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DEFINITIONS OF TERMS RELATED TO POLYMER BLENDS, COMPOSITES AND MULTIPHASE POLYMERIC MATERIALS

(Provisional Recommendations)

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SUMMARY

The document defines the terms most commonly encountered in the field of polymer blends and composites. The scope has been limited to mixtures in which the components differ in chemical composition or molar mass and in which the continuous phase is polymeric. Incidental thermodynamic descriptions are mainly limited to binary mixtures although, in principle, they could be generalized to multi-component mixtures.

The document is organized into three sections. The first defines terms basic to the description of polymer mixtures. The second defines terms commonly encountered in descriptions of phase domain behaviour of polymer mixtures. The third defines terms commonly encountered in the descriptions of the morphologies of phase-separated polymer mixtures.

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INTRODUCTION

It is the intent of this document to define the terms most commonly encountered in the field of polymer blends and composites. The scope has been limited to mixtures in which the components differ in chemical composition or molar mass or both and in which the continuous phase is polymeric. Many of the materials described by the term multiphase are two-phase systems that may show a multitude of finely dispersed phase domains. Hence, incidental thermodynamic descriptions are mainly limited to binary mixtures, although they can be and, in the scientific literature, have been generalized to multi-component mixtures. Crystalline polymers and liquid-crystal polymers have been considered in other documents,[1,2] and are not discussed here.

This document is organized into three sections. The first defines terms basic to the description of polymer mixtures. The second defines terms commonly encountered in descriptions of phase domain behaviour of polymer mixtures. The third defines terms commonly encountered in the descriptions of the morphologies of phase-separated polymer mixtures.

General terms describing the composition of a system as defined in reference 3 are used without further definition throughout the document. Implicit definitions are identified in boldface type throughout the document.

1.0 Basic Terms in Polymer Mixtures

1.1 polymer blend

A macroscopically homogeneous mixture of two or more different species of polymer.[4]

Notes:

1. In most cases, blends are homogeneous on scales larger than several times the wavelengths of visible light.
2. In principle, the constituents of a blend are separable by physical means.
3. No account is taken of the miscibility or immiscibility of the constituent macromolecules, i.e., no assumption is made regarding the number of phase domains present.
4. The use of the term "polymer alloy" for a polymer blend is discouraged, as the former term includes multiphase copolymers but excludes incompatible polymer blends. (see **1.39**) .
5. The numbers of polymeric components from which the blend is comprised are often designated by the adjectives: binary, ternary, quaternary, ...

1.2 miscibility

The capability of a mixture to form a single phase over certain ranges of temperature, pressure and composition.

Notes:

1. Whether or not a single phase exists depends on the chemical structure, molar mass distribution, and molecular architecture of the components present.
2. The single phase in a mixture may be confirmed by light scattering, x-ray scattering, and neutron scattering.
3. For a two-component mixture, a necessary and sufficient condition for stable or metastable equilibrium of a homogeneous, single-phase is $\left(\frac{\partial^2 \Delta_{\text{mix}} G}{\partial \phi^2}\right)_{T,p} > 0$,

   where $\Delta_{\text{mix}}G$ is the Gibbs energy of mixing per unit volume, and ϕ the composition, where ϕ is usually taken as the volume fraction of one of the component substances. The system is unstable if the above second derivative is negative. The borderline (spinodal) between (meta)stable and unstable states is defined by the above second derivative equalling zero. If the compositions of two conjugate (coexisting) phases become identical upon a change of temperature or pressure, the third derivative also equals zero (defining a critical state).

4. If a mixture is thermodynamically metastable it will demix if suitably nucleated (see **2.5**). If a mixture is thermodynamically unstable it will demix by spinodal decomposition (see **2.8**) and by nucleation and growth if suitably nucleated provided there is minimal kinetic hindrance.

1.3 miscible polymer blend
homogeneous polymer blend

A polymer blend that exhibits miscibility (see **1.2)**.

