隐身与反隐身技术关键材料与核心器件

隐身与反隐身技术作为现代战争中决定战场态势的重要技术，是我国航空工业和国防科技重大战略需求。

目前，“薄、轻、宽、强”隐身材料是各国军事竞争的核心领域。通过吸收电磁波实现隐身的吸波材料已被应用于隐身飞机、隐身导弹、隐身坦克、隐身舰船等各种隐身武器，提高了武器装备战场生存能力、防卫突击以及纵深攻击能力。通过改变电磁波传播路径实现隐身的超材料（超表面）有望打破目前隐身材料性能瓶颈，实现宽波带、宽角域、全极化的隐身斗篷，在新一代隐身材料和技术领域有巨大的应用潜力和发展空间。

反隐身技术则是研究如何使隐身措施的效果降低甚至失效。目前反隐身技术多种多样，但最有杀伤力的是高功率微波武器，当高功率电磁波照射隐身材料表面后，材料因吸收过多的能量受损甚至烧毁失效。这种武器既可以对付隐身飞机，还能够用于电子战，以及防空反导及反无人机，因此是重要的新概念战略武器。

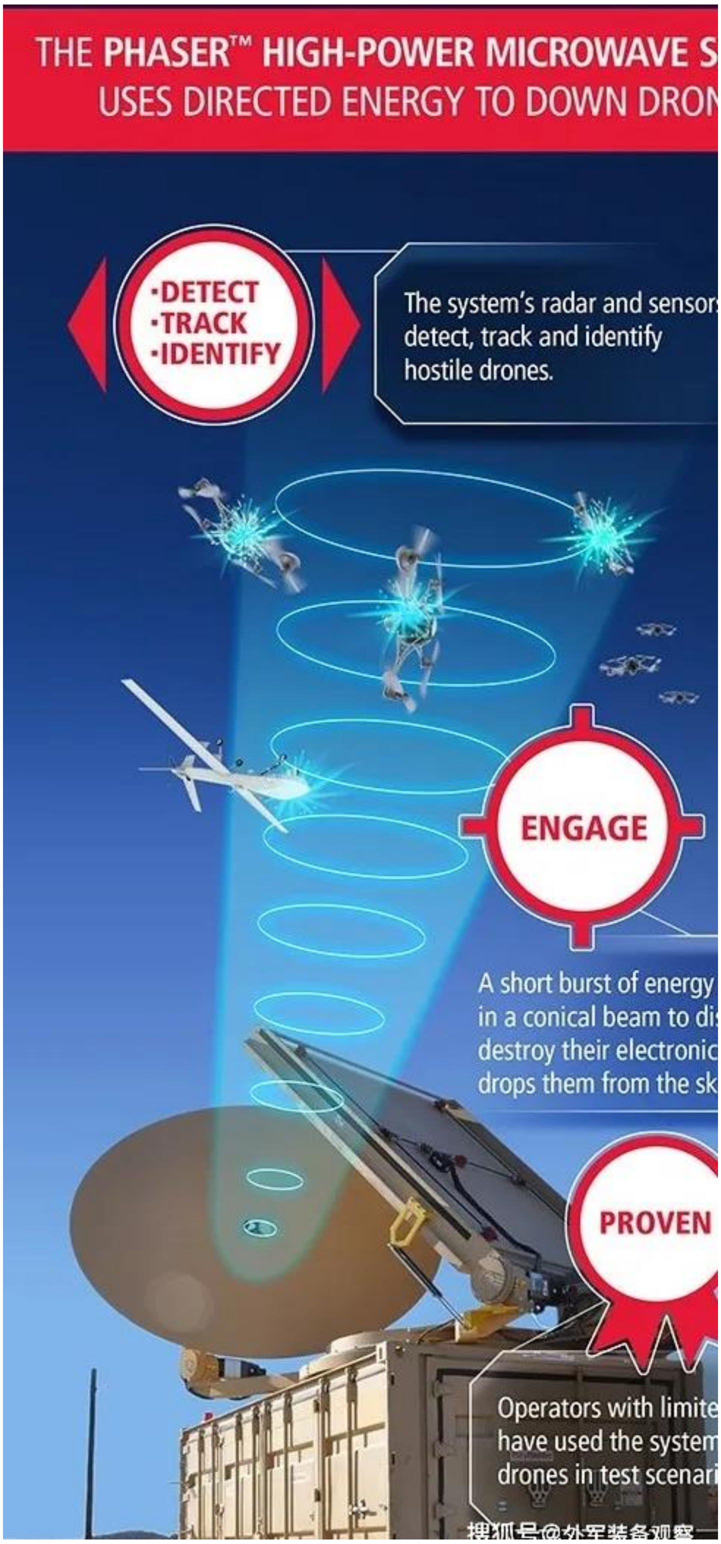
一、隐身材料

通过结构设计、计算模拟、工艺优化，为研发轻质多功能宽频带新型隐身材料和器件夯实理论基础，提供技术支撑。研究方向涵盖 Ni 基电磁波吸收材料、碳基电磁波吸收材料、矿物基电磁波吸收材料、高分子基电磁屏蔽材料、石墨烯以及相变超材料（超表面）等。

二、高功率微波武器专用环形阴极

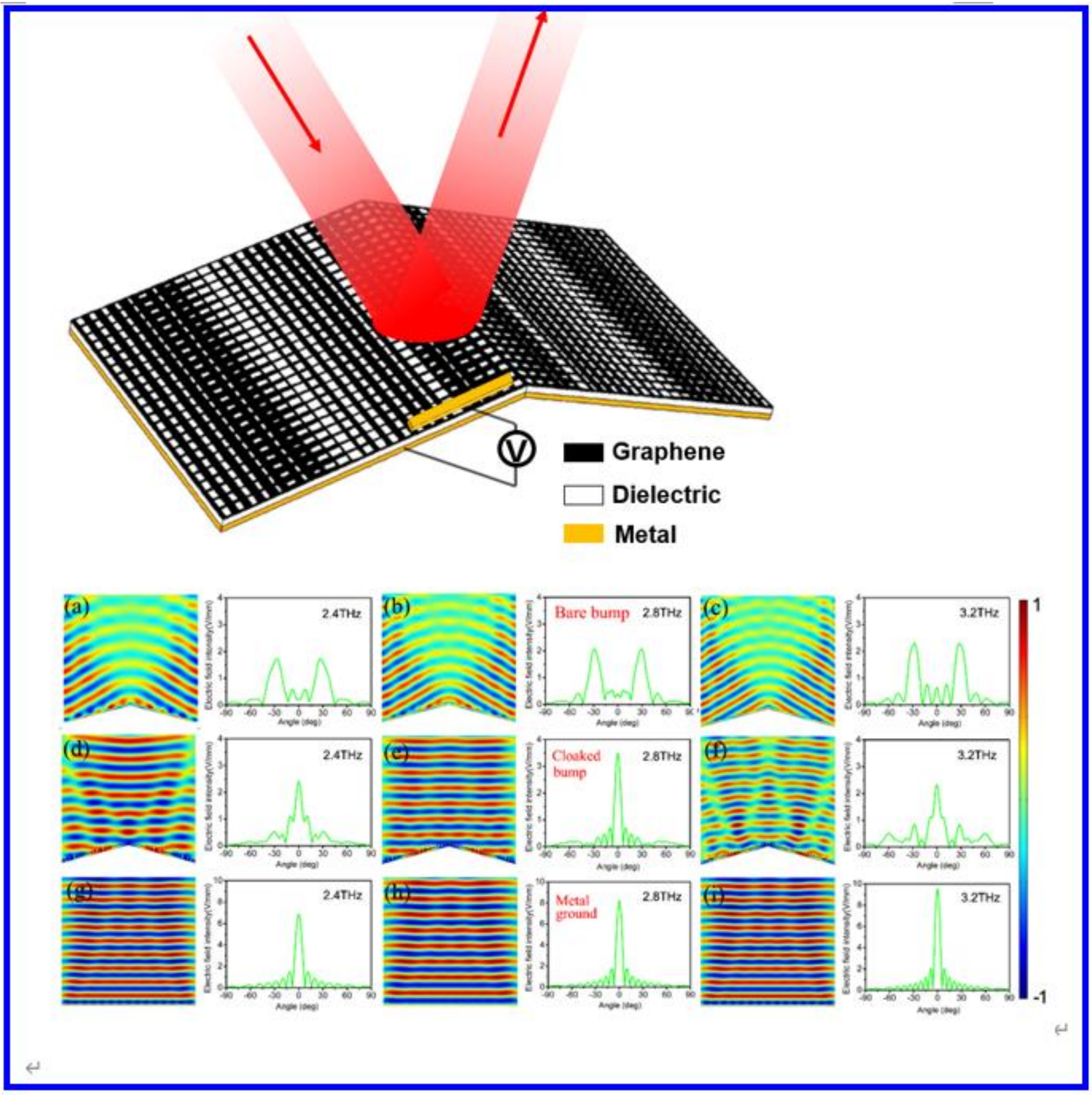
高功率微波是通过环形阴极发射的环形电子束振荡产生，因而环形阴极是高功率微波武器的核心器件。本团队研制的环形阴极经中国工程物理研究院应用电子学研究所高功率微波技术国防科技重点实验室试用后获得认可，连续获得该单位的研制订单，目前已成为该单位环形阴极的直接采购供货方。

