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国内外石墨烯标准化研究进展与思考

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摘　要：石墨烯材料的研发及应用关系到国家高新技术产业基础，发展石墨烯产业有望成为开启我国新一轮产业升级的关键之匙。然而当前石墨烯产业发展时间相对较短，石墨烯的标准化工作仍处于起步阶段，缺乏系统的、全面的研究。因此急需建立全面、规范、权威的石墨烯及其产品标准体系，以对石墨烯产业链的可持续发展起到重要支撑、保障作用。从国内外石墨烯研究政策及需求出发，分析了现阶段推进石墨烯标准化建设的必要性。重点概述了当前国内外石墨烯标准的研究进展，并基于现阶段我国石墨烯标准的发展特点，提出了石墨烯标准化研究的思考，为后续我国石墨烯标准化体系的建设提供参考。

关键词：石墨烯；标准化；产业链；标准体系；石墨烯标准
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Research Progress and Viewpoint of Graphene Standardization at Home and Abroad

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Abstract: The development and application of graphene materials are related to the foundation of national high-tech industries, and the development of graphene industry is expected to become a key to the opening of a new round of industrial upgrading in China. However, the current graphene industry is relatively new. Standardization of graphene is still in its infancy, and lacks systematic and comprehensive research. Therefore, it is urgent to establish a comprehensive, standardized and authoritative standard system for graphene and its products, to provide important support and guarantee for the sustainable development of the graphene industry chain. Based on the domestic and foreign graphene research policies and needs, this paper analyzed the necessity of promoting graphene standardization at the present stage. The current research progress of graphene standards was emphatically summarized, and according to the development characteristics of graphene standards in China, the viewpoints on graphene standardization research were put forward to promote the construction of graphene standardization system.

Key words: graphene; standardization; industry chain; standard system; graphene standard

1 前　言

石墨烯被称为“黑金”和“新材料之王”，集透光性好、导热系数高、电子迁移率高、电阻率低、机械强度高等多种优异性能于一身[1-3]，被认为是改变世界的颠覆性材料[4,5]。2004 年，英国曼彻斯特大学科学家安德烈·海姆和康斯坦丁·诺沃肖洛夫通过胶带粘取方式，在实验室首次从石墨上成功分离出晶体物质石墨烯。当前，石墨烯已逐步从实验室走向行业应用。石墨烯的应用涉及新能源、电子信息、大健康、环保、生物医药、化工、航天航空等国家高新技术产业，对国家的发展起着重要作用[6]。

在各国政策扶持下，已有 80 多个国家投入到石墨烯

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的研发和生产。欧盟、美国、日本等相继发布或资助了一系列相关研究计划和项目，以促进石墨烯产业发展[7]。欧盟及英国作为最早的石墨烯研发阵地，在政策及资金扶持上发展早、力度大。2007 年，欧洲研究理事会(ERC)批准对石墨烯物理性能和应用的研究项目；2011 年，英国政府把对石墨烯的研究定为国家未来 4 个重点发展方向之一。2006 至 2019 年，美国国家科学基金(NSF)资助的石墨烯相关项目达 1000 多项，资助项目领域涉及石墨烯复合材料、石墨烯电子器件开发等应用领域。与此同时，我国政府对石墨烯材料及其产业给予了极大的关注。2012 年我国发布的《新材料产业“十二五”发展规划》中首次强调突出纳米材料研发[8]，积极开发石墨烯新材料，把发展石墨烯相关产业上升到了国家战略的高度。2015 年，国务院印发了《中国制造 2025》[9]，明确要求高度关注颠覆性新材料，将石墨烯作为战略前沿材料进行提前布局和重点投入。随着石墨烯产业的发展，石墨烯应用领域相关标准的滞后问题也日益凸显。2021 年，我国工业和信息化部就发布了《2021 年工业和信息化标准工作要点》[10]，进一步强调要加强产业基础标准和强制性标准制定，其中就包括石墨烯等新材料和关键材料相关标准的制定。

