

Article

On the Transmittance of Metallic Superlattices in the Optical Regime and the True Refraction Angle

Pedro Pereyra 

Departamento de Ciencias Básicas, Universidad Autónoma Metropolitana, Acazotzalco, Av. S. Pablo 180, Ciudad de México 02200, Mexico; pereyra.pedro@gmail.com or ppereyra@uam.mx

Abstract: Transmission of electromagnetic fields through *(dielectric/metallic)ⁿ* superlattices, for frequencies below the plasma frequency ω_p , is a subtle and important topic that is reviewed and further developed here. Recently, an approach for metallic superlattices based on the theory of finite periodic systems was published. Unlike most, if not all, of the published approaches that are valid in the $n \rightarrow \infty$ limit, the finite periodic systems approach is valid for any value of n , allows one to determine analytical expressions for scattering amplitudes and dispersion relations. It was shown that, for frequencies below ω_p , large metallic-layer thickness, and electromagnetic fields moving along the so-called “true” angle, anomalous results with an apparent parity effect appear. We show here that these results are related to the lack of unitarity and the underlying phenomena of absorption and loss of energy. To solve this problem we present two compatible approaches, both based on the theory of finite periodic systems, which is not only more accurate, but has also the ability to reveal and predict the intra-subband resonances. In the first approach we show that by keeping complex angles, above and below ω_p , the principle of flux conservation is fully satisfied. The results above ω_p remain the same as in Pereyra (2020). This approach, free of assumptions, where all the information of the scattering process is preserved, gives us insight to improve the formalism where the assumption of electromagnetic fields moving along the real angles is made. In fact, we show that by taking into account the induced currents and the requirement of flux conservation, we end up with an improved approach, with new Fresnel and transmission coefficients, fully compatible with those of the complex-angle approach. The improved approach also allows one to evaluate the magnitude of the induced currents and the absorbed energy, as functions of the frequency and the superlattice parameters. We show that the resonant frequencies of intra-subband plasmons, which may be of interest for applications, in particular for biosensors, can be accurately determined. We also apply the approach for the transmission of electromagnetic wave packets, defined in the optical domain, and show that the predicted space-time positions agree extremely well with the actual positions of the wave packet centroids.

Keywords: transmittance of electromagnetic fields; metallic superlattices; the true refraction angle in metals; plasmon resonances in optical regime; induced currents and absorption; phase time in metallic superlattices; biosensors



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1. Introduction

Interest in the response of metallic structures to electromagnetic fields (EMFs) has grown as the possibilities of application of their properties increase. The research activity evolved along different trails, determined by the dimension, shape, size, and order of the metallic structure. The scattering of light by small metallic particles, or cylindrical and rectangular rods, requires different approaches than the scattering by layered metallic structures. The geometrical differences of the scatterer systems imply, naturally, the use of different mathematical tools, for example, scattering matrices S , in lower-dimensional cases, and transfer matrices M , for layered systems. Here, we are interested in layered structures, specifically *(dielectric/metallic)ⁿ* superlattices with n finite. As shown in ref. [1],

Metallic Superlattices

Jiyuan Zhang



Metallic Superlattices:

Metallic Superlattices Teruya Shinjō, Toshio Takada, 1987 The recent progress in evaporating techniques for preparing ultrathin films has made it possible to control each layer thickness on an atomic scale By alternate deposition of two or more elements artificial superstructures can be fabricated Artificially structured multilayers have now begun to attract attention as a new class of superlattice and the emphasis of this volume is on artificial superlattices formed from metallic elements The term superlattice is used to refer to all multilayers with short wavelength compositional modulation regardless of whether they are epitaxial or not Artificial superlattices can be used in a model system for fundamental research They can be controlled and designed to fit the study of a specific problem in solid state physics The many examples given in this volume verify that metallic superlattices are highly attractive for use in basic studies The reader is provided with an overview of metallic superlattices one can see in what combination an artificial superstructure can be constructed to which extent the structure can be tailored and what the physical and chemical properties are At the same time it is also recognised that a vast area remains unexplored The volume is intended as an aid not only for researchers in the field of physics but also for those involved in materials research in chemistry and technology It will also serve as a guide for new materials production and help to stimulate various applications in technology

