{140}$Nd and will not influence the measurements. Using the power of the classical semiconductor spectroscopy techniques in combination with radioactive dopants, we want to discriminate between electrical properties created by the dopants and defects related to the implantation and annealing procedure. The use of radioactive dopants also allows the accurate determination of the fraction of electrically activated dopants for different annealing procedures.

The ion energies have to be in the range of $4..6 MeV$ to reach an implantation depth of about 0.5..1.5$\mu m$, where the DLTS is sensitive. The diffusion of these large ions in SiC is not possible.

4. Experimental requirements

A post acceleration of the ISOLDE beam at the energy of 60$keV$ is required. Therefore REXTRAP, EBIS, the mass separator and the RFQ of the REX-ISOLDE post accelerator [5] will be used. They will operate at a repetition rate of 10$Hz$. For the EBIS, 100$ms$ are sufficient to charge breed the singly charged $^{140}$Nd ions to a charge of $23^+$ which corresponds to a mass over charge ratio of $\frac{A}{q} = 6$. With an ISOLDE yield of $1\times10^{8}\mu C^{-1}$, the number of ions per pulse is well below space charge limits both for REXTRAP and EBIS. These ions are separated from rest gas ions passing the mass separator. The RFQ accelerates them to an energy of $300keV/u$, i.e. a total energy of 42$MeV$. The acceleration scheme described for ions with relatively high masses has to be examined using a $^{133}$Cs test ion source.

The ions drift further downstream the linac and the collections will be performed at the 'second beam line' of the REX-ISOLDE post-accelerator in the solid state physics implantation chamber. Since the total energy is too high for the implantation depth required, the beam is decelerated by passing through a carbon foil of 5$\mu m$ thickness. This way, 75% of the $^{140}$Nd ions implanted into the SiC samples have energies between 4.0 and 5.5$MeV$. The implantation depth is 1.0$\mu m$ with a straggling of 0.2$\mu m$ [6].

The sample preparation before (cutting, cleaning, etching etc.) and after the implantation (thermal annealing, electrical contacts etc.) will be done in the solid state physics laboratory in building 115 at ISOLDE. For electrical measurements we need up to 10$m^2$ floor space in the ISOLDE hall or in a laboratory nearby.
5. Beam time request

Depending on the used spectroscopic technique, the total required number of implanted ions ranges from $10^9$ up to $10^{11}$ ions per sample. Assuming the yield of $1 \times 10^8 \mu C^{-1}$ of singly charged ions delivered by ISOLDE and a total efficiency in a single charge state of the post accelerator of 2%, implantation times between 5 minutes and 5 hours per sample are required.

We request a total of 3 shifts of ISOLDE beam:

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Half-life</th>
<th>Target</th>
<th>Ion source</th>
<th>Shifts</th>
<th>Proton Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{140}$Nd</td>
<td>3.4 d</td>
<td>Ta</td>
<td>W surface</td>
<td>3</td>
<td>1.0 GeV</td>
</tr>
</tbody>
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6. References