石墨烯产业潜力巨大，但发展时间相对较短。产业发展面临着产品质量良莠不齐、鱼龙混杂，产业发展不均衡等问题，缺乏统一的标准对石墨烯材料及产品性能进行科学、有效地评估。北京石墨烯研究院刘忠范院士团队的研究分析比较了当前石墨烯及其衍生物的特性、市场份额和应用，指出质量控制是石墨烯产业化面临的关键问题，石墨烯产业迫切需要统一的技术标准和明确的产品分级标准进行规范化[11]。因此，建立全面、规范、权威的石墨烯材料及产品标准体系，对石墨烯先进材料产业的可持续发展将起到重要的支撑、保障作用。本文在分析现有国内外石墨烯标准的基础上，基于现阶段我国石墨烯标准的特点，提出了未来石墨烯标准化研究的思考，为后续石墨烯标准化体系的建设提供参考。

2　国际石墨烯标准的研究进展

随着石墨烯产业的发展，国际上制定的相关标准数量与日俱增。但在当前世界范围内，石墨烯的标准化工作和布局都还处于初级发展阶段[12]。目前从事石墨烯标准研究制定的国际标准化组织主要有纳米技术标准化委员会(ISO/TC 229)、国际电工委员会分支纳米电工产品与系统技术委员会(IEC/TC 113)、欧洲电工委员会(CENELEC)等组织[13]。此外，研发石墨烯标准的组织还有各国行业组织，如欧盟石墨烯旗舰计划的标准化委员会(GFSC)、英国的国家物理实验室(NPL)、美国国家标准化研究所(NIST)等各国国家级标准化专业组织也在石墨烯标准化领域做出了许多贡献。各国际组织在石墨烯领域都有良好合作和协调，共同推进了石墨烯相关标准的制定工作。随着石墨烯产业标准化的发展，与石墨烯测量和表征相关的标准也相继发布。本文将国际现行石墨烯标准进行了总结，如表 1 所示。

通常按照标准化对象进行分类，标准可分为技术标准、管理标准和工作标准 3 大类；而技术标准又可分为基础标准、方法标准、产品标准、安全卫生与环境保护标准 4 类。基础标准是指在一定范围内作为其他标准的基础并具有广泛指导意义的标准。方法标准是以产品性能、质量方面的检测、试验方法为对象而制定的标准。产品标准是指对产品结构、规格、质量和检验方法所做的技术规定。安全卫生与环境保护标准是以保护人和物的安全、保护人类的健康、保护环境为目的而制定的标准。

在基础标准方面，2017 年，ISO 发布了石墨烯标准 ISO/TS 80004-13：2017《纳米技术 术语 第 13 部分：石墨烯以及相关的二维(2D)材料》。作为国际基础标准，该标准正式规定了 2D 材料、材料生产、材料特性等内容的术语和定义，为石墨烯的测试和验证提供了一致的标准。早些时候，基于石墨烯材料优异的理化性质和潜在的应用价值，石墨烯产业链也快速形成，但由于石墨烯自身定义、层数及其相关衍生物等概念还未明确，市场上很多石墨烯产品以次充好，出现以石墨片代替少层石墨烯的现象，造成石墨烯产品在性能方面的显著，使得新型石墨烯产品的开发和应用受阻，影响石墨烯商业化与产业化进程。此项标准的发布也为全球石墨烯产业标准化进程奠定了重要基础[14, 15]，为与石墨烯相关的研制单位、使用单位提供了清晰的判断依据。2019 年，ISO 发布石墨烯检测标材料的性质和测量技术矩阵》，该标准系统地将石墨烯和相关 2D 材料的关键特性与商业上可获得的测量技术以矩阵的形式联系，为石墨烯和相关 2D 材料的化学、物理、电学、光学、热学和机械性质的表征和测量技术提供指南。随后，ISO 相继发布了 ISO/TS 21356-1：2021《纳米技术 石墨烯结构表征 1 部分 石墨烯粉末和分散体》，该标准给出了石墨烯粉末和分散液中石墨烯层数/厚度、横向尺寸、无序程度、层排列和比表面积的测量技术[16]，该标准的实施可以帮助生产商和使用者分析石墨烯的物理性能，对石墨烯进行质量控制和分类，从而使它适应于下游石墨烯产品的应用。

