Advanced Polymers Enabled By ResonantAcoustic® Mixing

Testimonials • Published Articles • Patents & Patent Applications

June 2024

This is a portfolio of user testimonials, articles, and patents/patents pending that reference Resodyn's ResonantAcoustic® Mixing (RAM) technology in a variety of advanced polymer applications. These abstracts and links to published articles are intended to provide insight into the value of RAM technology as a means of solving challenges, improving quality, and raising productivity in the development and processing of advanced polymers.

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Advanced Polymer Materials

Polymers and polymer-based materials are ubiquitous throughout many industries. Innovations in processing and fabrication techniques have helped create advanced polymers that enable precise design down to the molecular level.

Resodyn's revolutionary, innovative, contactless **ResonantAcoustic® Mixing (RAM)** technology uses acoustic energy to rapidly and thoroughly, but gently (**RAM** does not break polymer chains) mix formulations with repeatable results. Advanced Polymer manufacturers use **RAM** technology to meet uniformity and performance requirements of leading-edge and emerging applications, including optoelectronic, aerospace, semiconductor, biomedical, and energy fields, and in traditional industries.

The new explorations in Advanced Polymers with **RAM** discussed in this Folio may dramatically change many industries. One article explains how brown kelp can be used to reliably produce cellulose fibers and films, which can be used as their own forms of polymers in industrial and biomedical capacity.

Developers of advanced polymers rely on RAM as a foundation technology to conceive and deliver new products across a wide spectrum of industries.

= Locations of customers of ResonantAcoustic® Mixers

What developers of advanced polymer materials are saying about RAM

…a new mixing technology called RAM…uses low frequency, high intensity vibrations to mix ingredients. Studies have found that RAM can significantly reduce processing times in comparison to vertical mixers… Greater strain capabilities in RAM results from stronger interfacial adhesion between solid particles and the liquid binder.

- M. Magana, California State University, Long Beach, 2023

RAM technology has a breadth of capability which has been demonstrated by the 10 unique applications at the KCNSC. In all cases, the mixing was successful. Initial results have led to the procurement of an additional RAM system within the plant as well as 2 other departments potentially pursuing systems as well.

6 Polymer examples among the 10 unique applications:

- *APO-BMI*
- *RTV cellular silicone with high viscosity*
- *RTV silicone foam resin with 5 medium viscosity constituents and 1 extremely fine powder*
- *Polysulfide with high viscosity and phenolic microballoons*
- *Epoxy*
- *Elastomers with high viscosity and 3 different mass filllers - low, medium, and high densities*

– Daniel Kessler, U.S. DOE's Kansas City National Security Campus

RAM: 21st Century Mixing Technology for 21st Century Materials

More than a thousand RAM systems are in use in more than 40 countries around the world. RAM is the world's preferred choice for innovation in materials processing.

PUBLISHED ARTICLES

Icon Legend

RAM testing, evaluation

Liquid/powder

Polymers

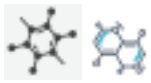
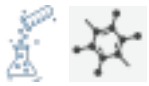
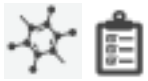
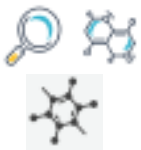
Material/chemical properties

Materials processing

Graphene

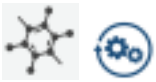
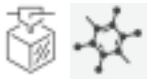
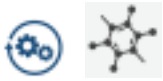
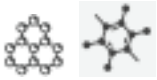
Powder/powder