本团队承担国家自然科学基金 5 项，航空基金 5 项，省部级科研项目 10 余项；研究成果已在 Small，Carbon 等国际一流学术期刊发表 SCI 学术论文 50 余篇，其中 ESI 高被引 10 余篇，封面论文 5 篇；授权国家发明专利 5 项；获得省部级奖项 4 项；指导学生荣获大学生“互联网+”等学科竞赛国家级奖励 1 项，省级奖励 6 项；省优秀硕士学位论文 2 篇。



高功率微波反无人机武器概念图

基于石墨孔或贴片结构的超表面隐身地毯设计与模拟计算



代表性论文

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Galvanic Replacement Reaction Involving Core–Shell Magnetic Chains and Orientation-Tunable Microwave Absorption Properties

*Biao Zhao, Yang Li, Qingwen Zeng, Lei Wang, Jingjun Ding, Rui Zhang, and Renchao Che**

Electromagnetic (EM) wave absorption materials have attracted considerable attention because of EM wave pollution caused by the proliferation of electronic communication devices. One-dimentional (1D) structural magnetic metals have potential as EM absorption materials. However, fabricating 1D core–shell bimetallic magnetic species is a significant challenge. Herein, 1D core–shell bimetallic magnetic chains are successfully prepared through a modified galvanic replacement reaction under an external magnetic field, which could facilitate the preparation of 1D core–shell noble magnetic chains. By delicately designing the orientation of bimetallic magnetic chains in polyvinylidene fluoride, the composites reveal the decreased complex permittivity and increased permeability compared with random counterparts. Thus, elevated EM wave absorption perfromances including an optimal reflection loss of −43.5 dB and an effective bandwidth of 7.3 GHz could be achieved for the oriented Cu@Co sample. Off-axis electron holograms indicate that the augmented magnetic coupling and remarkable polarization loss primarily contribute to EM absorption in addition to the antenna effect of the 1D structure to scatter microwaves and ohmic loss of the metallic attribute. This work can serve a guide to construct 1D core–shell bimetallic magnetic nanostructures and design magnetic configuration in polymer to tune EM parameters and strengthen EM absorption properties.

1. Introduction

Currently, because of the extensive blossoming of communication equipment and electric devices, electromagnetic interference (EMI) issues are increasingly severe, which might cause nearby valuable electronic devices to malfunction and even negatively affect human health.[1,2] By seeking out suitable electromagnetic (EM) wave absorption materials that interact with EM waves and transform microwave energy into types of heat, detrimental radiation can be diminished.[3–5] Generally, EM wave absorption properties are strongly linked with EM parameters (complex permittivity [$\varepsilon_r = \varepsilon' - j\varepsilon''$] and complex permeability [$\mu_r = \mu' - j\mu''$]) and microstructures.[6] The majority of studies focus on morphological-dependent EM wave absorption and the various shapes that have reportedly been used as microwave absorbers, including zero dimensional, 1D, 2D, and 3D structured materials.[7,8] Specifically, core–shell constructions, which can intensify interfacial polarization[9,10] and unique 1D structures, which can be considered micro-antennas to scatter microwaves,[11,12] are proven to be the competitive methods for microwave absorption.

