International Journal of Electromagnetics and Applications 2024, 13(1): 1-9
DOI: 10.5923/j.ijea.20241301.01

Invention of Mid-InfraRed Generating Atomizer (MIRGA), Its Atomic-Molecular-Chemical Bond Level Actions and Applications

Umakanthan T.[1,*], Madhu Mathi[2], Umadevi U.[3]

[1]Veterinary Hospital, Gokulam Annadhanam Temple Complex, Plot no.: 1684, Meenavilakku-Meenakshipuram Road, Anaikaraipatty Post, Bodinayakanur Taluk, Theni Dt, Tamil Nadu, India
[2]Veterinary Hospital, Vadakupudhu Palayam, Erode Dt, Tamil Nadu, India
[3]Assistant Professor, Department of Botany, The Standard Fireworks Rajaratnam College for Women, Sivakasi, Virudhunagar (Dt), Tamil Nadu, India

Abstract Mid-IR has potential use in every field but existing technologies are limited and do not have applications in day-to-day life. Available mid-IR sources are also lagging behind due to complexity and high cost. To overcome these hindrances, we pioneer the design and development of Mid-IR Generating Atomizer, named MIRGA. MIRGA contains an inorganic chemical formulation suspended in aqueous media. When MIRGA is sprayed at an average pressure of 3900 K Pascal, ions in the sprayed mist oscillate and generate 2–6 µm mid-infrared ray. The 2–6 µm mid-infrared penetrates the intervening media and acts on the inside target material (usables) which would nonetheless a composition of atoms. As most of the earthly objects have their frequencies in mid-infrared region, this easy and economically generated 2-6 µm mid-IR altered the target's chemical bonds. Thereby the physico-chemical properties of the target are rendered favorable to our requirement. This study details the design, action and applicability of MIRGA. Further research and studies are under way to explore MIRGA's use in various other scientific disciplines. This MIRGA technology can save resources, economy and ecology.

Keywords MIRGA, 2–6 µm mid-infrared, Target, Irradiation, Chemical bonds, Physico-chemical properties, Desirable change, Economy, Easy-to-use

1. Introduction

Atom is the basic element of everything in this universe, so manipulating an object at atomic level will be an effective way to resolve and restore a desirable entity. But this certainly is not an easy task. However electromagnetic waves having various properties at varying range could be a key to every atomic particle. Electromagnetic waves are a form of energy transfer through a medium, produced by current and charge distributions that vary with time **(Toru *et al*., 1989)**. They involve a continuous net transfer of energy and can be generated by various means such as electromagnetic wave devices **(Causebrook, 1993)**, plan waves **(Lev *et al*., 1975)**, and metal grating systems **(Yang *et al*., 2015)**. Electromagnetic waves have different characteristics and behaviors depending on factors such as frequency, polarization, and propagation velocity. They can be used for various applications including amplification, modulation, frequency conversion, and terahertz wave generation **(Weihao *et al*., 2018)**.

It is well-known that most of the objects in our day-to-day life have their foot print in infrared region. The spectral region of infrared (IR) is known to yield highly significant molecular data as a result of the stimulation of molecular vibrational and rotational changes **(Adam, 2024)**. Broadly speaking, the mid-infrared range is established as the realm of electromagnetic (EM) waves that possess a wavelength spanning approximately from 2 to 20 µm. Mid-infrared (MIR) light has various applications in sensing, security and defense, energy conservation, and communications.

The development of MIR sources has been a focus of research in recent years. Different approaches have been explored, including the use of mid-IR fiber-based supercontinuum sources **(Arnaud *et al*., 2022)**, passive mid-infrared spectroscopy **(Yusuke *et al*., 2022)**, MIR ultrafast laser generation via difference frequency generation **(Xin *et al*., 2022)**, and semiconductor lasers operating in the MIR range **(Stephen *et al*., 2020)**. These technologies aim to cover the entire MIR region, from short-wavelengths around 2 µm to long-wavelengths up to 20 µm. The advancements in MIR laser technologies have enabled precise measurements

* Corresponding author:
rkbuma@gmail.com (Umakanthan T.)
Received: Jan. 6, 2024; Accepted: Jan. 20, 2024; Published: Jan. 23, 2024
Published online at http://journal.sapub.org/ijea

and analysis of various molecules and their spectral characteristics in this wavelength range **(Amanda *et al.*, 2021)**.