Artificial Metallic Superlattices B. Y. Jin, J. B. Ketterson, 1989

Intercalation in Layered Materials M.S. Dresselhaus, 2013-12-19 This volume is prepared from lecture notes for the course Intercalation in Layered Materials which was held at the Ettore Majorana Centre for Scientific Culture at Erice Sicily in July 1986 as part of the International School of Materials Science and Technology The course itself consisted of formal tutorial lectures workshops and informal discussions Lecture notes were prepared for the formal lectures and short summaries of many of the workshop presentations were prepared This volume is based on these lecture notes and research summaries The material is addressed to advanced graduate students and postdoctoral researchers and assumes a background in basic solid state physics The goals of this volume on Intercalation in Layered Materials include an introduction to the field for potential new participants an in depth and broad exposure for students and young investigators already working in the field a basis for cross fertilization between workers on various layered host materials and with various intercalants and an elaboration of the complementarity of intercalated layered materials with deliberately structured superlattices

Competing Interactions and Microstructures: Statics and Dynamics Richard LeSar, Alan

Bishop, Robert Heffner, 2012-12-06 Many macroscopic properties of materials are determined primarily by inhomogeneous structures and textures These intermediate scale structures often arise from competing interactions operating on different length scales within the material Our understanding of such phenomena has increased substantially with the identification and theoretical description of solid state materials with incommensurate and long period modulated phases such as ferroelectrics charge density wave compounds epitaxial layers and polytypes Experimental diagnosis of inhomogeneous

ground states and metastable phases has advanced so far that these are now well accepted phenomena These proceedings bring together the work of physicists and materials scientists to review developments in this area and to examine possible future directions such as how the microscopic understanding emerging in bench top solid state systems can be applied in materials science

Elastic Properties of Metallic Superlattices, 1994 This Final Report describes some of the significant results from our research program on the elastic properties of metallic multi layers and superlattices This work resulted in 20 papers listed at the end of this report submitted to various refereed journals as well as 10 invited talks at international conferences The elastic properties of composition modulated metallic superlattice films have received considerable attention over the past fifteen years following the initial reports of anomalous enhancements of some elastic moduli as measured by the bulge tester method For example it was reported that the Ag Pd system exhibited an increase of the biaxial modulus of up to 500% However more recent measurements failed to reproduce such large enhancements of elastic moduli in the systems for which the elastic anomaly was originally measured The elastic anomalies observed in subsequent experiments were considerably smaller although they showed a functional dependence on A with either stiffening or softening taking place in different material systems for A in the range of 2540 Å In apparent contrast some Brillouin light scattering BLS measurements have shown a softening of the shear elastic constant c_{44} in some bcc fcc systems although a stiffening was found in Au Cr Because of these apparent contradictions coupled with the importance of this problem we initiated a program with ONR funding to investigate these effects In this report we review some of our significant results obtained with ONR funding on the structural and elastic properties observed metallic superlattice films

Nanophase Materials G.C. Hadjipanayis, Richard W. Siegel, 2012-12-06 Nanophase Materials is the first and as yet the only comprehensive book published in this new and exciting area of materials science It gives a broad overview of the revolutionary new field of nanophase materials a view which spans the materials physics and chemistry research communities at a tutorial level that is suitable for advanced undergraduates graduate students postdoctoral researchers and experts or would be experts in the science of nanostructured materials The articles are authored by many of the world's most prominent scientists in this field The book covers the diverse methods for synthesizing nanophase materials a variety of subsequent processing methodologies what is known about the structures of these materials on various length scales from atomic to macroscopic and the properties of these unique and novel materials The materials properties covered are mechanical electronic optical and magnetic and hence span a wide range of important new opportunities for technological applications

Oscillatory Behavior in the Transport Properties of Transition Metal Superlattices Sihong Kim, 1996

Electronic Structure of Metallic Superlattices: Mo/V, 1991 *The Physics of Metals and Metallography*, 1997 *Elastic Properties of Metallic Superlattices. Revision*, 1994 This Final Report describes some of the significant results from our research program on the elastic properties of metallic multilayers and superlattices The elastic properties of composition

modulated metallic superlattice films have received considerable attention over the past fifteen years following the initial reports of anomalous enhancements of some elastic moduli as measured by the bulge tester method. For example, it was reported that the Ag-Pd system exhibited an increase of the biaxial modulus of up to 500%. However, more recent measurements failed to reproduce such large enhancements of elastic moduli in the systems for which the elastic anomaly was originally measured. The elastic anomalies observed in subsequent experiments were considerably smaller, although they showed a functional dependence on λ with either stiffening or softening taking place in different material systems for λ in the range of approx 25–40 Å. In apparent contrast, some Brillouin light scattering (BLS) measurements have shown a softening of the shear elastic constant C_{44} in some bcc-fcc systems, although a stiffening was found in Au-Cr. Because of these apparent contradictions coupled with the importance of this problem, we initiated a program with ONR funding to investigate these effects. In this report, we review some of our significant results obtained with ONR funding on the structural and elastic properties observed in metallic superlattice films.

