

Sharlotte L.B. Kramer · Rachael Tighe · Ming-Tzer Lin ·
Cosme Furlong · Chi-Hung Hwang *Editors*

Thermomechanics & Infrared Imaging,
Inverse Problem Methodologies,
Mechanics of Additive & Advanced
Manufactured Materials, and
Advancements in Optical Methods &
Digital Image Correlation, Volume 4

Proceedings of the 2021 Annual Conference
on Experimental and Applied Mechanics



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Applied Mechanics

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Preface

Thermomechanics and Infrared Imaging, Inverse Problem Methodologies, Mechanics of Additive and Advanced Manufactured Materials, and Advancement of Optical Methods and Digital Image Correlation represents one of four volumes of technical papers to be presented at the 2021 SEM Annual Conference and Exposition on Experimental and Applied Mechanics organized by the Society for Experimental Mechanics scheduled to be held during June 14–17, 2021. The complete proceedings also include volumes on: *Dynamic Behavior of Materials; Challenges in Mechanics of Time-Dependent Materials, Mechanics of Biological Systems and Materials, and Micro- and Nanomechanics; and the Mechanics of Composite, Hybrid and Multifunctional Materials, and Fracture, Fatigue, Failure and Damage Evolution*.

Each collection presents early findings from experimental and computational investigations on an important area within experimental mechanics; residual stress, thermomechanics, and infrared imaging inverse problem methodologies; and the mechanics of additive and advanced manufactured materials being a few of these areas.

In recent years, the applications of infrared imaging techniques to the mechanics of materials and structures have grown considerably. The expansion is marked by the increased spatial and temporal resolution of the infrared detectors, faster processing times, much greater temperature resolution, and specific image processing. The improved sensitivity and more reliable temperature calibrations of the devices have meant that more accurate data can be obtained than were previously available.

Advances in inverse identification have been coupled with optical methods that provide surface deformation measurements and volumetric measurements of materials. In particular, inverse methodology was developed to more fully use the dense spatial data provided by optical methods to identify mechanical constitutive parameters of materials. Since its beginnings during the 1980s, creativity in inverse methods has led to applications in a wide range of materials, with many different constitutive relationships, across material heterogeneous interfaces. Complex test fixtures have been implemented to produce the necessary strain fields for identification. Force reconstruction has been developed for high strain rate testing. As developments in optical methods improve for both very large and very small length scales, applications of inverse identification have expanded to include geological and atomistic events. Researchers have used in situ 3D imaging to examine microscale expansion and contraction and used inverse methodologies to quantify constitutive property changes in biological materials.

Mechanics of additive and advanced manufactured materials is an emerging area due to the unprecedented design and manufacturing possibilities offered by new and evolving advanced manufacturing processes and the rich mechanics issues that emerge. Technical interest within the society spans several other SEM technical divisions such as composites, hybrids and multifunctional materials, dynamic behavior of materials, fracture and fatigue, residual stress, time-dependent materials, and the research committee.

The topic of mechanics of additive and advanced manufacturing included in this volume covers design, optimization, experiments, computations, and materials for advanced manufacturing processes (3D printing, micro- and nano-manufacturing, powder bed fusion, directed energy deposition, etc.) with particular focus on mechanics aspects (e.g., mechanical properties, residual stress, deformation, failure, rate-dependent mechanical behavior).

With the advancement in imaging instrumentation, lighting resources, computational power, and data storage, optical methods have gained wide applications across the experimental mechanics society during the past decades. These methods have been applied for measurements over a wide range of spatial domain and temporal resolution. Optical methods have utilized a full range of wavelengths from X-ray to visible lights and infrared. They have been developed not only to make two-dimensional and three-dimensional deformation measurements on the surface, but also to make volumetric measurements throughout the interior of a material body.

The area of Digital Image Correlation has been an integral track within the SEM Annual Conference spearheaded by Professor Michael Sutton from the University of South Carolina. The contributed papers within this section of the volume span technical aspects of DIC.

The conference organizers thank the authors, presenters, and session chairs for their participation, support, and contribution to this very exciting area of experimental mechanics.