Developments in MIR light sources have increased interest in developing MIR optical systems, sensors, and diagnostics for chem/bio detection and molecular analysis. MIR lasers, such as quantum and interband cascade lasers (QCLs, ICLs), are driving this interest **(Henry et al., 2022)**. Additionally thermal emitters and light emitting diodes (LEDs) are being explored as non-laser MIR light sources to fill gaps in spectral coverage for analytical applications and chem/bio sensing. These non-laser sources offer opportunities for MIR wavelength range analysis and diagnostics **(Loic et al., 2022)**. Overall, MIR has proven to be a valuable tool in various scientific and technological applications.

Key to both the fundamental and applied aspects of MIR technology, we invented Mid-IR Generating Atomizer, abbreviated as MIRGA, which emits 2–6 µm wavelength range. In this manuscript, we examine the recently developed MIR source MIRGA. Moreover, we provide a comprehensive overview of the actions of mid-IR on atomic and molecular levels, resulting in alterations in the chemical bonds of target materials. It should be noted that this investigation primarily focuses on the MIRGA, however, it is essential to concisely summarize, compare, and understand the advantages of MIRGA in various everyday applications in order to highlight its significance in diverse interdisciplinary fields.

2. Material and Method

Generation and estimation of Mid-IR

We formulated a chemical compound containing inorganic salts suspended in aqueous media to form an imbalanced ionic solution. This solution has approximately two sextillion cations and three sextillion anions and is contained in a 20 ml pocket sized atomizer called Mid-IR Generating Atomizer (MIRGA) *(granted patent no.: 401387)*. For an ionic solution to generate electromagnetic waves, more specifically in mid-IR range, it has to be energized optimally. After hundreds of trial and error experiments, we designed an atomizer *(Figure 1)* made of polypropylene plastic, 20ml capacity, size 86 x 55 x 11 mm, external orifice diameter 0.375 mm, ejection volume 0.062 ±0.005 ml at an average ejection pressure 3900 K pascal, cone liquid back pressure of 2000 N/m^2 and ejection time 0.20 second, per spraying. Approximately 1 microgram of water (as mist) was found to be lost from the ejected material immediately upon spraying and non-volatile material in the sprayed solution estimated to be 153 mg/ml. Every time spraying (0.062 ± 0.005ml) emits approximately seven quintillion cations and eleven quintillion anions.

The emissions from the atomizer during spraying was subjected to FTIR (retro-reflector) interferometer instrument (Detector type D* [cm HZ1/2 - 1] MCT [2-TE cooled] at Lightwind, Petaluma, California) and the spectra captured.

3. Results

During spraying the ionic solution moves through the atomizer and the resultant electromagnetic energy generated was estimated to be in 2–6 µm wavelength *(Figure 2)*, i.e. mid-infrared (mid-IR). In other terms, the energy has frequency 150–50 MHz and energy 0.62–0.2 eV. (Raw data files for estimation of 2-6 µm mid-IR generated from MIRGA while spraying available in: https://drive.google.com /open?id=1-ymE_xPAFixMNYR3gikdyVSdkTLeEkSU).

The inorganic compounds used in the generation of MIR are a perspective for biomedical applications **(Tishkevich *et al.*, 2019; Dukenbayev *et al.*, 2019)**. It is also a new synthesis method for preparation of functional material (2-6 µm mid-IR) **(Kozlovskiy *et al.*, 2021; El-Shater *et al.*, 2022)**. It is well known that the combination of different compounds, which have excellent electronic properties, leads to new composite materials which have earned great technological interest in recent years **(Kozlovskiy and Zdorovets, *2021;* Almessiere *et al.*, 2022)**.

Method of spraying

MIRGA spraying is applied from 0.25 to 0.50 meter distance externally over the targets. This distance is essential for the MIRGA sprayed solution to be able to form ion clouds, oscillation, and 2-6 µm mid-IR generation. The mid-IR penetrates the intervening media and acts on the inside contents. Close spraying does not generate energy.

