

# Dielectric and Microwave Properties of Graphene Nanoplatelets /Carbon Black Filled Natural Rubber Composites

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**Abstract** Natural rubber (NR) based nanocomposites containing a constant amount (50 phr) of standard furnace carbon black and graphene nanoplatelets (GNP) in concentrations from 1 to 5 phr have been prepared. Their dielectric (dielectric permittivity, dielectric loss) and microwave properties (coefficients of absorption and reflection of the electromagnetic waves and electromagnetic interference shielding effectiveness) have been investigated in the 1-12 GHz frequency range. The results achieved allow us to recommend GNP as second filler for natural rubber based composites to afford specific absorbing properties.

**Keywords** Natural Rubber Composites, Graphene Nanoplatelets, Dielectric and Microwave Properties

## 1. Introduction

Significant scientific and technological interest has focused on carbon - polymer nano-composites over the last two decades. The specific development of polymeric nanocomposites based on conventional polymers and conductive carbonaceous materials has drawn much attention as a route to obtain new materials with new structural and functional properties superior to those of the pure components that find applications in many industrial fields. Control of the size, shape and surface chemistry of the reinforcement materials is essential in the development of materials that can be used to produce devices, sensors and actuators based on the modulation of functional properties as[1]. At present, nanocomposites employing carbon-based reinforcement materials are dominated by carbon nanotubes (CNTs) as[2-4]. However, the development of CNT-reinforced composites has been impeded by both their difficult dispersion in the polymer matrix and their high cost.

The discovery of graphene[5] and the subsequent development of graphene-based polymer nanocomposites is

an important addition in the area of nanoscience and technology. Graphene is an allotrope of carbon, whose structure is one-atom thick planar sheets of  $sp^2$ -bonded carbon atoms packed in a honeycomb lattice. It is the basic structural element of some carbon allotropes including graphite, charcoal, carbon nanotubes and fullerenes[6].

Compared to carbon nanotubes, as well as its high aspect ratio and low density graphene has attracted considerable attention because of its unique and outstanding mechanical, electrical and electronic properties (e.g. exceptional in-plane electrical conductivity - up to  $\sim 20,000$  S/cm and highest thermal conductivity - up to  $\sim 5,300$  W/mK).

All these unique properties in a single nanomaterial have made physicists, chemists and material scientists excited about graphene's potential. The history, chemistry, preparation methods and possible applications of graphene are reviewed in[7-9]. Another new review focused on trends and frontiers in graphene-based polymer nanocomposites was published an year ago[10]. Recently, the trustees of Princeton University received a patent for graphene-elastomer nanocomposites where functionalized graphene sheets had been dispersed in vulcanized natural rubber, styrene butadiene rubber, *P*-isoprene-*P*s and Polydimethylsiloxane (PDMS)[11]. The authors concluded that graphene-rubber nanocomposites possess qualities like those of carbon nanotube composites but are much cheaper to make.

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# Microwave Properties Graphene Bernard Plaais

**Ali M. Ammar**



## **Microwave Properties Graphene Bernard Plaais:**

**Microwave Properties of Graphene** Bernard Plaais, Andreas Betz, 2015-12-07 The authors discuss electronic transport in 2 dimensional graphene and its implications for the design and performance of high speed electronic devices and photodetectors It aims to introduce engineers and scientists to the emerging field of graphene electronics which is very different from existing systems such as silicon MOSFETs or III V HEMTs The authors propose a global approach to graphene electronics ranging from basic concepts such as that of Dirac fermions to their implication in technological issues including device design and characterization

