Towards efficient detection and spectroscopy of photons emitted by Er^{3+} ions in silicon

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Abstract

We develop a highly sensitive apparatus for efficient room temperature detection of the emission by Er^{3+} ions co-implanted with oxygen atoms in a Si substrate. Our setup proves to be capable of detecting a lower bound value for the emission intensity of about 10^4 photons/s, corresponding to an ion surface concentrations down to 10^{12} cm^{-2}. Yet, the open challenge we aim here is to retrieve the spectroscopic fingerprint of Er^{3+} with high resolution at these low concentrations.

1. Introduction

The demand for single photon sources at the telecom wavelength, which follows from the consistent development of quantum networks based on commercial optical fibers, makes $Er{:}O_x$ centers in silicon still a viable resource thanks to the optical transition of Er^{3+}: $^4I_{13/2} \rightarrow {}^4I_{15/2}$. Ultra-low doses of implanted atoms in semiconductor nanostructures for both electronic [1–5] and optoelectronic devices [6-9] can achieve the limit of single atom doping by single ion implantation method. Yet, to date, the investigation and implementation of such systems remains hindered by its extremely low emission rate. We have recently observed room temperature photoluminescence [9] resonant at 1550 nm at concentrations down to 10^{12} cm^{-2}. Here, we report on the development of a state-of-the art microscpectroscopy which allows to retrieve the spectral fingerprint of extremely low concentration of Er^{3+} ions.

2. Results

We recently reported on the room-temperature photoluminescence (PL) at the telecom wavelength ($\lambda_{PL} \approx 1540$ nm) of very low implantation doses of Er:Ox in Si. The emitted photons, excited by a laser centered at $\lambda_{EX} = 792$ nm, are collected by a custom-made inverted confocal microscope. The lower-bound number of detectable emission centers within our diffraction-limited illumination spot was estimated to be down to about 10^4 using an InGaAs single photon avalanche diode (SPAD) [8]. This has allowed us estimating an emission rate per individual ion of about 4×10^3 photons/s, which is in good agreement with other values reported in literature [10]. Yet, retrieving the spectroscopic fingerprint of Er3+ at these extremely low concentrations and in confined devices remains to date an open challenge [11]. Here, we will report on our last experimental efforts obtained using our inverted confocal microscope equipped with a reflective high numerical aperture (NA) objective (NA = 0.65) and coupled with a Short-Wave InfraRed (SWIR) spectrometer equipped InGaAs CCD camera (Andor Kymera 328i + iDus 490).

We will show electroluminescence maps and emission spectra from photodiodes based on Er-doped silicon realized within the QUASIX project funded by the Italian Space Agency.

These preliminary studies are conducted with the aim of realizing Er-based single photon source for quantum information technology applied in space.

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