Materials/product quality

Icons	Publication Title (Live Links)*	RAM Application Summary	Year
	Facile synthesis: from Laminaria hyperborea to cellulose films and fibers	The dissolving process was aided by repetitive oven heating and vigorous mixing using an **acoustic mixer** (**LabRAM, Resodyn**, USA) until the cellulose was completely dissolved to form a homogeneous solution.	2024
	Dynamic Spreading Of Curatives And Plasticizers In Polymeric Binders	**Resodyn** laboratory-grade **RAM** I configuration. The goal in the mixing process is to maximize solids loading, processibility, and the wetting of solid particles by the liquid binder.	2023
	Determination and optimisation of Resonant Acoustic Mixing (RAM) efficiency in Polymer Bonded eXplosive (PBX) processing	An investigation into how the efficiency (time and energy required for homogeneity) of **Resonant Acoustic Mixing** (**RAM**) can be determined and optimised was undertaken. An idealised Polymer Bonded eXplosive (PBX) simulant based on glass microbeads (28.3 m D50, 62% v/v in binder and plasticiser) was used for mixing.	2022
	A novel method for preparing stabilized amorphous solid dispersion drug formulations using acoustic fusion	"...A diverse set of drug and polymer combinations have been effectively evaluated utilizing a newly developed method called acoustic fusion to form amorphous solid dispersions (ASD) on the mg-scale, indicating that this approach is a general procedure that can be applied for ASD drug formulations...**ResonantAcoustic Mixing** can be used to homogeneously mix high viscosity materials..."	2021
	Powder Processing and Properties Characterization of Polyamide 11-Graphene anocomposites for Selective Laser Sintering	"The **ResodynTM ResonantAcoustic® Mixer** [was evaluated for] powder-powder mixing techniques. After mixing, the powder samples were pressed into thin-films for characterization on TGA, SEM, four-probe conductivity, and Raman spectroscopy. Polymer nanocomposites of PA11 and nano-graphene platelets were mixed using powder mixing techniques. The **Resodyn ResonantAcoustic®** mixer [was] used with the addition of zirconia grinding media to aid in the breaking and exfoliation of graphene clusters..."	2020

PUBLISHED ARTICLES

Resodyn ACOUSTIC MIXERS
Innovative Mixing Solutions

Icons	Publication Title (Live Links)*	RAM Application Summary	Year
	Development of a quantitative method to evaluate the printability of filaments for fused deposition modeling 3D printing	"...Lack of a conventional quantitative method for filament printability has been recognized as a critical barrier to fused deposition modeling (FDM) 3-D printing application. A small molecule drug, indomethacin, was used as a model compound to mix with polymers with various solubility. The indomethacin and polymer excipients with various ratios were mixed using a **Resodyn LabRAM II ResonantAcoustic Mixer** at 60g for one minute..."	2020
	Milling of Energetic Crystals with the LabRAM	"...Over the last decade, the **Resodyn LabRAM acoustic mixer** has been widely used for mixing of powders and for the pharmaceutical industry, yet its use as a vibratory mill has not been published extensively. It has a long history of use for energetic materials processing that includes but is not limited to cocrystal synthesis, dry pyrotechnic powder mixing, rocket propellant mixing, and polymer bound explosives. It was shown that efficient dry vibratory milling could be achieved using the L**abRAM acoustic mixer**..."	2019
	3D printing of polymer-bonded magnets from highly concentrated, plate-like particle suspensions	"...[a] clear photo polymer resin binder was chosen as the fluid carrier for the NdFeB powder as it yields high NdFeB loading while maintaining sufficiently low viscosity for printing. The resin is composed of methacrylate oligomers and monomers and has a specific gravity of 1.1 g/cm3. According to Zguris [21], a UV curving wavelength of 405 nm would yield the best mechanical strength for the neat binder. For compounding the powder with the UV binder, a **Resodyn LabRAM II ResonantAcoustic®** mixer was used at a mixing intensity of 100 times gravitation for 5 min to allow thorough and uniform mixing..."	2019
	Surface cross-linking of ZIF-8/polyimide mixed matrix membranes (MMMs) for gas separation	"...remaining polymer was added and the mixture was further stirred and sonicatedfor 4 h and finally stirred for 24 h. Next, the polymer-ZIF dispersion was mixed in a **ResodynLabRam Acoustic Mixture** for 10 min to break any aggregations..."	2013
	Preparation morphology and properties of reduced graphene oxide/natural rubber nanocomposites	"... [The} research objective is to use graphene to replace carbon black in tire compounds to improve mechanical properties as well as improved electrical conductivity even at high strain (for anti-static purposes) while reducing tire weight. Two routes [mixing technologies: a **Resodyn Acoustic Mixer** and Ultrasonification] were used for exfoliation of graphite oxide to graphene oxide yield different aspect ratio platelets."	2011

PUBLISHED ARTICLES

Resodyn™ ACOUSTIC MIXERS
Innovative Mixing Solutions

Partial (edited) selection of searched technical articles using the following search terms (articles are live links): "resonant acoustic," "acoustic mixing" AND/OR: "Resodyn," "polymers," "polymeric nanomaterials," and "advanced materials."