**Microwave Enabled Dispersion of Highly Conductive Carbon Nanomaterials and Their Interfacial Assemblies** Pui Lam Chiu, 2013 Due to its phenomenal mechanical characteristics and remarkable electrical properties graphene a perfect single atomic thick two dimensional lattice carbon layer has attracted extensive attention in nanoscience and condensed matter physics With all the similarities it is believed that graphene can compete with or even surpass carbon nanotubes in many fields and it is expected to replace silicon in many electronic applications and in other advanced technologies A single layer of graphene sheet was first isolated in 2004 from highly oriented pyrolysis graphite with Scotch tape The invention of The Scotch tape method seems very simple and it has enabled a whole new path in many graphene based research areas It also resulted in Andre Geim and Konstantin Novoselov s winning the 2010 Nobel Prize in physics This solvent free method however suffers from low yields low repeatability and being extremely labor intensive Solution based fabrications have shown to be able to overcome these problems However the next challenge in the graphene research field and applications is the tedious chemical path that is required to convert oxidized graphene using toxic chemicals such as hydrazine In this thesis we first developed a novel and an unprecedentedly fast and simple approach to directly exfoliate graphite flakes with the aid of both nitronium ion and microwave irradiation with the aim of solving the main research problems in the field To utilize the produced graphene in practical applications our knowledge of interfacial science was exploited to controllably self assemble these wonderful materials into desired structures The research results combined with an introduction of the development and future aspects of these fields will be presented in the five chapters of this thesis Chapter 1 will include a general overview of basic but important information concerning the two main carbon based materials carbon nanotubes and graphene Their structures physical properties methods of fabrications and applications will be discussed in depth In addition interfacial science for self assembly of nanomaterials will be summarized In Chapter 2 an efficient simple and promising way to prepare graphene sheets directly from graphite flakes with the aid of nitronium ions and microwave irradiation will be presented Knowledge of the chemistries related to nitronium ions and microwave has enabled us to purposely omit strong oxidants such as  $\text{KMnO}_4$  with an aim not to heavily oxidize the materials as many methods are based on thus reduction reactions can be completely avoided Experimental results demonstrate that this non destructive method resulted in concentrated stable dispersions of flat high quality conductive graphene sheets in

both aqueous and organic solvents This mildly oxidized material was extensively characterized by atomic force microscope AFM Infrared spectroscopy FTIR ultraviolet visible spectroscopy thermo gravimetric analysis TGA X ray photoelectron spectroscopy XPS Raman spectroscopy and transmission electron microscopy TEM In chapter 3 we extended the nitronium ions and microwave enabled dispersed approach to carbon nanotubes Different sources of both single walled carbon nanotubes SWNTs and multi walled carbon nanotubes MWNTs were tested and the results showed that all the CNTs from different sources can be quickly dispersed into aqueous solutions with remarkably high concentrations compared to those of graphene solutions even though the same parameters were applied during dispersion We found that depending on the existence of a small amount of defects from the original CNT sources the yield and quality of the dispersed CNTs are varied With a long term aim of fabricating highly transparent and conductive films to replace Indium tin oxide ITO in a wide variety of optoelectronic devices in Chapter 4 a new method referred to as an interfacial self assembly approach is developed to assemble the microwave dispersed graphene and CNTs into highly conductive films The self assembly behavior of graphene CNT and a mixture of graphene and CNT with different ratios were studied separately and the knowledge obtained was used to fabricate graphene CNT and a hybrid of graphene CNT thin films at an oil water interface respectively Compared to the generally used vacuum filtration method this new approach does not need any membrane thus theoretically any size film can be easily fabricated To transfer the formed films to substrates for practical applications a simple film transferring method was also developed The films fabricated with different film fabrication methods will also be compared and a systematic study on how the compositions of these two materials affect the performance of the final films will be summarized The dispersed graphene sheets are often composed with graphene sheets of different sizes to separate them for different applications In Chapter 5 interfacial self assembly reactions were also applied to separate the graphene sheets based on their size and electronic dependent surface energies Chapter 6 will then focus on fine tuning the surface chemistry of the graphene sheets and the oil water ratio to efficiently emulsify the graphene sheets into core shell capsules for drug delivery applications Poly N isopropylacrylamide PNIPAA a thermally sensitive polymer is introduced to form a temperature sensitive and stable oil in water microemulsion with the ability to release the encapsulated materials in a graphene PNIPAA shell above its transition temperature Experimental observations show that the emulsion with graphene has a slightly increased transitional temperature from 34 C to 38 C

**Graphene** Jian Ru Gong,2011-09-15 The discovery of graphene has led to a deluge of international research interest and this new material in the field of materials science and condensed matter physics has revealed a cornucopia of new physics and potential applications This collection gives a roughly review on the recent progress on the synthesis characterization properties and applications of graphene providing useful information for researchers interested in this area

**Graphene** Serhii Shafraniuk,2015-05-05 Graphene is the first example of two dimensional materials and is the most important growth area of contemporary research It forms the basis for new nanoelectronic

applications Graphene which comprises field effect structures has remarkable physical properties This book focuses on practical applications determined by the unique properties of gr Graphene Viera Skakalova, Alan B. Kaiser, 2021-06-23