At present, microwave absorption properties of absorbers refer to the polymer composites introduced by absorbing fillers. Because of the random distribution of absorbing fillers in a polymer matrix, the optimization of EM parameters (ε_r and μ_r) to strengthen microwave absorption abilities is a problem that has yet to be solved. Researchers have invested considerable attention in the permittivity-tunable EM wave absorption.[13–18] Lv et al.[13] fabricated a sandwich electronic device with a conductive layer and a microwave absorption film and regulate the permittivity values using an external electrical field to control the EM wave absorption performance. Song et al.[14] prepared polymer ionic conductive gels capable of optically transparent microwave absorption. By controlling hydrogen bonding networks, complex permittivity can be tuned to obtain manipulatable microwave stealth properties. Ye et al.[15] designed edge-rich graphene grown on porous Si_3N_4 ceramics via the

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Highly Compressible Polymer Composite Foams with Thermal Heating-Boosted Electromagnetic Wave Absorption Abilities

Biao Zhao, Xiping Li, Shuiping Zeng, Ruoming Wang, Lei Wang, Renchao Che,* Rui Zhang, and Chul B. Park*

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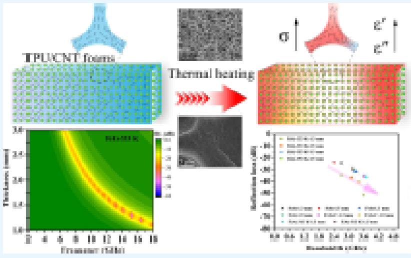

ABSTRACT: Polymer composite foams are desirable materials for electromagnetic (EM) energy attenuation. However, a number of challenges limit improvement in the EM energy attenuation properties of foams. In this study, a simple microcellular injection molding method was used to fabricate highly compressible thermoplastic urethane (TPU)/carbon nanotube (CNTs) composite foams, which also had increased conductivity with an increase in CNT content. Compared to unfoamed composites, foamed composites exhibited higher conductivity and EM attenuation properties because of the presence of a microcellular structure. Moreover, the TPU/CNT foam with 4 wt % CNTs (F(4)) demonstrated strong EM dissipation and an optimal reflection loss (RL) value of −30.4 dB. Furthermore, stimulated by thermal heating and cyclic compression, EM attenuation was observed to increase because of the higher conductivity. Note that F(4) foam having a small thickness of 1.3 mm when treated at 333 K had the highest EM dissipation and the lowest RL value of −51.8 dB. Enhanced polarization and ohmic losses and multiscattering were responsible for the increased EM absorption. This behavior is attributed to the movement of CNTs within the TPU elastomer walls via thermal or compression stimulation. For designing stimulation-dependent multifunctional materials, composite foams with response to thermal heating were proved to be an alternative approach.

KEYWORDS: *TPU/CNT composite foams, high flexibility, electromagnetic energy dissipation, thermal heating, electrical conductivity*

1. INTRODUCTION

The increase in environmental pollution has stimulated efforts to develop approaches that mitigate its effects on the ecological system. Because of the increase in wireless communication and electrical equipment in our daily life, electromagnetic radiation (EMR) has become a severe challenge in global environmental pollution; moreover, it poses a serious threat to human health and negatively impairs the operation of nearby valuable electronic devices.[1−5] To overcome this challenge, high-efficiency microwave absorption materials that could convert microwave energy into heat energy have proven to be an effective approach. The EM wave absorption ability is largely determined by the material microstructure.[6−10] Among the materials that dissipate EM energy, porous structural nanomaterials, such as hollow CuS,[11] hollow carbon microspheres,[12] hollow CoNi alloys,[13] porous SiC foam,[14] graphene foams,[15,16] hollow urchin-like MnO_2,[17] hollow CoS spheres,[18] porous magnetic carbon,[19] hollow Co/C,[20] and Fe_3O_4@void@TiO_2, are regularly used. These materials have been proven to be competitive EM wave absorbers because of their excellent properties such as light weight, tunable impedance match, and multiple scattering because of porous construction. However, low yield and poor mechanical properties are some of the limitations associated with these porous inorganic powders.

