Carrier Lifetime of Au-Hyperdoped Ge using Terahertz Spectroscopy

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Abstract— Gold-hyperdoped germanium extends the photodetection beyond the cut-off wavelength of germanium into the infrared wavelengths. Ion implantation followed by pulsed-laser melting process makes a single crystal material with ultrahigh dopant concentrations. The laser parameters influence the dopant’s atomic position which leads to different light absorption and carrier transport properties. Time resolved terahertz spectroscopy is used to evaluate the charge carrier lifetime which gives an insight into the defect energetics and atomic location.

I. INTRODUCTION

Germanium (Ge) with a bandgap energy of 0.67 eV (1.8 µm) is a good material candidate for room temperature photodetection in the short-wavelength infrared (SWIR) region due to its high absorption coefficients across a broad band and high carrier mobilities [1]. Conventional SWIR photodetectors use narrow bandgap semiconductors such as InAs or InGaAs, which are typically expensive, toxic or require low operation temperatures. Further extension of photodetection in elemental Ge into the IR region beyond its cut-off wavelength requires defect engineering methods.

To enhance the photodetection capability of Ge, laser-hyperdoping is utilized to incorporate dopant concentrations above the solid solubility limit, which enables the formation of an intermediate band between the conduction and valance bands [2]. To fabricate a high quality single crystalline hyperdoped material, ion implantation followed by nanosecond pulsed laser melting is carried out. High flux of dopant atoms amorphize the lattice structure of Ge, and therefore using a pulsed laser, the material is melted deeper than the damaged layer. The material crystalizes epitaxially from the crystalline substrate underneath and during this rapid re-solidification, the dopants are trapped at concentrations above the thermodynamic solubility limit. The rapid solidification process must be slow enough to ensure the recrystallization and at the same time it must be fast enough to allow the incorporation of non-equilibrium dopant concentrations into the sample. Thus, the energy density (fluence) of the pulsed laser have significant effect on the material quality.

In this work, we use hyperdoping to incorporate high concentrations of gold (Au) in Ge. Au hyperdoped Ge (Ge:Au) with different dopant doses and various pulsed laser melting fluences are studied. Time resolved terahertz spectroscopy (TRTS) is used to evaluate the charge carrier lifetime of Ge:Au. In addition, the dopant concentration profile is analyzed by Rutherford Backscattering Spectrometry (RBS). Moreover, the sub band gap absorbance and density functional theory (DFT) modelling of dopant distribution and their effect on band structure are being investigated [3].

II. RESULTS

In this study, we found that laser fluence determines the fraction of dopants incorporated substitutionally. Material characterization shows that lifetime and absorption correlate with substitutional dose (Figure 1). Moreover, DFT modeling indicates that substitutional dopants are deep level defects which lead to high absorption and short lifetime. We found that the charge carrier lifetime is very long even after high concentration of Au is incorporated. We also found laser parameters that lead to highly substitutional dopant incorporation which enhances infrared light absorption. THz lifetime characterization allows optimizing processing parameters and shows hyperdoped germanium is a promising material for SWIR photodetectors.

REFERENCES