Graphene Properties Preparation Characterization and Devices Second Edition provides a comprehensive look at the methods used to prepare and analyze graphene Since the first edition's publication there have been many advances in the understanding of graphene in particular its key properties and most relevant applications Updates to this new edition include chapters on liquid exfoliation production of graphene and scanning transmission electron microscopy of graphene New sections cover graphene's thermal optical mechanical chemical and biocompatibility with special attention paid to transport properties a main barrier to the realization of commercial applications Reviews the preparation and characterization of graphene covering the latest advances in liquid exfoliation production and the scanning transmission electron microscopy of graphene Includes a new section dedicated to the properties of graphene thermal transport optical mechanical chemical to reflect the latest understanding of this important material Discusses the most relevant applications of graphene such as biomedical sensing energy and electronic applications

**Reduction of Graphene Oxide Using Microwave and Its Effect on Polymer Nanocomposites Properties** Ali M. Ammar, 2018 Graphene and graphene oxide GO as Nano fillers have been used in numerous applications Reduced graphene oxide for example is one of the most attractive additives that have been targeted to use in polymer nanocomposites due to its strong mechanical properties electric conductivity and gas barrier properties However there are many of obstacles make it difficult to be produced in large quantity at low cost and safe processes There are many methods to reduce graphene oxide rGO and one of the interesting one that used in this research project is solution reduction of graphene oxide using Microwave In this project we have investigated the time effect on reduction of graphene oxide in Microwave and its polymer application properties We have three sub projects that have been studied for the comparison of adding graphene oxide to different time reduced graphene oxide at the same weight contents and conditions The first project the effect of GO and rGO on polymer thin films blend phase separation We observed that the domain size of the polymer blend phase separation changed with adding graphene oxide comparing to reduced graphene oxide due to the interaction with polymer chain The second project we have investigated the addition of GO and rGO on polymer gas barrier properties Two gases have been tested Oxygen O<sub>2</sub> and Carbon dioxide CO<sub>2</sub> at two different pressures The remarkable result of this project is that the addition of rGOs worked as a barrier for these gases comparing to GO and Pure films The last project we have studied the effect of adding GO and rGO on polymer fibers for its oil sorption capacity application and the structure morphology of these fibers Graphene Kazuyuki Takai, Seiya Tsujimura, Feiyu Kang, Michio Inagaki, 2019-10-15 Graphene Preparation Properties Applications and Prospects provides a comprehensive introduction on the science and engineering of graphene The book is composed of 9 chapters including a discussion on what graphene is detailed descriptions of preparation procedures applications based on respective properties including electrical chemical

mechanical thermal and biomedical and reviews on materials derived from graphene graphene derivatives and other layered materials Provides differentiation on two kinds of graphene graphene with highly crystalline layers and reduced graphene oxide with highly defective layers Thorough reviews a wide variety of preparation procedures of two kinds of graphene including the formation of graphene foams films and horns and the doping of foreign atoms Contains a comprehensive review of electrical chemical mechanical thermal and biomedical properties and applications based on these properties

Microwave Measurements on Graphene-like Structures Sonja Barkhofen,2010 Hierarchy of Electronic Properties of Chemically Derived and Pristine Graphene Probed by Microwave Imaging ,2010 Local electrical imaging using microwave impedance microscope is performed on graphene in different modalities yielding a rich hierarchy of the local conductivity The low conductivity graphite oxide and its derivatives show significant electronic inhomogeneity For the conductive chemical graphene the residual defects lead to a systematic reduction of the microwave signals In contrast the signals on pristine graphene agree well with a lumped element circuit model The local impedance information can also be used to verify the electrical contact between overlapped graphene pieces

**Measurement of the Dielectric Properties of Free-standing Graphene Oxide Paper Using Microwave Techniques** Anthony Ubah,2021 The world is facing an unprecedented problem with waste electronics and electrical equipment WEEE The amount of WEEE continues to increase annually and toxic materials used within their printed circuit components continue to leach into the environment Existing strategies such as recycling have been ineffective remedies to these problems Printed circuits based on graphene oxide a derivative of graphene may help solve this problem Graphene oxide is easily recycled by dissolution in water with the primary byproduct being humic acid a family of compounds commonly found in natural water bogs Historically research on graphene oxide has been focused on narrow applications in electronic elements However graphene oxide also has the potential to form the entire printed circuit board by simultaneously serving as the mechanical support the dielectric and with reductive treatment the conductive traces This thesis is a preliminary investigation into the dielectric properties of graphene oxide and an attempt to produce conductive traces of reduced graphene oxide The loss tangent of graphene oxide is extracted from S parameter microwave measurements using a transmissive coplanar waveguide transmission line where graphene oxide is the dielectric Additionally a dose test method is developed to ascertain ideal scanning laser parameters for the selective area photoreduction of graphene oxide for future development of graphene oxide reduced graphene oxide printed circuit boards