Notes:

1. For a polymer blend to be miscible it must satisfy the criteria of miscibility (see **1.2**).
2. Miscibility is sometimes erroneously assigned on the basis that a blend exhibits a single T_g or optical clarity.
3. A miscible system can be thermodynamically stable or metastable (see note 4 in **1.2**).

4. For components of given chain structures that would be expected to be miscible, miscibility may not occur if molecular architecture is changed, e. g. by crosslinking.

1.4 homologous polymer blend

A mixture of two or more fractions of the same polymer each of which has a different molar-mass distribution.

1.5 isomorphic polymer blend

A polymer blend of two or more different semi-crystalline polymers that are miscible in the crystalline state as well as in the molten state.

Notes:

1. Such a blend exhibits a single, composition-dependent glass-transition temperature, T_g, and a single, composition-dependent melting point, T_m.
2. This behaviour is extremely rare; very few cases are known.

1.6 polymer-polymer complex

A complex, at least two components of which are different polymers.[4]

Notes:

1. A **complex** is a molecular entity formed from two or more components that can be ionic or uncharged.
2. Although the intrinsic binding energy between the individual interacting sites giving rise to the complex is weaker than a covalent bond, the total binding energy for any one-component molecule may exceed the energy of a single covalent bond.
3. The properties of a complex defined here differ from those given in reference 3 because, owing to the repeating nature of a polymer molecule, many interacting sites may be present, which together will provide stronger bonding than a single covalent bond.

1.7 metastable miscibility

The capability of a mixture to exist for an indefinite period of time as a single phase that is separated by a small or zero energy barrier from a thermodynamically more stable multiphase system.

Note:

Mixtures exhibiting metastable miscibility may remain unchanged or they may undergo phase separation, usually by nucleation or spinodal decomposition.

1.8 metastable miscible polymer blend

A polymer blend that exhibits metastable miscibility.

Note:

In polymers, because of the low mobility of polymer chains, particularly in a glassy state, metastable mixtures may even exist for indefinite periods of time without phase separation. This has frequently led to confusion when metastable miscible polymer blends are erroneously claimed to be miscible.

1.9 interpenetrating polymer network (IPN)

A polymer comprising two or more polymer networks which are at least partially interlaced on a molecular scale but not covalently bonded to each other and cannot be separated unless chemical bonds are broken.[4]

Notes:

1. A mixture of two or more preformed polymer networks is not an interpenetrating polymer network.
2. Interpenetrating polymer networks may be further described by the process by which they are synthesized. When an IPN is prepared by a process in which the second component network is polymerized following the completion of polymerization of the first component network the IPN may be referred to as a **sequential IPN**. When an IPN is prepared by a process in which both component networks are polymerized concurrently, the IPN may be referred to as a **simultaneous IPN.**

1.10 semi-interpenetrating polymer network (SIPN)

A polymer comprising one or more polymer network(s) and one or more linear or branched polymer(s) characterized by the penetration on a molecular scale of at least one of the networks by at least some of the linear or branched chains.[4]

Notes:

1. Semi-interpenetrating polymer networks are different from interpenetrating polymer networks because the constituent linear-chain or branched-chain macromolecule(s) can, in principle, be separated from the constituent polymer network(s) without breaking chemical bonds, and, hence, they are polymer blends.

2. Semi-interpenetrating polymer networks may be further described by the process by which they are synthesized. When an SIPN is prepared by a process in which the second component polymer is polymerized or incorporated following the completion of polymerization of the first component polymer the SIPN may be referred to as a **sequential SIPN**. When an SIPN is prepared by a process in which both component polymers are polymerized concurrently, the SIPN may be referred to as a **simultaneous SIPN.** (This note has been changed from that which appears in reference 4 to allow for the possibility that a linear or branched polymer may be incorporated into a network by means other than polymerization, e.g. by swelling of the network and subsequent diffusion of the linear or branched chain into the network.)

1.11 immiscibility

The inability of a mixture to form a single phase.

