Nanocantilever Beams

Modeling, Fabrication, and Applications

edited by

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Pan Stanford Publishing

Published by

Pan Stanford Publishing Pte. Ltd.
Penthouse Level, Suntec Tower 3
8 Temasek Boulevard
Singapore 038988

Email: editorial@panstanford.com
Web: www.panstanford.com

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

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Cover image: Courtesy of Profs. Takahito Ono and Masaya Toda, Department of Mechanical Systems and Design, Tohoku University, Sendai, Japan. The image shows a single nanocantilever beam with a magnetic microsphere and an array of bimaterial nanocantilever beams.

ISBN 978-981-4613-23-1 (Hardcover)
ISBN 978-981-4613-24-8 (eBook)

Printed in the USA

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Preface

The cantilever beam is an important structure of microelectro-mechanical system (MEMS) devices. This simple structure, fixed at one side and not connected at the opposite side, was inspiring Kurt Peterson, in the classic paper "Silicon as Mechanical Material." He was the first scientist to think of the fabrication of this structure in silicon. Since this pioneering study to fabricated cantilever beam in silicon was performed, a large number or research groups have joined this field and greatly expanding the scope of microcantilever beam structure. At this moment, the cantilever beam is an active research topic and there are many interesting applications based on this concept especially in the areas of chemical and biological sensors. The special advantages of these types of sensors rely on their versatile qualities such as microscale dimensions of the sensor area, label-free detection, high sensitivity, simple integration with electric circuits, and the potential for simultaneous detection of tens or even hundreds of targets by using arrays of cantilever beams. The cantilever beam arrays could be mass fabricated using the semiconductor and MEMS technologies. The performance of these devices has been dramatically improved through the development of new materials and micro and nanotechnologies.

In the past decade, microtechnology has explored the submicron regime, and nanomechnical systems (NEMS) have started to attract interest for a wide range of applications due to their unique properties. Micro- and nanosized cantilever beams are robust devices whose high sensitivity and selectivity allow them to detect physical, chemical, and biological components by measuring changes in cantilever bending or in resonant frequency. Several types of optical and electrical signal transductions have been reported for diverse application in vacuum, air, or liquid. Nanocantilever beams have an intrinsically high mass sensitivity and thus evolved into a powerful tool for absolute mass detection of molecules.

This book focuses on the nanocantilever beam. Nanometer-size mechanical structures show exceptional properties generated by their reduced dimensions. These properties enable new sensing concepts and transduction mechanisms that will allow the enhancement of the performance of the actual devices to their fundamental limits. The book is divided into three parts and covers important research that was performed in this area in the past decade. The first part is about nanocantilever beam fabrication using silicon or polymer as substrate materials. The second part studies the nonlinearity of nanocantilever beam resonators. At small vibrational amplitudes, nanocantilever beams behave as mechanical devices. The nonlinear effects are manifested when the vibration amplitude increases. Euler–Bernoulli beam theory is widely used to successfully predict the linear dynamics of micro- and nanocantilever beams. However, its capacity to characterize the nonlinear dynamics of these devices has not yet been rigorously assessed, despite its use in nanoelectromechanical systems (NEMS) development. The study of nonlinear dynamics of nanocantilever beam provides an analytical tool in order to optimize the resonant nanosensor design and enhance its performance for precision measurements applications. The third part focuses on important applications of diverse nanostructures such as carbon nanotubes, nanomembrane structures, lead zirconate titanate (PZT) nanofibers, and nanomechanical beams. Nanocantilever beams have important applications as optical transducers and actuators. Fully integrated cavity optomechanical transducers for mechanical position and motion sensing with high precision, high bandwidth, and a small footprint are described in the book. Nanophotonics has emerged as a viable option for addressing the transduction issues of nanomechnical beams decreasing sizes. Integrated nano-optomechanical systems have demonstrated exceptional displacement sensitivity. Nanobridge structures fabricated from zinc oxide (ZnO) nanowires and used as gas sensors are also presented in the book. The fabrication techniques for the ZnO nanowire chemical sensor and the experimental testing of the sensor are discussed. An important application of nanocantilever beams is in the area of biotechnology. When the nanocantilever beam is fabricated from materials with different thermal expansion coefficients, it could act as a calorimeter used to detect the temperature of mammalian cells. The nanocantilever beam functionalized with an antibody was demonstrated as a highly sensitive sensor for the detection of diverse biomolecules.

This book offers very diverse information about the nanocantilever beam, nanobridge, and nanomembrane structures whose high sensitivity allow them to detect physical, chemical, and biological components. A variety of materials could be used for the fabrication of nanocantilever beams. Several types of optical and electrical signal transductions methods have been reported for diverse applications in the air, liquid, and vacuum. This book presents the state of the art of all presented subjects, and the editors hope that this book will be very useful for researchers in this field. We would like to thank the authors for their efforts to contribute to this collection of research topics focused on nanocantilever beams. We were fortunate to meet each author and discussed each chapter at the NMC 2013 Workshop on Nanomechanical Sensing, at Stanford University. We hope that this collected work will provide excellent scientific reference for an audience with a diversity of backgrounds and interests, including students, academic researchers, industry specialists, policy-makers, and enthusiasts.

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PART 3: APPLICATIONS OF NANOCANTILEVER BEAMS