**Microwave Enabled Fabrication of Highly Conductive Graphene and Porous Carbon/metal Hybrids for Sustainable Catalysis and Energy Storage** Keerthi Savaram,2017 Carbon is the most abundant material next to oxygen in terms of sustainability The potential of carbon based materials has been recognized in recent decades by the discovery of fullerene 1996 Nobel prize in chemistry carbon nanotubes 2008 Kavli prize in nanoscience and graphene 2010 Nobel prize in physics The synthesis of carbon materials with well controlled morphologies lead to their exploration in both fundamental

research and industrial applications Graphene also commonly referred to as a wonder material has been under extensive research for more than a decade due to its excellent electronic optical thermal and mechanical properties However the realization of these applications for practical purposes require its large scale synthesis The common method of graphene synthesis involves reduction of graphene oxide Nevertheless complete restoration of intact graphene basal plane destroyed by oxidation cannot be achieved limiting the application of as synthesized graphene in flexible macro electronics mechanically and electronically reinforced composites etc Hence research was pursued in regards to achieve controlled oxidation sufficient enough to overcome the Vander Waals forces and preserving the graphene domains One such approach reported by our group is the solution processable graphene achieved via controlled oxidation by the use of nitronium oxidation approach However toxic NO<sub>x</sub> gases and byproducts generated during the synthesis limits the scalability of this approach In this thesis for the first time we reported the synergy of piranha etching solution with intercalated graphite for the controlled oxidation of graphite particles via microwave heating in chapter 2 The controlled oxidation leads to rapid 60 seconds and direct generation of highly conductive clean low oxygen containing graphene sheets without releasing any detectable toxic gases or aromatic by products as demonstrated by gas chromatography mass spectrometry These highly conductive graphene sheets have unique molecular structures different from both graphene oxide and pristine graphene sheets They can be dispersed in both aqueous and common organic solvents without surfactants stabilizers producing clean graphene sheets in solution phase Paper like graphene films are generated via simple filtration resulting in films with a conductivity of  $2.26 \times 10^4 \text{ S m}^{-1}$  the highest conductivity observed for graphene films assembled via vacuum filtration from solution processable graphene sheets to date After 2 hour low temperature annealing at 300 °C the conductivity further increased to  $7.44 \times 10^4 \text{ S m}^{-1}$  This eco friendly and rapid approach for scalable production of highly conductive and clean solution phase graphene sheets would enable a broad spectrum of applications at low cost Irrespective of the vast applications of highly conductive graphene it exhibits limited catalytic centers is impervious and limits the diffusion of ions This inadequacy can be overcome by the hole generation on highly conductive graphene Current approaches for large scale production of holey graphene require graphene oxide GO or reduced GO rGO as starting materials Thus generated holey graphene derivatives still contain a large number of defects on their basal planes which not only complicates fundamental studies but also influences certain practical applications due to their largely decreased conductivity thermal and chemical stability This work reports a novel scalable approach exploiting the wireless joule heating mechanism provided by microwave irradiation of partially oxidized graphite intercalation compounds in chapter 3 The wireless joule heating mechanism affords region selective heating which not only enable fabrication of holey graphene materials with their basal plane nearly intact but also engineers the edges associated with holes to be rich in zigzag geometry The term pristine holey graphene was given to differentiate from the holey graphene derivatives with basal plane defects as reported in the literature The pristine holey