Facile synthesis: from Laminaria hyperborea to cellulose films and fibers

Yanqi Dai, Dongyang Sun, Senthilarasu Sundaram, Angelo Delbusso, Dominic O'Rourke, Mark Dorris & Mohan Edirisinghe

A mixture of EMIM OAc and DMSO with a weight ratio of 1:1 was used to dissolve Laminaria hyperborea cellulose. The dissolving process was aided by repetitive oven heating and vigorous mixing using an **acoustic mixer** (**LabRAM, Resodyn**, USA) until the cellulose was completely dissolved to form a homogeneous solution.

Dynamic Spreading Of Curatives And Plasticizers In Polymeric Binders

Marc Anthony Magana

Resodyn laboratory-grade **RAM I** configuration. The goal in the mixing process is to maximize solids loading, processibility, and the wetting of solid particles by the liquid binder. Bimodal and trimodal AP compositions are chosen to increase packing density and minimize void spaces.

Determination and optimisation of Resonant Acoustic Mixing (RAM) efficiency in Polymer Bonded eXplosive (PBX) processing

A.J. Claydon, A.N. Patil, S. Gaulter, G. Kister & P.P. Gill

An investigation into how the efficiency (time and energy required for homogeneity) of **Resonant Acoustic Mixing** (**RAM**) can be determined and optimised was undertaken. An idealised Polymer Bonded eXplosive (PBX) simulant based on glass microbeads (28.3 m D50, 62% v/v in binder and plasticiser) was used for mixing.

A novel method for preparing stabilized amorphous solid dispersion drug formulations using acoustic fusion

Zack Guo a, Christopher Boyce, Timothy Rhodes, Lina Liu, Gino M. Salituro, Keun-joong Lee, Annette Bak & Dennis H. Leung

… benchtop **resonant acoustic mixer** by **Resodyn**. The block can hold up to 24 different 4 mL glass vials… one polymer and heating the mixture to a temperature higher than the glass transition or melting point temperatures of at least one of the polymers or the API, the crystalline API and polymers…

Powder Processing and Properties Characterization of Polyamide 11-Graphene anocomposites for Selective Laser Sintering

D.Z. Chen, S. Laoa, J.H. Kooa, M. Londaa & Z. Alabdullatifb

Nano-graphene platelets (NGPs) were added to polyamide 11 (PA11) powder in 1%, 3%, and 5% weight loading in an attempt to create electrostatic dissipative polymer nanocomposites (PNC) using SLS, a rapid manufacturing process. Powder-powder mixing techniques were explored as a potential replacement for twin-screw extrusion for dispersing nano-graphene platelets (NGPs) within a PA11 matrix. The **Resodyn Resonant Acoustic Mixer**...

PUBLISHED ARTICLES

Resodyn ACOUSTIC MIXERS
Innovative Mixing Solutions

Development of a quantitative method to evaluate the printability of filaments for fused deposition modeling 3D printing

Pengchong Xu, Jiangwei Li, Alvin Meda, Frederick Osei-Yeboah, Matthew L. Peterson, Michael Repka & Xi Zhan

… Indomethacin and polymer excipients with various ratios were mixed using a **Resodyn LabRAM II ResonantAcoustic® mixer** at 60G for 1 min. The physical mixtures were then fed into the extruder at 3–5 g/min (depending on the torque) using a magnetic feeder (Model: FTOC, Syntron) and …

