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Compressed Sensing Spectral Photoluminescence Imaging of Wide Bandgap Semiconductor Materials for Power Electronics Applications

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Summary:
A compressed sensing approach has been adopted for spectral photoluminescence imaging measurements at NPL. The features and performance of the proposed methodology is initially studied with simulations, which looked at the requirements for a measurement system implementation. Simulation results are presented for a typical homoepitaxial 4H-SiC defect, while an experimental implementation is proposed. Compressed sensing can offer a higher signal to noise ratio and faster measurement acquisition for spectral PL measurements than conventional techniques.

Keywords: spectral photoluminescence, compressed sensing, semiconductor metrology, power electronics, silicon carbide

Introduction

Wide bandgap (WBG) semiconductors such as silicon carbide (SiC) and gallium nitride (GaN) exhibit higher critical (breakdown) electric field strength, higher electron mobility, and better thermal properties than silicon (Si) [1][2]. Such attributes make them highly attractive for high-power and high-temperature applications for electronic devices, such as power electronics. A major challenge for high quality SiC and GaN production has been the elimination of defects that can affect device performance, such as stacking faults, edge dislocations, screw dislocations, polytype inclusions, and basal plane dislocations. Photoluminescence (PL) imaging spectroscopy is a useful method to detect defects, using PL spectroscopy with a 325 nm laser.

In this work, a novel spectral PL imaging method for WBG materials is presented. The methodology is based on compressed sensing, an advanced sampling methodology that can allow single pixel imaging, higher signal to noise ratio and increased measurement speed compared to a point-by-point scan. The method is validated through simulations and the experimental implementation is discussed.

Compressed sensing methodology

Compressed sensing (CS) refers to a methodology to solve inverse problems, where signals are reconstructed from incomplete or inaccurate measurements [3]. Reconstruction from undersampled datasets is possible by carefully designed measurements using assumptions about signal structure (sparsity).

For compressed sensing, a series of patterns is projected on the sample under test, instead of a point-by-point scan, with a measurement applied for each pattern. In this work the Walsh-Hadamard Transform (WHT) is used to generate patterns, wavelets are used as the sparsifying transform and the SPGL1 algorithm (Spectral Projected Gradient for $\ell 1$ minimization) [4] is used to reconstruct high resolution images in a few seconds on a conventional computer.

Simulation results

In order to investigate the application of CS for spectrally and spatially resolved photoluminescence measurements on WBG materials, a real spectral photoluminescence dataset was used. The dataset is from measurements of a polytype inclusion in homoepitaxial 4H-SiC. The initial PL map was acquired using a scanning spectral PL microscopy system with a 325 nm excitation laser, to provide the data cube for the simulations. In order to apply CS on this dataset, a smaller 64 × 64 area of the dataset was selected. The area corresponds approximately to a 50 µm × 50 µm area of the SiC wafer, around the centre of the defect. A series of binary structured patterns were projected on the selected area, with the total spectral profile for each pattern recorded, as presented in Fig. 1. Only contributions from pixels that correspond with unmasked areas of the pattern are taken into account, and their sum is calculated for each wavelength.

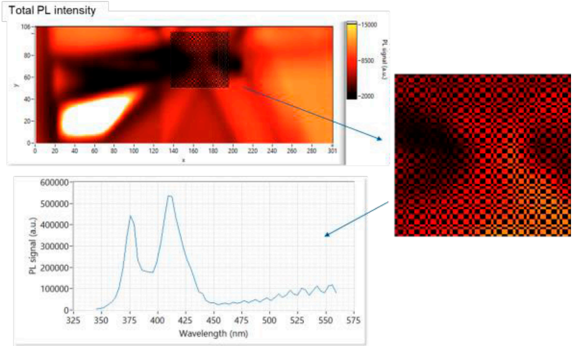

Fig. 1. The sampling process for the CS simulations. An area of the PL map is selected, a series of patterns is applied on this area.

The sampled data were then used to reconstruct a spectral map for each wavelength through the optimisation algorithm. Fewer samples than the pixels of the map (64 × 64 = 4096) are required for reconstruction, which means the final dataset can be acquired with undersampled datasets. Distinctive PL peaks are clearly observed corresponding to emission from polytypes with reduced bandgap.

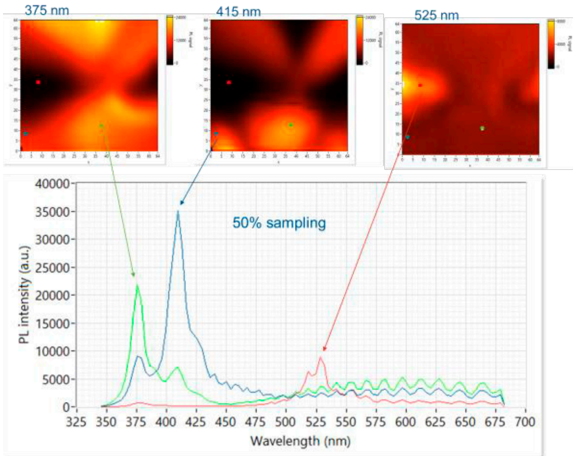

Fig. 2. Reconstruction results at 50% undersampling, for the three different PL emission peaks, along with the spectra of the selected points (red, green, blue spots) on the maps for each reconstruction case.

In order to get a more realistic understanding of the application of compressed sensing for spectral PL mapping, noise has been added in the sampling process. Noise levels from 0.1 % up to 1 % were tested, with the changes being apparent when higher levels of noise are added. The results are presented in Table 1, for the 410 nm reconstructed map at 50 % sampling, with different noise levels. Reconstruction results with noise higher than 0.5% of measured signal are significantly degraded.

Table 1. Correlation coefficient between initial and reconstructed PL image for different noise levels.

SAMPLING LEVELS / GAUSSIAN NOISE	25%	50%	75%
0.10%	0.990	0.992	0.996
0.20%	0.986	0.988	0.986
0.50%	0.961	0.943	0.923
1%	0.873	0.810	0.745

Experimental implementation

A simplified schematic of the experimental implementation is presented in Fig 3. A digital micromirror device (DMD) is used for pattern generation and a 325 nm UV laser for excitation. The spectrum for each pattern is measured using a spectrometer.

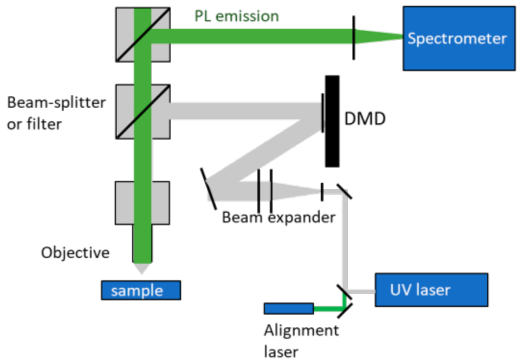

Fig. 2. Schematic of the CS spectral PL experimental setup of this work.

Conclusions

Compressed sensing has been demonstrated for spectral PL imaging measurements at NPL, through a simulation process using real measurement data. The potential for faster measurements due to undersampling has been observed and the noise requirements for the experimental implementation have been defined.

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