__**Notes:**__

1. Immiscibility may be limited to certain ranges of temperature, pressure, and composition.
2. Immiscibility depends on the chemical structures, molar-mass distributions and molecular architectures of the components.

1.12 immiscible polymer blend
heterogeneous polymer blend

A polymer blend that exhibits immiscibility.

1.13 composite

A multicomponent material comprising multiple different (non-gaseous) phase domains in which at least one type of phase domain is a continuous phase (see **3.12**).

__**Note:**__

Foamed substances, which are multiphased materials that consist of a gas dispersed in a liquid or solid, are not normally considered to be composites.

1.14 polymer composite

A composite in which at least one component is a polymer.

1.15 nanocomposite

A composite in which at least one of the phases has at least one dimension of the order of nanometers.

1.16 laminate

A material consisting of more than one layer, the layers being distinct in composition, composition profile or anisotropy of properties.

Notes:

1. Laminates may be formed by two or more layers of different polymers.
2. Composite laminates generally consist of one or more layers of a substrate, often fibrous, impregnated with a curable polymer, curable polymers or liquid reactants.
3. The substrate is usually a sheet-like woven or non-woven material (e. g., glass fabric, paper, copper foil).
4. A single layer of a laminate is termed a **lamina.**

1.17 lamination

The process of forming a laminate.

1.18 delamination

A process that separates the layers of a laminate by breaking their structure in planes parallel to those layers.

1.19 impregnation

Penetration of monomeric, oligomeric, or polymeric liquids into an assembly of fibers.

Note:

Impregnation is usually carried out on a woven fabric or a yarn.

1.20 prepreg

Sheets of a substrate that have been impregnated, with a curable polymer, curable polymers or liquid reactants, or a thermoplastic, ready for fabrication of laminates.

Notes:

1. See **1.16** notes 2 and 3
2. During the impregnation the curable polymer, curable polymers, or liquid reactants may be allowed to react to a certain extent (sometimes termed **degree of ripening**).

1.21 intercalation

A process by which a substance becomes transferred into pre-existing spaces of molecular dimensions in a second substance.

1.22 exfoliation

A process by which thin layers individually separate from a multi-layered structure.

Note:

In the context of a nanocomposite material, the individual layers are of the order of at most a few nanometers in thickness.

1.23 wetting

The process by which an interface between a solid and a gas is replaced by an interface between the same solid and a liquid.

1.25 adhesion

The holding together of two bodies by interfacial forces or mechanical interlocking on a scale of micrometres or less.

1.26 chemical adhesion

Adhesion (see **1.25**) in which two bodies are held together at an interface by ionic or covalent bonding between molecules on either side of the interface.

1.27 interfacial adhesion

Adhesion (see **1.25**) in which interfaces between phases or components are maintained by intermolecular forces, chain entanglements, or both, across the interfaces.

Notes:

1. Interfacial adhesion is also referred to as **tack**
2. **Adhesive strength** (Recommended symbol: F_a, Unit: $N\ m^{-2}$) is the force per unit area of interface required to separate one condensed phase domain from another at the interface between the two phase domains.
3. **Interfacial tension** (Recommended symbol: γ, Unit: $N\ m^{-1}$, $J\ m^{-2}$) is the change in Gibbs energy per unit change in interfacial area for substances in physical contact.
4. Use of the term **interfacial energy** for interfacial tension is not recommended.

1.28 interfacial bonding

Bonding in which the surfaces of two bodies in contact with one another are held together by intermolecular forces.

Note:

Examples of intermolecular forces include covalent, ionic, van der Waals, and hydrogen bonds.

1.29 interfacial fracture

A brittle fracture that takes place at an interface.

1.30 craze

A crack-like cavity formed when a polymer is stressed in tension that contains load-bearing fibrils spanning the gap between the surfaces of the cavity.

Note:

Deformation of continua occurs with only minor changes in volume; hence, a craze consists of both fibrils and voids.

1.31 additive

A substance added to a polymer.