Milling of Energetic Crystals with the LabRAM

LN Kotter & LJ Groven

… Over the last decade, the **Resodyn LabRAM acoustic mixer** has been widely used for mixing of powders and for the … polymer, anywhere from 5 % to 15 % ethylene is doped within the polymer. This doping of the PP chains by ethylene links randomizes the structure of the polymer …

3D printing of polymer-bonded magnets from highly concentrated, plate-like particle suspensions

Alan Shen, Xiaoguang Peng, Callum P. Bailey, Sameh Dardona & Anson W.K. Ma

… Recently, 3D printing of polymer-bonded magnets has gained research interest over … In this method, ferromagnetic particles (NdFeB) are first dispersed in a UV curable polymer binder ... For compounding the powder with the UV binder, a **Resodyn LabRAM II acoustic mixer** was …

Surface cross-linking of ZIF-8/polyimide mixed matrix membranes (MMMs) for gas separation

Sumudu N. Wijenayake, Nimanka P. Panapitiya, Saskia H. Versteeg, Cindy N. Nguyen, Srishti Goel, Kenneth J. Balkus, Jr., Inga H. Musselman & John P. Ferraris

… Then, the remaining polymer was added and the mixture was further stirred and sonicated or 4 h and finally stirred for 24 h. Next, the polymer-ZIF dispersion was mixed in a **Resodyn LabRam Acoustic Mixture** for 10 minutes to break any aggregations and was concentrated to about…

Preparation morphology and properties of reduced graphene oxide/natural rubber nanocomposites

TJ Boyle, J Potts, O Shankar, R Ruoff & TN Lambert

"... [The} research objective is to use graphene to replace carbon black in tire compounds to improve mechanical properties as well as improved electrical conductivity even at high strain (for anti-static purposes) while reducing tire weight. Two routes [mixing technologies: a **Resodyn Acoustic Mixer** and Ultrasonification] were used for exfoliation of graphite oxide to graphene oxide yield different aspect ratio platelets."

Relevant Patents

Approved and pending applications for work involving the use of ResonantAcoustic® mixing technology.*

*Including patents with RAM as the preferred embodiment

Composition, magnetic particle-containing cured substance, magnetic particle-introduced substrate, and electronic material

WO EP US JP KR TW US20230420167A1 Tetsushi Miyata & Tatsuo Ishikawa Fujifilm Corporation
Priority 2021-03-22 • Filed 2023-09-07 • Published 2023-12-28

A first object of the present invention is to provide a composition that is capable of forming a cured substance having a high magnetic permeability and a low magnetic loss and has excellent hole filling suitability and excellent storage stability. A second object of the present invention is to provide a magnetic particle-containing cured substance formed of the composition. A third object of the present invention is to provide a magnetic particle-introduced substrate and an electronic material that contain the magnetic particle-containing cured substance.

The composition according to an embodiment of the present invention is a composition containing

magnetic particles and
an organic solvent,
in which the magnetic particles include magnetic particles X having a sphericity of 100 to 120,
the magnetic particles X include ferrite particles,
a content of magnetic particles that are included in the magnetic particles X and have an equivalent circle diameter of less than 11 μm is 15% to 70% by mass with respect to a total mass of the magnetic particles X, and
a volume average particle size of the magnetic particles X is 5 to 50 μm.

Highlighted Use: RAM technology created 53 different examples and five comparative examples.

Photocurable compositions for stereolithography, method of forming the compositions, stereolithography methods using the compositions, polymer components formed by the stereolithography methods, and a device including the polymer components

WO EP US CN JP KR TW US20240002554A1 Trevor Polidore, Dirk Baars, Thomas A. Koes, Bruce Fitts & Murali Sethumadhavan Rogers Corporation
Priority 2019-05-30 • Filed 2023-08-30 • Published 2024-01-04

A photocurable composition for stereolithographic three-dimensional printing, wherein the photocurable composition comprises a photoreactive oligomer component comprising a hydrophobic oligomer comprising a photoreactive end group, a photoreactive monomer component comprising a photoreactive monomer having a photoreactive end group, and a photoinitiation composition comprising a photoinitiator; the photocurable composition has a viscosity of 250 to 10,000 centipoise at 22° C., determined using a Brookfield viscometer; and the photocured composition has a dielectric loss of less than 0.010, preferably less than 0.008, more preferably less than 0.006, most preferably less than 0.004, each determined by split-post dielectric resonator testing at 10 gigahertz at 23° C.