在方法标准方面，2016 年，IEC 发布了世界首个石墨烯标准 IEC/TS 62607-6-4：2016《纳米制造 关键控制

表 1 现行国际石墨烯标准分类总结

Table 1 Summary and classification of current international graphene standards

Standard classification	Standard number	Standard content	Scope of application	Measurement technique
Basic standards	ISO/TS 80004-13:2017	Terms, definitions, code names	Graphene and related two-dimensional materials	—
	ISO/TR 19733:2019	Matrix of properties and measurement techniques of materials	Graphene and related two-dimensional materials; techniques for measuring chemical, physical, electrical, optical, thermal and mechanical properties of materials	—
Method standards	IEC/TS 62607-6-4:2016	Performance testing method (surface conductivity)	Single-layer or multi-layer graphene materials prepared by chemical vapor deposition, epitaxial growth, and oxidation-reduction graphite methods	Resonant cavity measurement technology
	ISO/TS 21356-1:2021	Feature testing method (layer number/thickness, lateral dimensions, degree of disorder, layer arrangement, and specific surface area)	Graphene, bilayer graphene, graphene nanosheets, and corresponding dispersions	Optical microscope, scanning electron microscope, transmission electron microscopy, atomic force microscopy, Raman spectrometer, specific surface area analyzer
	IEC/TS 62607-6-1:2020	Performance testing method (volume resistivity)	Graphene, few layer graphene, and reduced graphene oxide	Four probe method
	IEC/TS 62607-6-6:2021	Performance testing method (uniformity of strain)	Monolayer graphene	Raman spectrometer
	IEC/TS 62607-6-9:2022	Performance testing method (thin layer resistance)	Graphene-based thin film material	Eddy current measurement technology
	IEC/TS 62607-6-10:2021	Performance testing method (thin layer resistance)	Graphene film materials grown on or transferred to a dielectric substrate by chemical vapor deposition or other methods	Terahertz time-domain spectroscopy measurement technology
	IEC/TS 62607-6-11:2022	Feature testing method (defect density)	Graphene thin films grown by chemical vapor deposition and exfoliated graphene flakes	Raman spectrometer
	IEC/TS 62607-6-13:2020	Feature testing method (oxygen functional group content)	Oxidized graphene, reduced graphene oxide, and other types of functional graphene can be measured as carboxyl, lactone, hydroxyl, and reactive carbonyl functional groups	Boehm titration measurement technique
	IEC/TS 62607-6-14:2020	Feature testing method (defect level)	Graphene powder or graphene based materials, such as reduced graphene oxide, bilayer graphene, trilayer graphene, and few layer graphene	Raman spectrometer
	IEC/TS 62607-6-19:2021	Feature testing method (the content of carbon, sulfur, oxygen, nitrogen, and hydrogen)	Powdered graphene, oxidized graphene, and reduced oxidized graphene	CS analyzer and ONH analyzer
	IEC/TS 62607-6-3:2020	Feature testing method (domain size)	Films made of graphene grown on copper by chemical vapor deposition, a destructive, sample reuse method	Base oxidation technology
	IEC/TS 62607-6-21:2022	Feature testing method (element composition)	Graphene, double-layer graphene, three-layer graphene, few layer graphene, graphene nanosheets, oxidized graphene, and functionalized graphene powder; testing of major elements including carbon, oxygen, nitrogen, sulfur, chlorine, and silicon	X-ray photoelectron spectrometer
	IEC/TS 62607-6-20:2022	Feature testing method (metal impurity content)	Graphene powder and related materials, including bilayer graphene, trilayer graphene, multilayer graphene, reduced graphene oxide, and oxidized graphene	Inductively coupled plasma mass spectrometer
Product standards	IEC/TS 62607-4-6:2018	Infrared absorption method (carbon content for nano electrode materials)	Nanoelectrode materials containing carbon	Infrared absorption spectroscopy measurement technology

