Friedrich Schiller Universität Jena
PAF

Dissertation

High-Fluence Ion Beam Irradiation of Semiconductor Nanowires

Andreas Johannes

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Abstract

Hier alles Bla

Contents

1 Introduction

2 High Doping Concentrations in Nanowires

This chapter will discuss the concentration of dopants incorporated into ion irradiated nanowires. Some of the first results were published in reference [JNP+14]. The simulations and experiments presented in this chapter where all performed on Mn^+ irradiated ZnO nanowires, however the effects are easily applied to other material combinations.

2.1 Doping and Sputtering

With *iradiana* the distribution of the places where the ions come to rest gives the profile of the concentration of dopants per fluence. Locally the concentration, in $[atoms/cm^3]$, increases a certain amount per fluence, in $[ions/cm^2]$, leading to the somewhat awkward unit of for the doping efficacy, $[(atoms/cm^3)/(ions/cm^2)]$. An example of simulation results is shown in figure 2.1a for the irradiation of a ZnO nanowire with $175\,keV$ Mn^+. The ions enter the $y-z$ plane at random locations an an angle of $45°$ to the z-axis, which is periodically continued outside the plane of the image. It is clear, that a homogeneous doping profile is not easy to obtain for the irradiation of a nanowire from one side. As with the creation of a box profile in bulk irradiation, multiple irradiation steps with varying energy are required. Note that $175\,keV$ ion energy

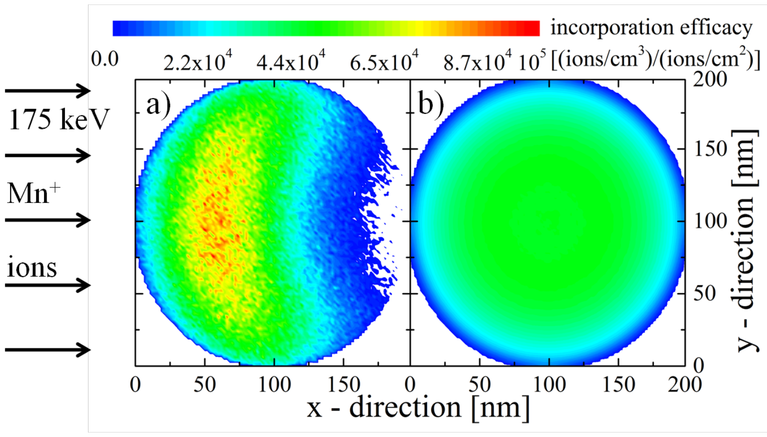

Figure 2.1: a) Color plot of the increase in concentration per fluence for the irradiation of a ZnO nanowire with 175 keV Mn^+ ions at an angle of 45° to the z-axis. The energy was selected so that the rotation of this profile produces a radially homogeneous dopant distribution, as shown in b). The mean dopant incorporation efficacy is $3.4 \cdot 10^4$ $(atoms/cm^3)/(ion/cm^2)$.

are obviously not enough to permeate the whole nanowire diameter of 200 nm, so that a higher ion energy is required. Rotating the nanowire under the ion beam is a much easier way of increasing homogeneity of the doping profile. Figure 2.1b shows the local dopant incorporation efficacy for the rotation of the profile show in 2.1a. Irradiation with a single, relatively low ion energy produces a homogeneous doping profile.

As lower energy ions have lower ranges, there are fewer paths that cause the ion to leave the nanowire, particularly in the forward direction. Therefore, the first advantage of decreasing the ion energy is that the doping efficacy is larger for lower ion energies, so a lower irradiation fluence is required to achieve doping at a desired level. Furthermore, lower ion energy impacts also produce less damage in the irradiated matrix. Together with an optimal irradiation temperature the rotated irradiation was utilized to improve the magnetic properties of Mn^+ irradiated $GaAs$ nanowires [BMB+11, PKB+12, Bor12, KPJ+13, PKJ+14].

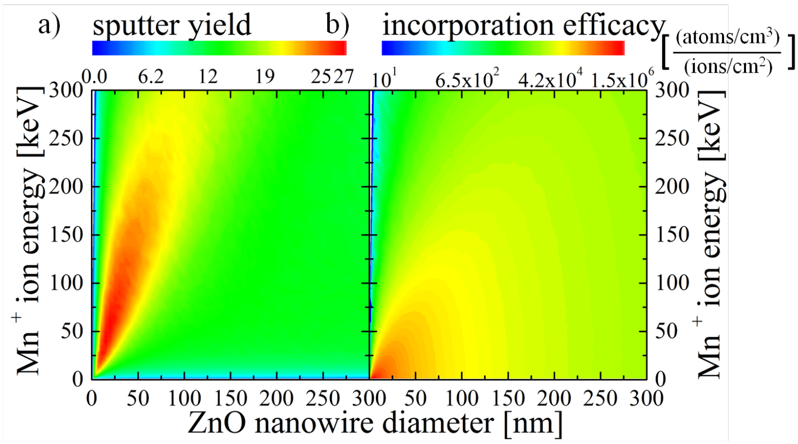

Figure 2.2: a) Sputter yield for the irradiation with Mn^+ of ZnO nanowires with varying diameters an ion energies. From the same simulations the dopant incorporation efficacy was determined and plotted in b).

The assumption underlying the doping efficacy and using it to calculate the required fluence for a desired doping concentration is that the concentration increases linearly with the irradiated fluence. This is only true in the absence of sputtering. In figure 2.1b the outermost layer of the nanowire has a lower dopant incorporation efficacy than the rest of the wire volume. Since the sputtered atoms predominantly originate from this outer layer, the matrix of the nanowire is eroded at the same time as dopants are incorporated. Sputtering therefore leads to a non-linear increase in the concentration of dopants with the irradiated fluence.

2.2 Pseudo-dynamic simulation

The non-linear incorporation of dopants is not

2.3 Results from optimal irradiation conditions

2.4 Discussion of relevant effects

redeposition from substrate (numeric Simulation)
shadowing with old results

Discussion

3 Summary and Outlook

check: Master Thesis Noack, Ogrisek, Conference proceding D. Sage, Rutherford, Nordlund

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