Highlighted Use: A LabRAM II worked on a heated oligomer and other materials to create a curable film material.

Patents, cont'd.

Polymer matrix composites comprising functional particles and methods of making the same

WO EP US CN JP US20230356186A1 Jerald K. Rasmussen, Derek J. Dehn, Clinton P. Waller, Jr., Bharat R. Acharya, Satinder K. Nayar 3M Innovative Properties company

Priority 2017-11-16 • Filed 2023-07-12 • Published 2023-11-09

A polymer matrix composite comprising a porous polymeric network; and a plurality of functional particles distributed within the polymeric network structure, and wherein the polymer matrix composite has an air flow resistance at 25° C., as measured by the "Air Flow Resistance Test," of less than 300 seconds/50 cm3/500 micrometers; and wherein the polymer matrix composite has a density of at least 0.3 g/cm3; and methods for making the same. The polymer matrix composites are useful, for example, as filters.

Highlighted Use: LabRAM combined ultra-high molecular weight polyethylene and functional azlactone.

Magnesium oxide powder and resin composition which uses same

WO WO2024004736A1 Toshihiko Tsuneyoshi, Motoharu Fukasawa & Takuto Okabe Denka Corporation

Priority 2022-06-28 • Filed 2023-06-19 • Published 2024-01-04

Provided are: a magnesium oxide powder which exhibits excellent moisture resistance and is capable of attaining a low dielectric tangent which is also applicable to high-frequency-band devices; and a resin composition which uses the same. A magnesium oxide powder (I) which contains coated particles (X) obtained by coating the surface of core particles (A) containing magnesium oxide with a coating layer (B) which contains MgAl2O4, wherein the proportion of the MgAl2O4 to the total mass of the magnesium oxide powder (I) is less than 13 mass%, and the BET specific surface area (Si) of the magnesium oxide powder (I) is less than 2.3m2/g.

Highlighted Use: RAM technology created resin from polyethylene resin powder and magnesium hydroxide.

Chemical-free production of graphene-reinforced polymer matrix composites

WO US CN JP KR CN108602675B Arjuna Zam & Zhang Bozeng Nanotek Instruments Inc

Priority 2015-12-10 • Filed 2016-12-07 • Granted 2023-08-18 • Published 2023-08-18

Provided is a simple, fast, scalable, and environmentally benign method of producing a graphene-reinforced polymer matrix composite directly from a graphitic material, the method comprising: (a) mixing multiple particles of a graphitic material and multiple particles of a solid polymer carrier material to form a mixture in an impacting chamber of an energy impacting apparatus; (b) operating the energy impacting apparatus with a frequency and an intensity for a length of time sufficient for peeling off graphene sheets from the graphitic material and transferring the graphene sheets to surfaces of solid polymer carrier material particles to produce graphene-coated or graphene-embedded polymer particles inside the impacting chamber; and (c) forming graphene-coated or graphene-embedded polymer particles into the graphene-reinforced polymer matrix composite. Also provided is a mass of the graphene-coated or graphene-embedded polymer particles produced by this method.

Highlighted Use: RAM technology created graphene from expanded graphite with ABS pellets.

Solvent-free emulsion process using acoustic mixing

US EP JP CA2700696C Zhen Lai, Chieh-Min Cheng, Shigang S. Qiu, Emily L. Moore, Tie Hwee Ng Xerox Corp.