特性第 6-4 部分：石墨稀：利用谐振腔的表面电导测量》，该项标准提出用谐振腔法来测量石墨烯材料的电导率，该方法标准不依赖纳米碳层的厚度，可测定由化学气相沉积法、外延生长法、氧化还原石墨法等多种方法制备的单层或多层石墨烯材料的表面电导。该标准为石墨烯材料电导的标准化测量提供了依据，也是全球出台的第一个石墨烯电学性能相关的国际标准。此外，IEC/TC 113 等组织也先后合作研究成立了多个石墨烯标准相关项目。如标准 IEC/TS 62607-6-1：2020《纳米制造 关键控制特性 第 6-1 部分：石墨烯基材料体积电阻率：四探针法》、IEC/TS 62607-6-6：2021《纳米制造 关键控制特性 6-6 部分 石墨烯应变均匀性：拉曼光谱》和 IEC/TS 62607-6-19：2021《纳米制造 关键控制特性 6-19 部分：石墨烯基材料元素组成：CS 分析仪、ONH 分析仪》等 12 项石墨烯特征和性能测试方法的标准，这些 IEC 62607 系列的国际标准重点致力于石墨烯材料的电学特性、结构特性、组成特性等物化参数的测量表征，对石墨烯材料表征与测量技术推广应用具有重要意和分类，从而决定石墨烯材料的质量是否适用于对应义[17-19]。能够帮助石墨烯制造商对其材料质量进行判断和分类，从而决定石墨烯材料的质量是否适用于对应的石墨烯产业链下应用。

在产品标准方面，2018 年，IEC 发布了 IEC/TS 62607-4-6：2018《纳米制造 关键控制特性 第 4-6 部分：纳米储能 纳米电极材料中的碳含量测定 红外吸收法》，针对电极材料中碳含量会影响电池的导电性能、倍率性能、循环性能的特点，该项标准利用红外吸收法测量范围广、准确、快速、灵敏度高等优点，通过粉体压片可对碳含量为 0%～100%的纳米电极材料进行测量，可用于评估石墨烯等含碳纳米电极材料中碳的含量，帮助应用端选择含碳量合适的纳米电极材料。

综上，由表 1 的标准统计结果可知，当前石墨烯标准的研制还处于初级发展阶段，国际相关标准主要集中在针对石墨烯材料及其衍生物自身特性和性能测试的方法标准上，而针对石墨烯下游产品的产品标准还有待进一步完善，例如石墨烯发热膜的热性能、石墨烯涂料的防腐性能等的检测。另外，对于石墨烯方法标准，还需进一步完善石墨烯材料光学、热学、力学等方面的测量标准。

3　国内石墨烯标准的研究进展

我国石墨烯标准的制定主体以标准化委员会、地方标准化机构、联盟、高校为主。当前，我国石墨烯的发展正处于科研与产业化并进阶段，迫切需要通过制定相关石墨烯标准来规范石墨烯产业发展。表 2 列出了我国现行石墨烯相关的国家标准。经统计，我国现行石墨烯相关的国家标准 8 项、行业标准 2 项、地方标准 31 项、团体标准 70 项，这些标准的发布和实施有助于我国石墨烯科技成果的产业化落地。

2018 年，我国发布首个石墨烯国家标准 GB/T 30544.13：2018《纳米术语 第 13 部分：石墨烯及相关二维材料》，该基础标准由泰州巨纳新能源有限公司、东南大学等单位联合起草。该项标准的制定及发布，为石墨烯的生产、应用、检验、流通、科研等提供统一技术用语的基本依据，是开展石墨烯各种技术标准研究及制定工作的重要基础及前提[20]。在该项标准的基础上，我国陆续发布了系列方法标准、产品标准和其他标准。