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Contents

1	Super-Resolution Optical Microscopy to Detect Viruses (SARS-CoV-2) in Real Time	1
	C. A. Sciammarella, L. Lamberti, and F. M. Sciammarella	
2	Mesostructure Evolution During Powder Compression: Micro-CT Experiments and Particle-Based Simulations	15
	Marcia A. Cooper, Joel T. Clemmer, Stewart A. Silling, Daniel C. Bufford, and Dan S. Bolintineanu	
3	Surface Pressure Reconstruction in Shock Tube Tests Using the Virtual Fields Method	23
	R. Kaufmann, E. Fagerholt, and V. Aune	
4	Stress Concentration Evaluation of a Plate with Symmetrical U-Notches Under Tensile Load Using TSA and a Lepton IR Camera	29
	V. E. L. Paiva, D. G. G. Rosa, G. L. G. Gonzáles, and J. L. F. Freire	
5	Evaluation of Thermal Deformation of Fastening Structure of Carbon Fiber Reinforced Plastic and Aluminum Using Stereo Image Correlation	41
	Ayumu Fuchigami, Satoru Yoneyama, Ken Goto, and Kosei Ishimura	
6	Full-Field Analysis of the Strain-Induced Crystallization in Natural Rubber	45
	S. Charlès and J. -B. Le Cam	
7	Evaluating Pulse Simulator Using Fluorescent DIC	49
	Chi-Hung Hwang, Rui-Cian Weng, Yen-Pei Lu, Wei-Chung Wang, Tzu-Yu Kuo, and Chun-Wei Lai	
8	Predicting Temperature Field in Powder-Bed Fusion (PBF) Additive Manufacturing Process Using Radial Basis Neural Network (RBNN)	57
	Ehsan Malekipour, Homero Valladares, Suchana Jahan, Yung Shin, and Hazim El-Mounayri	
9	Thermoelastic Characterization of 3D Printed Thermoplastic Elastomers	65
	A. Tayeb, J. -B. Le Cam, and B. Loez	
10	Reduction of Micro-Crack in Ni-Based Superalloy IN-713LC Produced by Laser Powder Bed Fusion	73
	M. Mohsin Raza, Hung-Yu Wang, Yu-Lung Lo, and Hong-Chuong Tran	
11	Analysis of the Thermomechanical Behaviour of SMP in Equi-Biaxial Condition by Means of Hydraulic Bulge Test	77
	Mattia Coccia, Attilio Lattanzi, Gianluca Chiappini, Marco Sasso, and Marco Rossi	
12	Inverse Identification of the Post-Necking Behavior of Metal Samples Produced with Additive Manufacturing	85
	Marco Rossi, Gianluca Chiappini, Emanuele Farotti, and Mattia Utzeri	
13	Heat Source Reconstruction Applied to Fatigue Characterization Under Varying Stress Amplitude	91
	C. Douellou, A. Gravier, X. Balandraud, and E. Duc	

- 14 Analysis of the Thermomechanical Response of a Rubber-like Granular Material 97**
K. Jongchansitto, P. Jongchansitto, I. Preechawuttipong, J. -B. Le Cam, F. Blanchet,
M. Grédiac, and X. Balandraud
- 15 Which Pattern for a Low Pattern-Induced Bias? 103**
Frédéric Sur, Benoît Blaysat, and Michel Grédiac

Chapter 1

Super-Resolution Optical Microscopy to Detect Viruses (SARS-CoV-2) in Real Time



C. A. Sciammarella, L. Lamberti, and F. M. Sciammarella

Abstract This article describes the use of evanescent light fields to directly observe and detect the newly discovered coronavirus SARS-CoV-2 that causes COVID-19. The proposed technique provides a low-cost, fast, and highly accurate method of detection. This approach builds from previous work from the authors that enables microscopic observations of nano-objects with the accuracy of nanometers and sensitivities of the order of fraction of a nanometer.

Keywords Optical super-resolution · Evanescent fields · Holography at the nanoscale · Carrier gratings · Digital microscopy · Covid-19 virus · Techniques of detection of covid-19

1.1 Introduction

The observation of objects in the nanometric range is at the cutting edge of current technology and is of paramount importance in the detection of viruses such as the SARS-CoV-2 which causes COVID-19. Currently the virus images are observed with electron microscopes that require freezing the virus at extremely low temperatures. This is a time-consuming and costly process. To effectively combat this virus, it would be critical to make observations of live samples in real time. The authors present previous work that can be extended to the observation of the COVID-19 virus at room temperature using visible light from an optical microscope in real time. In 2009, the authors [1] presented a comprehensive approach using an optical microscope with a methodology that obtained metrological information from prismatic crystals and spheres in the ranges of 10–200 nm that achieved a level of resolution of 0.1 nm, with the accuracy of ± 3 nm comparing experimental results with known theoretical sizes.

To achieve the resolution and accuracies with this setup the following conditions must be met. First, it is important to establish an evanescent field within the field of view, via laser light by total internal reflection. The laser light has a similar function to feeding illumination in a laser resonator. It excites the objects to generate light that is defined by the molecular structure of the observed object composition, geometry, and dimensions. The second condition is having the presence of gratings in the optical system. These gratings provide carriers encoding the sought information. The third condition is having a small ball-lens in the sub-millimeter range. This lens acts as a relay in the microscope setup that transmits the near-field information to the far field. At the same time provides the geometry required to produce a nano-resonator in the electromagnetic field. Finally, signal decoding software extracts information from the images that allows reconstruction of the observed objects. Since 2005, the authors made use of evanescent fields in several technical applications [2–7] and in larger fields of view, utilizing several optical configurations. Based on this experience, the authors propose the design of a super-resolution digital microscope that would be capable of observing COVID-19 in real time at an affordable cost. An important characteristic of the system is the utilization of artificial intelligence software to make real-time detection feasible. The following sections will summarize the main topics necessary to set the foundations of the proposed technology.