graphene with zigzag edges were studied and explored as a metal free catalyst for reduction reactions via hydrogen atom transfer mechanism. The pristine holey graphene nanoplatelets not only exhibited high catalytic activity and desired selectivity but also provided excellent chemical stability for recyclability which is very different from its counterpart holey graphene derivatives with basal plane defects. It was also reported that the reduction of nitrobenzene occurs via condensation pathway with this catalyst. To further provide insight into combustion of graphite in air with microwave irradiation, the stabilized intercalated graphene without point defects was used to generate holes in chapter 4. The co-intercalated O<sub>2</sub> into graphite intercalated compound act as the internal oxidant to oxidize the carbon along with the surrounding air. High local temperatures were achieved via joule heating mechanism hence promoting combustion of graphene to generate holes and edges. We observed that in combination to hole generation, higher conductivity was also observed in comparison to the holey graphene synthesized in chapter 3. The highly conductive holey graphene was tested for their electro catalytic activity in the reduction of oxygen. The reduction of oxygen occurs via 2e<sup>-</sup> pathway where peroxide with 90% yield was recorded. This opens path for onsite peroxide production in alkaline media and therefore allowing its use in bleaching industries. In concern of carbon based materials being explored for catalysis, their high amount to facilitate the reaction limits practicality of the catalyst for industrial applications. However, the immobilization of metal nanoparticles onto porous carbon supports synthesized from sustainable and cheap biomass was widely pursued. It was widely reported that the doping of carbon support with N further improved their interaction with the metal and promoted higher catalytic activity. In chapter 5, for the first time, the influence of P doped carbon support on catalytic activity of Pd was reported. A single step microwave assisted fabrication of Pd embedded into porous phosphorous doped graphene like carbon was demonstrated. Structural characterization revealed that the metal nanoparticles are in the range of 10nm with a surface area of 1133m<sup>2</sup> g<sup>-1</sup>. The developed method is not only sustainable as it is synthesized from biomass and anti nutrient molecule phytic acid but also energy efficient as microwave irradiation 50sec is used for the catalyst synthesis. The as synthesized catalyst recorded 90% conversion with a TOF of 23000h<sup>-1</sup> for benzyl alcohol oxidation which remained constant even after 8 recycles indicating the stability of catalyst. Different wt% of Pd onto PGC was tested for their alcohol oxidation capacity and found that the 3% Pd PGC which activates O<sub>2</sub> more towards 4e<sup>-</sup> in ORR has the best conversion and selectivity. The biomass molecule phytic acid used for the synthesis of phosphorous doped carbon support was also used as a phosphorous source in the synthesis of tin phosphides in chapter 6. Current studies have shown that sodium, a low cost and naturally abundant metal, can act as a substituent for lithium in lithium ion batteries LIB hence allowing their applications in real world. This transition towards the use of sodium ion batteries SIB has entailed research to improve the cycle stability and energy density of battery by introducing tin phosphides as anodes for batteries. Tin phosphides exhibit a self healing mechanism hence decreases the capacity decay as observed in the case of Sn metal. However, it was reported that the self healing mechanism is not



completely reversible with partial pulverization observed Therefore we pursued a time efficient method to synthesize tin phosphide in a phosphorous doped carbon matrix SnP PGc via microwave irradiation The SnP PGc formed when tested as anode for SIBs demonstrated superior capacity of 515 mAh g after 750 cycles at a charge and discharge current of 0.2 C The superior cycle stability can be attributed to the protection against volume expansion by phosphorous doped porous carbon shell during battery charge and discharge process and hence mitigating the pulverization of tin phosphides

**Graphene** Viera Skakalova, Alan B. Kaiser, 2014-01-24 Graphene Properties Preparation Characterisation and Devices reviews the preparation and properties of this exciting material Graphene is a single atom thick sheet of carbon with properties such as the ability to conduct light and electrons which could make it potentially suitable for a variety of devices and applications including electronics sensors and photonics Chapters in part one explore the preparation of including epitaxial growth of graphene on silicon carbide chemical vapor deposition CVD growth of graphene films chemically derived graphene and graphene produced by electrochemical exfoliation Part two focuses on the characterization of graphene using techniques including transmission electron microscopy TEM scanning tunneling microscopy STM and Raman spectroscopy These chapters also discuss photoemission of low dimensional carbon systems Finally chapters in part three discuss electronic transport properties of graphene and graphene devices This part highlights electronic transport in bilayer graphene single charge transport and the effect of adsorbents on electronic transport in graphene It also explores graphene spintronics and nano electro mechanics NEMS Graphene is a comprehensive resource for academics materials scientists and electrical engineers working in the microelectronics and optoelectronics industries

**Dirac Fermion Optics and Plasmonics in Graphene Microwave Devices** Holger Graef, 2019 This thesis addresses three different phenomena in the DC and GHz electronic transport properties of ballistic hBN encapsulated graphene Firstly the total internal reflection of electrons is investigated in a gate defined corner reflector Both geometric and coherent electron optics effects are demonstrated and the device is shown to be sensitive to minute phonon scattering rates It is then used as a proof of concept for GHz electron optics experiments in graphene paving the way for phonon time of flight measurements Secondly we introduce top gated graphene field effect capacitors as a platform to study ultra long wavelength plasmons with a vector network analyzer We simultaneously measure resistivity capacitance and kinetic inductance A resonance is observed at 40 GHz corresponding to a plasmon of 100 nm wavelength This result sets a milestone for the realization of resonant plasmonic devices and the investigation of plasmon propagation in bipolar superlattices Finally we move our attention to the quantum Hall breakdown in a bilayer graphene sample DC transport and GHz noise measurements show that the elusive intrinsic breakdown field can be reached in graphene Its signature is an abrupt increase of noise with a super Poissonian Fano factor A magnetoexciton instability is proposed as the origin of breakdown

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