2019 年起，我国陆续发布了 7 项国家标准，均是与石墨烯材料特性测量相关的方法标准。其中，石墨烯薄膜的层数与其透明度和导电性有很大的关系，石墨烯良好的电导性能和透光性能使它在触摸屏、液晶显示、发光二极管等透明电导电极方面有非常好的应用前景。石墨烯相关二维材料的层数是影响其性能的关键参数。因此，石墨烯层数的准确测量是研究、开发和应用石墨烯相关二维材料的核心问题之一。2021 年，中国科学院半导体研究所和贝特瑞新材料集团股份有限公司等单位联合起草了国家标准 GB/T 40069：2021《纳米技术 石墨烯相关二维材料的层数测量 拉曼光谱法》，该标准利用拉曼光谱特征模式的光谱参数如 G 模的峰高和 2D 模的线型随层数的变化规律开发了石墨烯相关二维材料的层数测量方法，为机械剥离方法制备的石墨烯薄片的层数测量提供科学可靠的依据以及标准的实验方法，并为石墨烯相关二维材料的生产和研究提供技术指导[21, 22]。同年，北京市理化分析测试中心和冶金工业信息标准研究院等单位针对石墨烯疏水性较强、阴离子分布不均匀、前处理困难等问题，起草了 GB/T 41068：2021《纳米技术 石墨烯粉体中水溶性阴离子含量的测定 离子色谱法》，该标准开发了适合石墨烯粉体游离阴离子和总阴离子测定的可靠性、重复性和再现性良好的测试方法，为石墨烯材料的研发、质量控制、应用选型、产品贸易等提供了技术支撑。

此外，与石墨烯材料相关的方法标准里还有很多地方标准，涉及到石墨烯材料的理化性质的测量方法，如石墨烯材料及复合物的厚度/层数、比表面积和孔结构、官能团含量、金属元素含量、非金属元素含量、水溶性阴离子含量、固含量、灰分等；涉及到石墨烯电学方面参数的测量方法，如方阻、电阻率、电导率等；也有涉及少量光学方面参数的测量方法，如透光率等。其他类

型的标准里也涉及了少量关于石墨烯理化性能参数和热学性能参数的测量方法，如微区覆盖度、热扩散系数、导热系数等。为石墨烯材料的特征或性能参数测量提供了指导[23-25]。

从产品标准分类中查阅到一项关于石墨烯锌粉涂料的行业标准 HG/T 5573：2019《石墨烯锌粉涂料》，该标准由中国石油和化学工业联合会提出，起草单位包括常州第六元素材料科技股份有限公司等诸多石墨烯和涂料生产企业、涂料应用企业和相关研究单位。该标准对石墨烯和锌粉共同应用于钢铁防腐蚀复合涂料相关的产品要求、检验规则、包装和贮存条件等内容进行了描述，适用于由墨烯涂料、锌粉、无机或有机漆基等组成的涂料的检测。

表 2 中国现行石墨烯标准分类总结

Table 2 Summary and classification of Chinese current graphene standards

Standard classification	Standard grading	Standard number	Standard content	Scope of application	Measurement technique
Basic standards	National standard	GB/T 30544.13:2018	Terms, definitions, code names	Graphene and related two-dimensional materials	—
Method standards	National standards	GB/T 40066:2021	Feature testing method (thickness)	Measurementthe thickness of graphene oxide, which is not less than 300 nanometers, other two-dimensional materials can refer to the method	Atomic force microscopy
		GB/Z 38062:2019	Feature testing method (specific surface area)	Graphene materials prepared by thermal exfoliation, chemical intercalation exfoliation, and mechanical exfoliation of oxidized graphite	Methylene blue adsorption method
		GB/T 41067:2021	Feature testing method (content of sulfur, fluorine, chlorine and bromine)	Determination of sulfur, fluorine, chlorine, and bromine content in graphene powder	Combustion ion chromatography
		GB/T 41067:2021	Feature testing method (content of water soluble anion)	Determination of water-soluble fluoride ions, chloride ions, nitrite ions, bromide ions, nitrate ions, and phosphate ions in graphene powder	Ion chromatography method
		GB/T 38114:2019	Feature testing method (quantification of oxygen-containing functional groups)	Determination of oxygen-containing functional group content on the surface of graphene powder materials	Chemical titration method
		GB/T 40069:2021	Feature testing method (number of layers)	The preparation of graphene flakes with lateral dimensions not less than 2 microns using mechanical exfoliation method; the graphene flakes prepared by chemical vapor deposition with AB or ABC stacking	Raman spectroscopy
		GB/T 40071:2021	Feature testing method (number of layers)	Graphene thin films with high crystal quality, lateral dimensions not less than 2 microns, and no more than 5 layers produced by mechanical exfoliation or chemical vapor deposition methods	Optical contrast method
	Industry standards	SN/T 1690.3:2019	Performance testing method (qualitative identification)	Qualitative identification of graphene modified nylon fibers, graphene modified adhesive fibers, and graphene modified polyester fibers	Microscopic method, dissolution method, Raman spectroscopy
	Provincial standards	DB62/T 4619:2022	Technical requirements, preparation process, inspection rules, *etc.*	Production, inspection and application of graphene and rubber modified asphalt	—
		DB13/T 5256:2020	General technical specifications such as terminology, requirements, test methods, inspection rules, *etc.*	Graphene-modified polystyrene granular materials with electrical conductivity	—