Josephson Junctions Edward L. Wolf, Gerald B. Arnold, Michael A. Gurvitch, John F. Zasadzinski, 2017-09-07 This book summarizes the history and present status and applications of Josephson junctions. These devices are leading elements in superconducting electronics and provide state-of-the-art performance in detection of small magnetic fields and currents in several digital computing methods and in medical diagnostic devices and now provide voltage standards used worldwide. Astronomical infrared (IR) telescopes including the South Pole Telescope use these junctions in combinations called superconducting quantum interference devices (SQUIDs).

Interfaces, Superlattices, and Thin Films John D. Dow, Ivan K. Schuller, 1987 *Mechanic and Dielectric Properties* Maurice H. Francombe, 2013-10-22 *Mechanic and Dielectric Properties* deals with the mechanical and dielectric properties of thin films. Topics covered range from the deposition and mechanical properties of superlattice thin films to the preparation of hard coatings by sputtering and arc evaporation. The use of thin films in microwave acoustics is also discussed along with ferroelectric films for integrated electronics and the physics, chemistry, and technology of electrochromic tungsten oxide-based thin films. Comprised of five chapters, this volume begins with an analysis of the growth, characterization, and mechanical behavior of films comprising multilayers primarily of metal and refractory metallic compound components. The next chapter reviews the mechanical properties of hard coatings prepared by sputtering and arc evaporation together with the influence of multilayer and gradient structures and of film crystallinity, crystal orientation, and morphology on properties such as hardness, coating smoothness, and friction behavior. Subsequent chapters focus on the unique role played by piezoelectric films in signal processing devices utilizing bulk or surface acoustic waves, the properties and applications of ferroelectric films in integrated electronics, and the underlying physics and chemistry of electrochromic tungsten oxide-based thin films. This book should be of interest to physicists.

Scientific Information Bulletin, 1988

Stability of Metallic Superlattices P. E. A. Turchi, M. Sluiter, LAWRENCE LIVERMORE NATIONAL LAB, CA., 1992 With the constant progress

made in designing and manufacturing materials with composition modulation in one dimension on an atomic scale artificial superlattices have opened up new opportunities to study both theoretically and experimentally a wide range of properties. This new class of materials consists of a sandwich of layers of different species or mixtures thereof and with the development of atom by atom deposition techniques composition layer repeat period growth orientation and chemical order may be controlled. Such atomic engineering has led to the discovery of new phenomena such as the supermodulus effect, giant magneto resistance effect and also complex phenomena at or near interfaces such as solid state amorphization. Moreover, unusual properties are expected in one dimensional quasiperiodic multilayers.

Metals Abstracts, 1997 **Structural Characterization Epitaxial Co-Cr Superlattices** Sezai Elagöz, 1993 Metallic Superlattices, 1990. The fabrication and structural characterization of metallic superlattices is discussed. Methods to determine the elastic properties of these materials which can only be prepared as thin films are reviewed and the results obtained using various techniques are summarized. Contrary to theoretical expectation the elastic properties are found to depend on the modulation wavelength. 52 refs, 6 figs. Elastic Properties of Strained Metallic Superlattices D. Ariosa, NEUCHÂTEL UNIV (Switzerland) INST DE PHYSIQUE., 1992. Due to the improvement of metal deposition techniques in the last ten years high quality epitaxial metallic superlattices made from non soluble materials with different crystal structures and important lattice mismatches are now available for varied applications. One exciting aspect of this kind of superlattices among others is their novel elastic properties different from those of the constituents or their eventual alloys due to the lattice deformation caused by epitaxial stress. As an example one can cite the average lattice expansion in the growth direction and the softening of the sound velocity that have been reported for Mo/Ni superlattices. The above papers have been chosen because as we will see later they illustrate some controversial interpretation of X Ray diffraction data and sound velocity measurements. Theory of surface electronic states in metallic superlattices B. Djafari-Rouhani, Léonard Dobrzynski, P. Masri, 1984.

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