Note:

1. An additive is usually a minor component of the mixture formed and usually modifies the properties of the polymer.
2. Examples of additives are antioxidants, plasticizers, flame retardants, processing aids, other polymers, colourants, UV absorbers, and extenders.

1.32 interfacial agent

An additive that reduces the interfacial energy between phase domains.

1.33 compatibility

The capability of the individual component substances in either an immiscible polymer blend (see **1.12**) or a polymer composite (see **1.14**) to exhibit interfacial adhesion (see **1.27**).

Notes:

1. Use of the term compatibility to describe miscible systems is discouraged.

2. Compatibility is often established by the observation of mechanical integrity under the intended conditions of use of a composite or an immiscible polymer blend.

1.34 compatibilization

Process of modification of the interfacial properties in an immiscible polymer blend, that results in formation of the interphases (see **3.6**) and stabilization of the morphology, which leads to the creation of a polymer alloy.

Note:

Compatibilization may be achieved by addition of suitable copolymers or by chemical modification of interfaces through physical treatment (i.e. irradiation or thermal) or reactive processing.

1.35 degree of compatibility
degree of incompatibility

A measure of the strength of the interfacial bonding between the component substances of a composite or immiscible polymer blend (see **1.12**).

Note:

Estimates of the degree of compatibility are often based upon the mechanical performance of the composite, the interphase thickness (see **3.6**), or the sizes of the phase domains present in the composite, relative to the corresponding properties of composites lacking compatibility.

1.36 compatible polymer blend

An immiscible polymer blend (see **1.12**) that exhibits macroscopically uniform physical properties.

Note:

The macroscopically uniform interactions are usually caused by sufficiently strong interactions between the component polymers.

1.37 compatibilizer

A polymer or copolymer that, when added to an immiscible polymer blend (see **1.12**) modifies its interfacial character and stabilizes its morphology.

Note:

Compatibilizers usually stabilize morphologies over distances of the order of micrometres or less.

1.38 coupling agent
adhesion promoter

An interfacial agent comprised of molecules possessing two or more functional groups, each of which exhibits preferential interactions with the various types of phase domains in a composite.

Notes:

1. A coupling agent increases adhesion between phase domains.
2. An example of the use of a coupling agent is in a mineral-filled polymer material where one part of the coupling agent molecule can chemically bond to the inorganic mineral while the another part can chemically bond to the polymer.

1.39 polymer alloy

A macroscopically homogeneous polymeric material that is comprised of either a compatible polymer blend (see **1.36**), a miscible polymer blend (see **1.3**), or a multiphase copolymer (see **3.3**).

1.40 dispersion

A system containing more than one phase where at least one of the phases consists of finely divided phase domains (see **3.2**), often in the colloidal size range, distributed throughout a continuous phase domain.

Notes:

1. Particles in the colloidal size range have linear dimensions[3] between 1 nm and 1000 nm.
2. The finely divided domains are called the dispersed or discontinuous phase domains (see **3.13**).
3. For a definition of continuous phase domain see **3.12**.
4. A dispersion is often further characterized on the basis of the size of the phase domain as a **macrodispersion** or a **microdispersion**. To avoid ambiguity when using these terms, the size of the domain should also be defined.

1.41 dispersing agent
dispersing aid
dispersant

An additive (see **1.31**), exhibiting surface-activity that is added to a suspending medium to promote uniform and maximum separation of extremely fine solid particles, often of colloidal size (see note in **1.40**).[6]

Note:

Although dispersing agents achieve results similar to compatibilizers (see **1.37**), they function differently in that they reduce the attractive forces between fine particles, which allows them to be more easily separated and dispersed.

1.42 agglomeration
aggregation

A process in which dispersed molecules or particles form clusters rather than remain as isolated single molecules or particles.

1.43 aggregate

A cluster of dispersed molecules or particles that results from agglomeration **(**see **1.42)**.

1.44 extender

A substance, especially a diluent or modifier, added to a polymer to increase its volume without substantially altering the desirable properties of the polymer.

Note:

An extender may be a liquid or a solid.