续表

Standard classification	Standard grading	Standard number	Standard content	Scope of application	Measurement technique
Method standards	Provincial standards	DB13/T 5255:2020	Performance testing method (square obstruction)	The determination of the square resistance of graphite conductive ink, and the square resistance of carbon nanotube conductive ink and other carbon material conductive inks can be referred	Four probe method
		DB1310/T 230:2020	Terms, definitions, technical requirements, test method	Determination of resistance of graphene modified polyethylene for mines	—
		DB1310/T 228:2020	Definition, requirements, and testing method	It is suitable for graphene modified heat resistant polyethylene heat conduction masterbatch	—
		DB32/T 3792:2020	Performance testing method (light transmittance)	It is suitable for uniformly covered graphene films on copper foil substrates prepared by chemical vapor deposition method, and graphene films covered on transparent substrates	Transmittance meter method
		DB13/T 5025.3:2019	Definition, method, test, *etc.*	It is suitable for the determination of magnetic foreign body content in graphene-carbon nanotube composite conductive paste, and other types of paste	Inductively coupled plasma emission spectrometer
		DB13/T 5026.3:2019	Performance testing method (specific resistance)	It is suitable for measuring the resistivity of graphene conductive paste electrode sheets, and also applicable to other pastes with carbon materials as the main solid component	Four probe method
		DB13/T 5026.2:2019	Performance testing method (fineness of slurry)	Determining the fineness of graphene conductive paste, and also applicable to other pastes with carbon materials as the main solid component	Scraper fineness meter method
		DB13/T 5026.1:2019	Performance testing method (slurry viscosity)	Measuring the viscosity of graphene conductive paste, and also applicable to other pastes with carbon materials as the main solid component	Rotational viscometer method
		DB13/T 5025.1:2019	Performance testing method (solid content)	Determination of solid content in graphene conductive slurries, and also applicable to other slurries with carbon materials as the main solid component	—
		DB13/T 5025.2:2019	Performance testing method (water content)	Determination of water content of graphene conductive paste, and also for other pastes with carbon material as the main solid component	Micro moisture analyzer
		DB13/T 2768.4:2018	Feature testing method (specific surface area, pore volume, and pore size)	Determination of specific surface area, pore volume, and pore size applicable to graphene materials	Fully automatic physical adsorption instrument
		DB13/T 2768.3:2018	Performance testing method (conductivity)	Determination of conductivity of graphene materials, the determination of conductivity of other graphene materials can be carried out with reference	Four probe resistivity tester
		DB13/T 2768.1:2018	Performance testing method(ash content)	Determination of ash content in graphene powder materials and their powder derivatives, the determination of ash content in other solid carbon based materials can be referred to for execution	—
Product standards	Industry standards	HG/T 5573:2019	Terminology, product classification, requirements, testing methods, *etc.* (graphene zinc powder coating)	It is suitable for coatings composed of graphene coatings, zinc powder, inorganic or organic paint base, *etc.* It is not suitable for zinc powder coating products with less than 30% metal zinc content in non-volatile	—

