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Article / Book Information

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Title(English)	Characterization of local physicochemical properties of nano-sized materials by micro and nano-Raman spectroscopy
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Type(English)	Summary

（博士課程）
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論 文 要 旨

THESIS SUMMARY

専攻： Department of	Electronic Chemistry 専攻	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of (Science)
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

This thesis deals with analyses of local physicochemical properties of strained-silicon nanowires (e-SiNWs) and carbon nanotubes (CNTs) via micro and nano-Raman spectroscopy, respectively, to improve transistor technology. This work's significance is addressing the effects of size reduction and complexity increase of transistor geometry – a trend dictated by Moore's law – on transistor performance. Present-day transistors employ e-Si as channel material using high stress to increase carrier mobility. The amount of stress is altered, however, during nanopatterning inducing dimension-dependent anisotropic stress relaxation, suggesting reduced carrier mobility and size limitations. To overcome these problems, CNTs as alternative materials are considered because of their intrinsic electronic transport properties and ultrathin body. Function optimization can be realized through characterization of CNT's local electronic properties utilizing nano-Raman.

Chapter 1 Introduction briefly discusses the two materials of interest, e-SiNWs and CNTs, and their role in present and future transistor technology, respectively. The current problems of e-SiNWs due to Moore's law and the possible solutions of CNTs as channel material are presented. To study such nano-sized materials, characterization methods, particularly micro-Raman and nano-Raman spectroscopy, are explained. From here, the objective and the significance of this work were stated.

Chapter 2 Properties of a focused three-dimensional field across an interface for micro-Raman spectroscopy. The theory and physics on how focused light is diffracted across an interface is described in detail. The three types of polarization (linear, radial, and azimuthal) are explained and the effects of polarization on the components of the focused electric field (E_x, E_y, and E_z) are compared. A simple two-layer system consisting of a glass/air interface was studied as proof-of-principle and is later extended to a more complex system (three-layers) in Chapter 3. Utilizing the integral representation of an electric field for each polarization, the electric field was calculated and visualized as it travelled between the glass/air interface. It was shown that each polarization generated different electric field distributions in the transverse (E_x + E_y) and longitudinal (E_z) components and such information would be useful depending on the application.

Chapter 3 Strained Silicon: a theoretical study. The theory of Raman scattering in Silicon and the polarization selection rules based on the Raman tensors are presented and discussed. Stress in Si (particularly e-Si) can be quantified through the detection of longitudinal optical (LO) and transverse optical (TO) phonons. The detection of these phonon modes is dictated by their respective Raman tensor, known as the polarization selection rules. In a backscattering geometry, TO modes cannot be detected and reflects a limitation of micro-Raman spectroscopy. This technique could only detect the average amount of stress and was insensitive to anisotropy. It was hypothesized that if a high numerical aperture (NA) was used, it would be possible to detect TO modes. A Raman spectroscopy experiment was modeled based on this hypothesis, using 1) an illuminating beam with either linear or radial polarization, 2) a high numerical aperture lens and 3) a sample consisting of a three-layer system (oil/e-Si/air). Three-dimensional electric calculations were conducted based on the electric field distribution inside silicon using the theory developed in Chapter 2, which was then applied to the Raman tensor of both LO and TO modes. It was shown via numerical simulations that through the use of a high NA lens and appropriate polarization, it is possible to directly detect the undetectable TO phonons. Therefore making the initially insensitive micro-Raman spectroscopy sensitive anisotropy.

This makes it possible to accurately determine the stress in strained Silicon structures such as nanowires.

Chapter 4 Strained Silicon: a micro-Raman spectroscopy characterization study of stress after nanopatterning via precise polarization control. By implementing the experimental conditions simulated in Chapter 3, TO phonon splitting was experimentally observed for the first time via micro-Raman spectroscopy. As a result, analysis on the redistribution of stress after nanopatterning could be done. It was found that stress relaxation anisotropy was experienced by the nanowires and this anisotropy was greatly influenced by the nanowire's geometry. It was also found that even at small dimensions, high anisotropic stress can still be attained. This finding is important because it is contrary to the prevalent belief that as the dimensions of e-SiNWs become smaller, the stress also decreases. The work in Chapter 4 presents a new method of stress characterization that is sensitive to anisotropic stress and will be very useful for strain nanoengineering of transistors.

Chapter 5 Carbon Nanotubes: theory, properties and tip-enhanced Raman spectroscopy. The discussion shifts to carbon nanotubes giving a brief background on their properties. The Raman spectrum of CNTs was also discussed and what information can be extracted from these spectra was explained. To study CNTs whose diameters range from 0.7 to 10 nm, nano-Raman spectroscopy techniques such as tip-enhanced Raman spectroscopy (TERS) must be employed to spatially resolve them. This chapter demonstrates the power of TERS in terms of spatial resolution and signal enhancement.

Chapter 6 Carbon Nanotubes: tip-enhanced terahertz Raman scattering, a nano-Raman spectroscopy study. In order to precisely study CNTs, and any other sample for that matter, using TERS, possible sources of problems from the technique must be addressed. It has been said that TERS is a non-invasive analytical tool, but TERS generates a strong enhanced electric field, and it is unavoidable that this electric field can generate heat. This heating can affect the sample, tip and substrate (if it is metallic), thus affecting sample analysis. In this light, TERS can be viewed as invasive. In order to establish TERS as a truly non-invasive analytical tool, the local temperature generated at the tip apex must be determined and controlled. This is most especially important when studying heating effects in CNTs, which is an important aspect for transistors. To overcome this challenge, a novel temperature determination technique that can detect the temperature and temperature changes at the nanoscale has been developed. This technique is called tip-enhanced THz Raman spectroscopy (TE-THzRS). Through the detection of the RBM of CNTs and the Boltzmann distribution, the temperature of the CNTs was determined. It was also found that at low temperatures (less than 100˚C) the temperature can be controlled by controlling the power of the illuminating laser. TE-THzRS is not only useful for CNTs but can be extended to other fields and applications as well, such as biological samples.

Chapter 7 Summary and Conclusions. A brief summary of this thesis is given and the important conclusions from each chapter are mentioned.