1.45 filler

A solid extender.

Note:

Fillers may be added to modify mechanical, optical, electrical, thermal, flammability properties, or simply to serve as extenders.

1.46 fill factor

Recommended symbol: ϕ_{fill}

The maximum volume fraction of a particulate filler that can be added to a polymer while maintaining the polymer as the continuous phase domain.

1.47 thermoplastic elastomer

A melt-processable polymer blend or copolymer in which a continuous elastomeric phase domain is reinforced by dispersed hard (glassy or crystalline) phase domains that act as junction points over a limited range of temperature.

Notes:

1. The behaviour of the hard domains as junction points is thermally reversible.
2. The interfacial interaction between hard and soft phase domains in a thermoplastic elastomer is often the result of covalent bonds between the phases and is sufficient to prevent the flow of the elastomeric phase domain under conditions of use.
3. Examples of thermoplastic elastomers include block copolymers and blends of plastics and rubbers.

2.0 Phase Domain Behaviour

2.1 miscibility window

In polymer mixtures, at least one component substance of which is a copolymer, the miscibility window is the range of copolymer compositions that gives miscibility (see **1.2**) over a range of temperatures and pressures.

Notes:

1. Outside the miscibility window immiscible mixtures are formed.
2. The compositions of the copolymers within the miscibility window usually exclude the homopolymer compositions of the monomers from which the copolymers are prepared.
3. The miscibility window is affected by the molecular weights of the component substances.
4. The existence of miscibility windows has been attributed to an average force between the monomer units of the copolymer that leads to those units associating preferentially with the monomer units of the other polymers.

2.2 miscibility gap

The area within the coexistence curve of an isobaric phase diagram (temperature versus composition) or an isothermal phase diagram (pressure versus composition).

Note:

A miscibility gap is observed at temperatures below an upper critical solution temperature (UCST) (see. **2.15**) or above the lower critical solution temperature (LCST) (see.**2.14**). Its location depends on pressure. In the miscibility gap there are at least two phases coexisting.

2.3 Flory-Huggins theory
Flory-Huggins-Staverman theory

A statistical thermodynamic mean-field theory of polymer solutions, formulated independently by Flory, Huggins, and Staverman, in which the thermodynamic quantities of the solution are derived from a simple concept of combinatorial entropy of mixing and a reduced Gibbs-energy parameter, the "χ interaction parameter" (see **2.4**).

Note:

1. The Flory-Huggins theory has often been found to have utility for polymer blends; however, there are many equation-of-state theories that provide more accurate descriptions of polymer-polymer interactions.
2. The present definition has been modified from that which appears in reference 8 to acknowledge the contributions of Staverman and to further clarify the statistical basis of the theory.

2.4 χ interaction parameter

Recommended symbol: χ

An interaction parameter, employed in the Flory-Huggins theory (see **2.3**), to account for the contribution of the non-combinatorial entropy of mixing and the enthalpy of mixing to the Gibbs energy of mixing.

Notes:

1. The definition and the name of the term has been modified from that which appears in reference 8 to reflect its broader use in the context of polymer blends. In its simplest form the χ parameter is defined according to the Flory-Huggins equation for binary mixtures

$$\frac{\Delta_{\text{mix}}G}{RT} = n_1 \ln\phi_1 + n_2 \ln\phi_2 + \chi x_1 n_1 \phi_2 \,,$$

   for a mixture of n_1 and n_2 moles of components denoted 1 and 2, giving volume fractions ϕ_1 and ϕ_2, with the molecules of component 1 each conceptually consisting of x_1 segments whose Gibbs energy of interaction with segments of equal volume in the molecules of component 2 is characterised by the interaction parameter χ.
2. The χ interaction parameters characterizing a given system vary with composition, molar mass, and temperature.
3. B is an alternative parameter to χ, where $B=\chi RT/V_m$, in which V_m is the molar volume of one of the components of the mixture.

2.5 nucleation of phase separation

Initiation of phase domain formation through the presence of heterogeneities.