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1.2 Background on the Generation of Optical Signals at the Near Field

When analyzing super-resolution images to obtain both shape and size, it is necessary to understand the processes of generation of the signals that contain information about the properties and dimensions of the objects. There are two basic ranges that depend on the relationship of the illuminating beam wavelength λ to the dimensions of the observed objects. The dimensions of the object are such that minimum dimension $d_{min} > \lambda$, and the other case is when the dimensions of the object are smaller than the wavelength of the object, $d_{min} < \lambda$. In the case of objects smaller than the wavelength of light let us consider a simple case, observations of prismatic shapes. Experimental evidence shows that observing a face of a prism, for example, the face with dimensions $[L_o, W_o]$, Fig. 1.1, one gets 3 shifted images (Fig. 1.2) corresponding to three partially overlapping wavefronts. In [1] a model was introduced for the signal generation by objects smaller than the wavelength of light, nanocrystals, nanospheres. The model is based in the Brillouin scattering process in the ultrasound range [8, 9]. Scattering in this context means collision between particles, in this case collision between phonons and electrons. The Brillouin scattering in the ultrasound range is based in the piezo-electric effect in materials. Piezoelectric effect is the ability of certain materials to generate electric charges in response to applied mechanical stresses. An acoustic wave is generated in a crystal that propagates with the velocity of sound in the material medium. This acoustic wave produces the conversion of mechanical energy of the deformed into the electro-magnetic energy of emitted light.

The process of getting the crystal dimensions gives an insight on the different steps that lead to the determination of the prism proportions. Dimensional information is obtained through the eigen mode of vibration of the prism. The prism vibrates axially along the symmetry axis, alternatively expanding and contracting. The phenomenon that produces the observed shifted images of a wavefront is called Bragg's diffraction, in analogy to X-ray diffraction where a similar process takes place. The acousto-optic effect is akin to the photoelastic effect, in the sense that the permittivity ϵ of an observed crystal is changed due to strain components ϵ_{ij} . The equivalent of a standing diffraction grating is formed by the sound waves propagating in the medium. Through this process mechanical energy is transmitted to the electronic field. This diffraction pattern is characterized by a diffraction angle θ_n with respect to the direction of propagation of the light wavefront, and is given by,

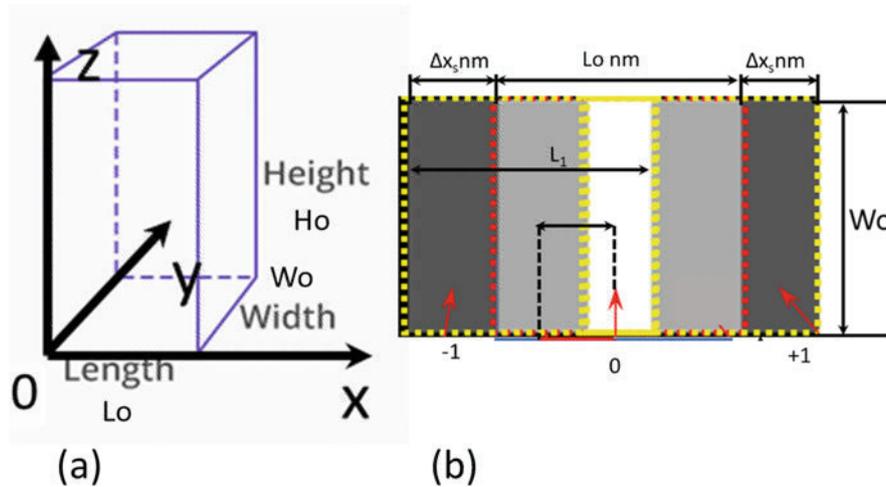


Fig. 1.1 (a) Rectangular prismatic single crystal; (b) Observed face $L_o \times W_o$ of a prism, three shifted images of the face are observed

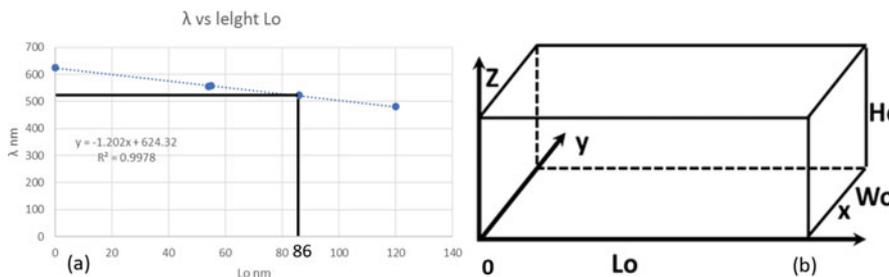


Fig. 1.2 (a) Wavelength λ of the resonant modes as a function of the crystals length L_o ; (b) Observed single crystals geometry and corresponding reference axis