续表

Standard classification	Standard grading	Standard number	Standard content	Scope of application	Measurement technique
Other standards	Provincial standards	DB32/T 4027:2021	Performance testing method(conductivity)	Measurement of electrical conductivity of graphene powder with no macroscopic anisotropy after compaction prepared by methods such as oxidation-reduction and chemical intercalation stripping	Dynamic four probing method
		DB32/T 4026:2021	Performance testing method (thermal diffusivity coefficient)	It can be applicable to graphene powder that can be pressed into shape, composite materials and graphite powder containing graphene can refer to the implementation	Laser flash method
		DB13/T 5025.4:2019	Feature testing method (metal element content)	It is suitable for the determination of metal element content in graphene-carbon nanotube composite conductive paste, and other types of paste can be referenced	Inductively coupled plasma emission spectrometer
		DB32/T 3596:2019	Feature testing method (thermal diffusivity and thermal conductivity)	It is suitable for testing the thermal diffusion coefficient and calculating the thermal conductivity of graphene materials and composite thin films within the temperature range of 20 ~ 400 ℃ and the thermal diffusion coefficient range of $10^{-7} \sim 10^{-3}$ m^2/s	Flash method
		DB32/T 3595:2019	Feature testing method (content of carbon, hydrogen, nitrogen, sulfur and oxygen)	Determination of carbon, hydrogen, and nitrogen content with a mass fraction greater than 0.3%, and sulfur and oxygen content with a mass fraction greater than 0.5%	Elemental analyzer method
		DB23/T 2492:2019	Feature testing method (content of carbon, hydrogen, nitrogen, sulfur and oxygen)	Determination of carbon, hydrogen, nitrogen, sulfur, and oxygen content of graphene materials	Elemental analyzer
		DB32/T 3459:2018	Feature testing method (microcoverage)	Determination of microregion coverage of graphene films with domain spacing less than 200 μm on various metal substrates prepared by chemical vapor deposition	Scanning electron microscopy method

综上，依据表 2 的标准统计结果可知，当前国内石墨烯标准在标准分类占比方面与国际标准相类似，主要还是集中在方法标准方面。石墨烯材料相关的产品标准还相对较少，仍需要进一步研究以满足实际生产、应用需求。通过比较分析国内外石墨烯方法标准发现我国石墨烯的方法标准有以下特点：首先体现在方法标准中石墨烯材料的特征测量内容更丰富，不仅涉及到石墨烯材料的理化参数测量、电学参数测量，还涉及到石墨烯材料的光学参数测量、热学参数测量等。其次，国内石墨烯方法标准中不仅涉及到石墨烯材料的特征测试方法研究，还包括部分石墨烯复合材料及产品的性能测试方法研究，这为我国石墨烯材料相关产品标准的后续研究奠定了重要基础。

4 结 语

当前，我国发布的石墨烯相关标准为石墨烯材料的分析检测和计量表征奠定了良好基础，通过石墨烯相关标准的制定，能够深入促进石墨烯材料及产品质控水平的提升，推进石墨烯材料及产品市场化应用。但现阶段我国石墨烯相关的标准仍不完善，相关标准涉及到的范围较窄，亟需建立完善的石墨烯标准体系。

(1)强化石墨烯产品标准的建立，健全石墨烯产业链标准体系。当前，国内外石墨烯标准主要集中在石墨烯材料及其衍生物自身特性和性能测试上，石墨烯产业链下游的石墨烯产品相关标准普遍较少，应围绕国家石墨烯材料产业高质量发展及重点领域的应用需求，加快开展以石墨烯产品为导向的产品标准研究，丰富和健全石墨烯产业链标准体系。

(2)推进多领域石墨烯方法标准的研制，完善方法标准的全方位建设。我国石墨烯标准化工作仍然处于起步阶段，缺乏系统的、全面的研究。尽管现阶段已有相关的方法标准用于石墨关键特性参数的测量，但主要集

中在关键理化性能参数、少量的电学性能参数。要使石墨烯在多个高端领域进行广泛应用，研究其在电磁学、力学、热学、光学等领域的方法标准也至关重要。

(3)加快新材料领域人才队伍建设，为石墨烯标准的制定提供人才支撑。石墨烯材料及产品的相关标准制定涉及多领域、多角度的应用。许多关键测试技术有待突破，测试装置有待研发，检测方法有待研究，产业链相关标准有待制定，急需引进专业技术人才进行深入探究；并将人才引进与人才培养机制相结合，提高人才队伍的专业技术水平，充分发挥人才在石墨烯标准研究中的引领作用。

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