Note:

In a metastable region of a phase diagram (see **1.2**), phase separation is initiated only by nucleation.

2.6 binodal
binodal curve
coexistence curve

A curve defining the region of composition and temperature in a phase diagram for a binary mixture across which a transition occurs from miscibility of the components to conditions where single-phase mixtures are metastable or unstable (see note 4 in **1.2**).

<u>**Note:**</u>

Binodal compositions are defined by pairs of points on the Gibbs-energy-of-mixing versus composition curve that have common tangents, corresponding to compositions of equal chemical potentials of each of the two components in two phases.

2.7 spinodal
spinodal curve

A curve defining the region of composition and temperature for a binary mixture across which a transition occurs from conditions where single-phase mixtures are metastable to conditions where single-phase mixtures are unstable and undergo phase separation by spinodal decomposition (see **2.8**).

<u>**Notes:**</u>

1. The spinodal curve for a binary mixture is defined as the geometrical locus of all states with $(\partial^2 \Delta_{\text{mix}} G / \partial\phi^2)_{T,p} = 0$ (see **1.2**, note 4).
2. In the unstable region, bounded by the spinodal curve, phase domain separation is spontaneous, i.e. no nucleation step is required to initiate the separation process.

2.8 spinodal decomposition
spinodal phase-demixing

Long range, diffusion limited, spontaneous phase domain separation initiated by delocalised concentration fluctuations occurring in an unstable region of a mixture bounded by a spinodal curve.

<u>**Note:**</u>

Spinodal decomposition occurs when the magnitude of Gibbs energy fluctuations with respect to composition are zero.

2.9 cloud point

An experimentally measured point in the phase diagram of a mixture at which a loss in transparency is observed due to light scattering caused by a transition from a single phase to a two-phase state.

<u>**Notes:**</u>

1. The phenomenon is characterized by the first appearance of turbidity or cloudiness.
2. A cloud point is heating-rate or cooling-rate dependent.

2.10 cloud point curve

A curve of temperature versus composition defined by the cloud points (see **2.9**) over range of compositions of two substances.

Note:

Mixtures are observed to undergo a transition from a single-phase to a two-phase state upon heating or cooling.

2.11 cloud-point temperature

The temperature at a cloud point (see **2.9**).

2.12 critical point

A point in the composition-temperature plane for a binary mixture where the compositions of all coexisting phases become identical.

Notes:

1. In a phase diagram, the slope of the tangent to the spinodal is zero at this point.
2. At a critical point, binodals and spinodals coincide.
3. Although the definition holds strictly for binary mixtures, it is often erroneously applied to multi-component mixtures.
4. See **1.2 Note 3.**

2.13 lower critical solution temperature

Recommended abbreviation: LCST

A critical temperature below which a mixture is miscible.

Note:

1. Below the LCST and above the UCST (see **2.14**), if it exists, a single phase exists for all compositions.
2. The LCST depends upon pressure and the molar mass distributions of the constituent polymer(s).
3. For a mixture containing or consisting of polymeric component substances, the polymeric components may be different polymers or species of different molar mass of the same polymer.

2.14 upper critical solution temperature

Recommended abbreviation: UCST

A critical temperature above which a mixture is miscible.

Note:

1. Above the UCST and below the LCST (see **2.13**), if it exists, a single phase exists for all compositions
2. The UCST depends upon the pressure and molar mass distributions of the constituent polymer(s).
3. For a mixture containing or consisting of polymeric component substances, the polymeric components may be different polymers or species of different molar mass of the same polymer.

2.15 phase inversion

A process by which an initially continuous phase domain becomes the dispersed phase domain and the initially dispersed phase domains become the continuous phase domain.

Notes:

1. Phase inversion may be observed during the polymerization or melt processing of polymer blend systems.
2. The phenomenon is usually observed during polymerization of a monomer containing a dissolved polymer.

2.16 interdiffusion

The process by which homogeneity in a mixture is approached by means of spontaneous mutual molecular diffusion.