Filed 2010-04-13 • Granted 2014-01-14 • Published 2014-1-14

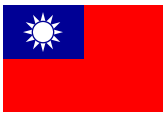
A process for making toner particles is provided. In embodiments, a suitable process includes melt mixing a resin in the

Patents, cont'd.

absence of an organic solvent, optionally adding a surfactant to the resin, adding to the resin at least one colorant and other optional toner additives, adding to the resin a basic agent and water to form a mixture, and subjecting the mixture to acoustic mixing at a suitable frequency to form to form an emulsion. A phase inversion may then be performed to create a phase inversed emulsion including a disperse phase comprising molten resin and the optional ingredients of the toner composition, at which time toner-sized droplets may be solidified from the disperse phase into toner particles, which can be recovered for use.

Highlighted Use: A LabRAM combined crystalline resin and branched sodium dodecyl benzene sulfonate.

Method of making polymer matrix composites



WO JP EP US CN TW US20200347200A1 Derek J. Dehn, Clinton P. Waller, Jr., Jeanne M. Bruss, Bharat R. Acharya, Brandon A. Bartling, Michael S. Graff, Noah O. Shanti, Fabian Stolzenburg & Satinder K. Nayar 3M Innovative Properties Co.

Filed 2018-11-15 • Priority 2018-11-15 • Granted 2023-11-07 • Published 2023-11-07

Method of making a polymer matrix composite comprising a porous polymeric network structure; and a plurality of particles distributed within the polymeric network structure, the method comprising: combining a thermoplastic polymer, a solvent that the thermoplastic polymer is soluble in, and a plurality of particles to provide a slurry; forming the slurry in to an article; heating the article in an environment to retain at least 90 percent by weight of the solvent, based on the weight of the solvent in the slurry, and inducing phase separation of the thermoplastic polymer from the solvent to provide the polymer matrix composite.

Highlighted Use: A LabRAM combined ultra-high molecular weight polyethylene with boron nitride.

Improvements in or relating to energetic materials

GB EP WO US US20180305270A1 Kenneth Lewtas, Daniel Jubb & Mark Price Lewtas Science and Technologies Ltd.

Filed 2016-10-12 • Assigned 2018-05-31 • Granted 2023-10-31 • Published 2023-10-31

Energetic materials comprising active components, a polymer binder matrix and a tackifying resin are useful as propellants, fuels, pyrotechnic materials and explosives; the tackifying resin improves the adhesion and dispersion of the active components throughout the binder resin.

Highlighted Use: A LabRAM II H combined the active components, polymer binder matrix and resin.

High molecular weight zwitterion-containing polymers

JP MX EP BR KR LT DK KR CN PT WO SI AU US AU2011239423 4B2 Didier G. Benoit, Stephen A. Charles, Lane A. Clizbe, Victor D. Perlroth, Jeanne M. Pratt, Wayne To, Linda J. Zadik Kodiak Sciences Inc

Filed 2011-04-15 • Granted 2015-04-30 • Published 2015-04-30 • Priority 2015-07-30

The present invention provides multi-armed high MW polymers containing hydrophilic groups and one or more functional agents, and methods of preparing such polymers.

HIghlighted Use: RAM technology is noted as "particularly attractive" for the highly viscous polymers.

Dental composite compositions for reduced shrinkage stress

EP WO US JP CA US9931280B2 Hui Lu, Xiaoming Jin, Joachim E. Klee, Bernard Koltisko Dentsply Sirona Inc

Patents, cont'd.

Filed 2014-10-03 • Priority 2014-10-03 • Granted 2018-04-03 • Published 2018-04-03

A dental composite composition is disclosed that includes a polymerizable resin, filler particles, and at least one polymerizable stable radical. A variety of polymerizable stable radicals may be employed, including those that have a 2,2,6,6-tetramethylpiperidinyl-1-oxyl moiety. Compositions as described herein exhibit excellent mechanical strength, hardness, and flexural modulus, while also significantly decreasing shrinkage stress caused by polymerization.

Highlighted Use: RAM technoloy mixed the paste in a low-temperature, low-pressure environment.

RAM 5

RAM 5 Continuous

RAM 55

OmniRAM Continuous

OmniRAM H

RAM 5 H

RAM 55 H

OmniRAM

LabRAM II LabRAM I

PharmaRAM I PharmaRAM II

LabRAM II H

Resodyn™ ACOUSTIC MIXERS

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