Continued efforts to develop a more effective electromagnetic interference (EMI) shielding material has led to the development of conductive polymer composites (CPCs) in which conductive fillers are dispersed in insulating polymers, which have the advantages of shaping capability, chemical stability, and design flexibility.[21−23] However, a vital limitation associated with CPCs is the significant aggregation of conductive filler in the polymer, which affects both the mechanical and EMI shielding properties. Furthermore, the EMI-shielding mechanism of CPCs is primarily attributed to reflection rather than absorption, which could result in secondary EM pollution. The introduction of a microcellular structure in the CPCs is an effective approach to solve this secondary EM radiation problem because the cellular structure

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A versatile foaming platform to fabricate polymer/carbon composites with high dielectric permittivity and ultra-low dielectric loss†

Biao Zhao, ‡ Mahdi Hamidinejad, ‡ Chongxiang Zhao, Ruosong Li, Sai Wang, Yasamin Kazemi and Chul B. Park *

There is an urgent need for dielectric-based capacitors to manage the increase in storage systems related to renewable energy production. Such capacitors must have superior qualities that include light weight, a high dielectric constant, and ultra-low dielectric loss. Poly(vinylidene fluoride) (PVDF)/carbon (carbon nanotube (CNT) or graphene nanoplatelet (GnP)) nanocomposite foams are considered promising alternatives to solid PVDF/carbon nanocomposites. This is because they have excellent dielectric properties, which are due to the preferred orientation of their carbon materials occurring in the foaming process. In the PVDF/carbon foams, their microcellular structure significantly influenced their electrical conductivity and dielectric properties. In the PVDF/CNT composite foams, the electrical conductivity was increased by an increased degree of foaming that was below a critical foaming degree. The CNTs even formed conductive networks and this caused current leakage. Thus, in the PVDF/CNT foam sample with an expansion ratio of 4.0 where a high dielectric constant of 80.6 was obtained, a relatively high dielectric loss of 3.51 was observed at the same time. In the PVDF/GnP composite foams, the presence of a microcellular structure forcefully increased the distance between GnPs. This induced and produced the insulating quality of the PVDF/GnP foams. In addition, the parallel graphene nanoplatelets that accompanied this process were close together, and they isolated the polymer layer, or air, as a medium between themselves. An unprecedentedly high dielectric constant of 112.1 and an ultra-low dielectric loss of 0.032 at 100 Hz were obtained from the PVDF/GnP composite foam with a high expansion ratio of 4.4 due to charge accumulation at the aligned conductive filler/insulating polymer (or air bubble) interface.

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1. Introduction

Due to population growth, global warming, and the energy crisis, the development of renewable, cost-effective and green energy techniques to supply future generations with renewable energy is both challenging and urgent.[1] Of the various energy storage systems that exist, dielectric capacitors with an ultrafast charging–discharging ability have fast become one of the most important new technologies. They could greatly benefit the high-performance power electronics used in military power systems, hybrid electric vehicles, and in some portable electronics.[2,3] Ceramic-based dielectric materials, such as $SrTiO_3$,[4] SiC,[5] and $BaTiO_3$,[6] have high dielectric constant values, which is why they play a major role in current practical applications. However, their numerous serious defects, which include an insurmountable brittleness and a low electrical breakdown strength, have hindered the development of dielectric materials.[7–9] Compared to conventional ceramic-based dielectric materials, polymer-based dielectric materials have several advantages: large-scale processability, mechanical flexibility, light weight, low cost, and high electrical breakdown strength. However, most polymers' dielectric constant is low compared to the dielectric constant of inorganic ceramics. For example, polypropylene, polystyrene, polyacrylates, and polymethacrylates usually have dielectric constant values between 2 and 5.[10]

To address these issues, significant efforts have been made to create polymer-based dielectric materials with high permittivity. One effective strategy has been to introduce high-dielectric-constant (high-k) ceramics into the polymer matrix, and this strategy has been extensively investigated in the past few decades.[11–16] However, it was reported that these composites always possess a high concentration of ceramic particles, which severely damaged the polymer composites' processability and mechanical flexibility. In addition, the poor compatibility between the inorganic fillers and the organic polymer matrix