2.17 blooming

The process in which one component of a polymer mixture, usually not a polymer, undergoes phase separation and migration to an external surface of the mixture.

2.18 coalescence

A process in which two phase domains of essentially identical composition in contact with one another form a larger phase domain.

Notes:

1. Coalescence reduces the total interfacial area.
2. The flocculation of a polymer colloid, through the formation of aggregates, may be followed by coalescence.

2.19 morphology coarsening
phase ripening

The process by which phase domains increase in size during the aging of a multiphase material.

Note:

1. In the coarsening at the late stage of phase separation, volumes and compositions of phase domains are conserved.
2. Representative mechanisms for coarsening at the late stage of phase separation are: (1) material flow in domains driven by interfacial tension (observed in a co-continuous morphology), (2) the growth of domain size by evaporation from smaller droplets and condensation into larger droplets, and (3) coalescence (fusion) of more than two droplets. The mechanisms are usually called (1) Siggia's mechanism, (2) Ostwald ripening (or the Lifshitz-Slyozov mechanism), and (3) coalescence.
3. Morphology coarsening can be substantially stopped by, for example, vitrification, crosslinking, and **pinning**, the slowing down of molecular diffusion across domain interfaces.

3.0 Domains and Morphologies

Many types of morphologies have been reported in the literature of multiphase polymeric materials. It is the intent of this document to define only the most commonly used terms. In addition, some morphologies have historically been described by very imprecise terms that may not have universal meanings. However, if such terms are widely used they are defined here.

3.1 morphology

The shape, optical appearance, or form of domains in substances, such as high polymers, polymer blends, composites, and crystals.

Note:

For a polymer blend or composite, the morphology describes the structures and shapes observed, often by microscopy or scattering techniques, of the different phase domains present within the mixture.

3.2 phase domain

An entity of a material system that is uniform in chemical composition and physical state.

Notes:

1. A phase in a multiphase material can form domains differing in size.
2. The term domain may be qualified by the adjective microscopic or nanoscopic or the prefix micro- or nano- according to the linear dimension of the domain.
3. The prefixes micro-, and nano- are frequently incorrectly used to qualify the term "phase" instead of the term "domain"; hence, "microphase domain", and "nanophase domain" are often used. The correct terminology that should be used is "**phase microdomain**" and "**phase nanodomain**".

3.3 multiphase copolymer

A copolymer comprising phase-separated domains

3.4 domain interface
domain boundary

A surface forming a common boundary between two phase domains.

Note:

A representation of the domain interface as a two-dimensional surface over-simplifies the actual structure. All interfaces have a third dimension, namely, the interphase or interfacial region (see **3.6**).

3.5 domain structure

The morphology of individual phase domains in a multiphase system.

Note:

Domain structures may be described for phase domains or domains that are themselves multiphased structures.

3.6 interfacial region
interphase

The region between phase domains in an immiscible polymer blend in which a gradient in composition exists.

3.7 phase interaction

Molecular interaction between the components present in the interphases of a multiphase mixture.

Note:

The **interphase elasticity** is the capability of a deformed interphase to return to its original dimensions after the force causing the deformation has been removed.

3.8 interfacial-region thickness
interphase thickness
interfacial width

The width of the composition gradient in an interfacial region.

Note:

The width at half the maximum of the composition profile across the interfacial region (see **3.6**) or the distance between locations where $d\phi/dr$, (with ϕ the composition of a component and r the distance through the interfacial region) has decreased to 1/e are used as measures of the interfacial-region thickness.

3.9 hard-segment phase domain

A phase domain of microscopic or smaller size, usually in a block, graft, or segmented copolymer, comprised essentially of those segments of the polymer that are rigid and capable of forming strong intermolecular interactions.

Note

Hard-segment phase domains are typically of 2-15 nm linear size.

3.10 soft-segment phase domain

A phase domain of microscopic or smaller size, usually in a block, graft, or segmented copolymer, comprised essentially of those segments of the polymer that have glass transition temperatures lower than the temperature of use.

Note:

Soft-segment phase domains are often larger than hard segment phase domains and are often continuous.

3.11 segmented copolymer

A copolymer containing phase domains of microscopic or smaller size, with the domains constituted principally of single types of structural unit.

Note:

The types of domain in a segmented copolymer usually comprise hard-segment and soft-segment phase domains.

3.12 continuous phase domain
matrix phase domain

A single-phase domain in a heterogeneous mixture through which a continuous path to all phase domain boundaries may be drawn without crossing a phase domain boundary.

Note:

In a polymer blend, the continuous phase domain is sometimes referred to as the **host polymer**, **bulk substance**, or **matrix**.

3.13 discontinuous phase domain
discrete phase domain
dispersed phase domain

A phase domain in a phase-separated mixture that is spatially surrounded by a continuous phase but isolated from all other similar phase domains within the mixture.

Note:

The discontinuous phase domain is sometimes referred to as the **guest polymer.**

3.14 dual phase domain continuity
co-continuous phase domains

In a phase-separated, two-component mixture, the topological condition in which a continuous path through either phase domain may be drawn to all phase domain boundaries without crossing any phase domain boundary.

3.15 core-shell morphology

A two-phase domain morphology, of approximately spherical shape, comprised of two polymers, each in separate phase domains, in which phase domains of one polymer completely encapsulates the phase domains of the other polymer.

Note:

This morphology is most commonly observed in copolymers or blends prepared in emulsion polymerization by the sequential addition and polymerization of two different monomer compositions.

3.16 cylindrical morphology

A phase domain morphology, usually comprised of two polymers, each in separate phase domains, in which the phase domains of one polymer are of cylindrical shape.

Notes:

1. Phase domains of the constituent polymers may alternate, which results in many cylindrical layers surrounding a central core domain.
2. Cylindrical morphologies can be observed, for example, in triblock copolymers.

3.17 fibrillar morphology

A morphology in which phase domains have shapes with one spatial dimension much larger than the other two spatial dimensions.

Note:

Fibrillar phase domains have the appearance of fibers.

3.18 lamellar domain morphology

A morphology in which phase domains have shapes with two spatial dimensions much larger than the third spatial dimension.

<u>**Note:**</u>

Plate-like phase domains have the appearance of extended planes that are often oriented essentially parallel to one another.

3.19 microdomain morphology

A morphology consisting of phase microdomains.

<u>**Notes:**</u>

1. See **3.2.**
2. Microdomain morphologies are usually observed in block, graft, and segmented copolymers.
3. The type of morphology observed depends upon the relative abundance of the different types of structural units and the conditions for the generation of the morphology. The most commonly observed morphologies are spheres, cylinders, and lamellae.

3.20 nanodomain morphology

A morphology consisting of phase nanodomains.

<u>**Note:**</u>

See **3.2.**

3.21 onion morphology

A multiphase morphology of roughly spherical shape that comprises alternating layers of different polymers arranged concentrically, all layers being of similar thickness.

3.22 ordered co-continuous double gyroid morphology

A co-continuous morphology in which a set of two gyroid-based phase domains exhibits a highly regular, three-dimensional lattice-like morphology with Ia3d space group symmetry.

<u>**Notes:**</u>

1. The domains are composed of tripoidal units as the fundamental building structures.
2. The two domains are interlaced.

3.23 multi-coat morphology

A morphology observed in a blend of a block copolymer with the homopolymer of one of the blocks and characterized by alternating concentric shells of the copolymer and the homopolymer.

Note

The morphology is identical to onion morphology (see **3.21**) within a matrix of homopolymer.[5]

3.24 rod-like morphology

A morphology characterized by cylindrical phase domains.

3.25 multiple inclusion morphology
salami-like morphology

A multiphase morphology in which dispersed phase domains of one polymer contain and completely encapsulate many phase domains of a second polymer that may have the same composition as the continuous phase domain (see **3.12**).

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