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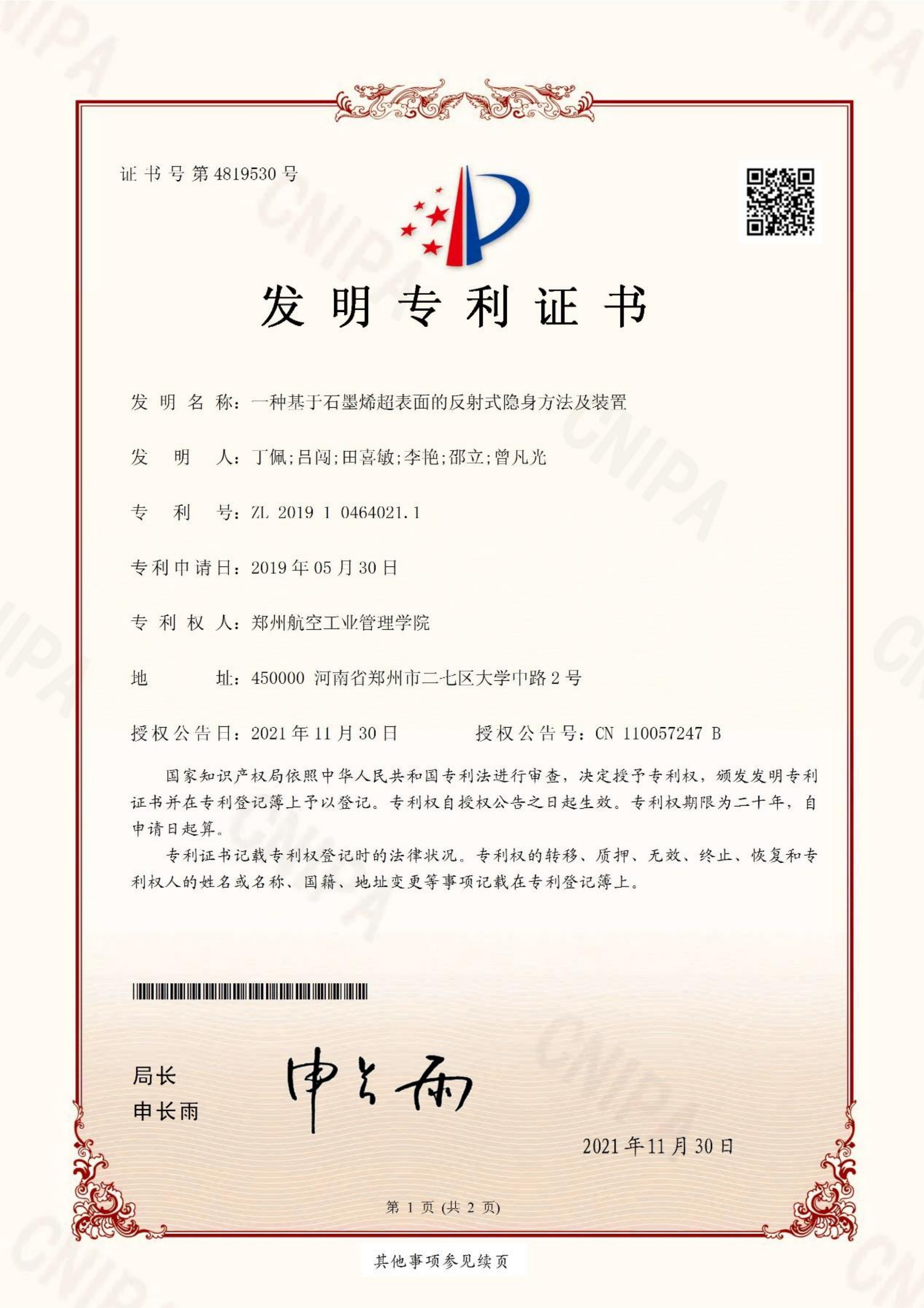

证书号第4819530号

发明专利证书

发 明 名 称：一种基于石墨烯超表面的反射式隐身方法及装置

发 明 人：丁佩；吕闯；田喜敏；李艳；邵立；曾凡光

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第1页（共2页）

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证书号第4568874号

发明专利证书

发明名称：一种柔性压力传感器及其制备方法

发　明　人：赵彪；邓久帅；张茜；郭晓琴；白中义；张锐；任玉美；樊磊
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证书号第14423024号

实用新型专利证书

实用新型名称：基于石墨烯相位梯度超表面的全极化隐身地毯

发　明　人：丁佩;苏金朝;麻华丽;许坤;曾凡光

专　利　号：ZL 2021 2 0342614.3

专利申请日：2021年02月04日

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