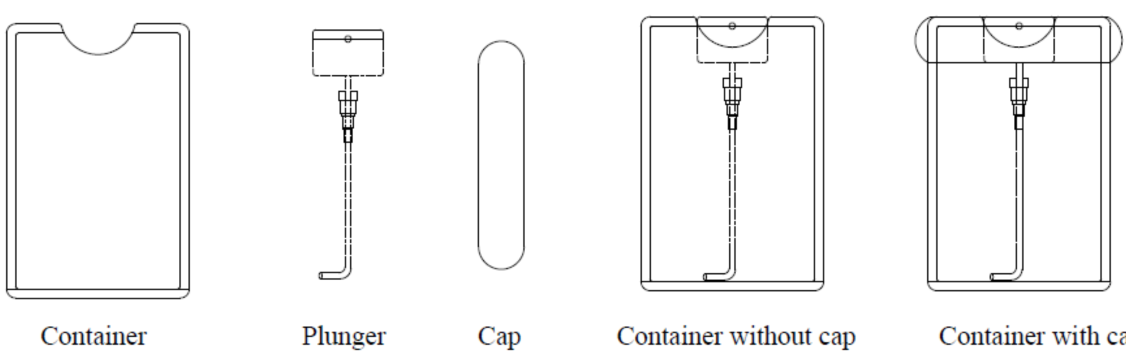

Figure 1. MIRGA spray

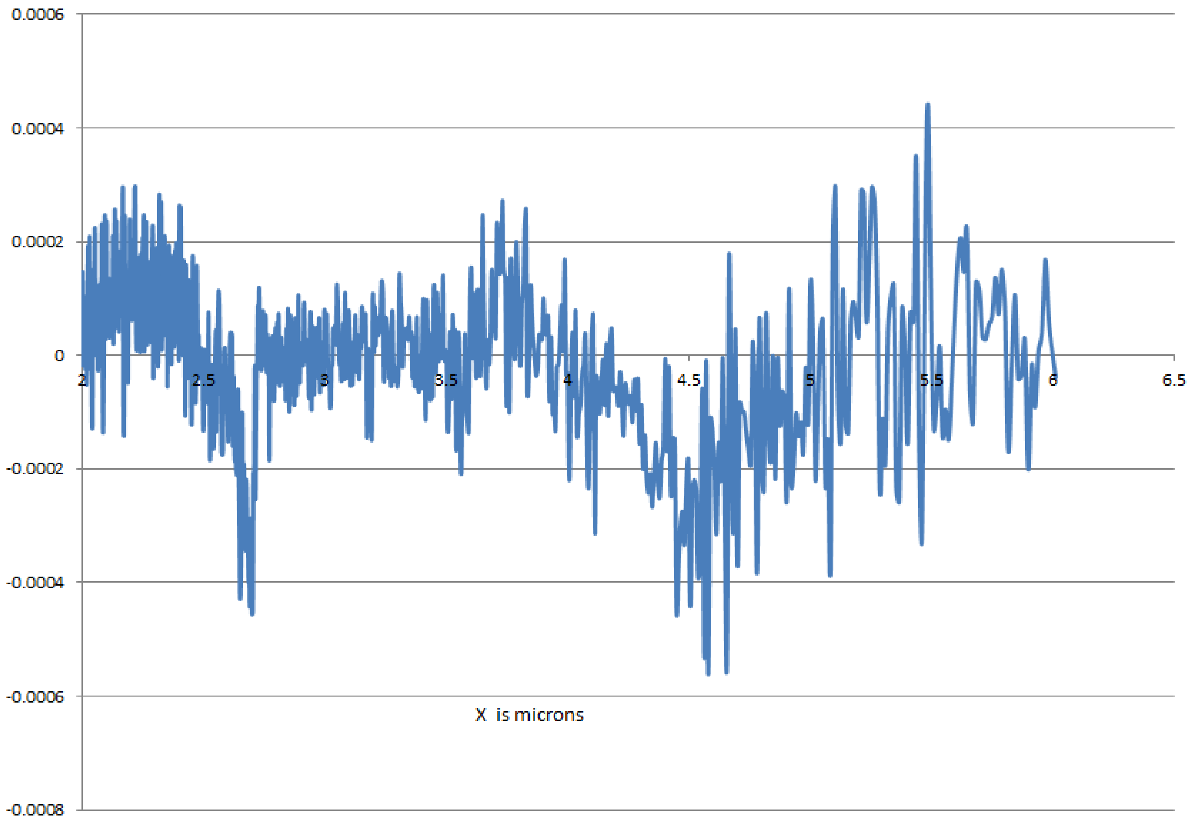

Figure 2. Estimation of 2–6 µm mid-infrared while spraying the atomizer (MIRGA)

4. Discussion

Invention background: The four observable states of matter (solid, liquid, gas, plasma) are composed of intermolecular and intramolecular bonds. The inherent characteristics of neutrons, protons and electrons are unique, however, difference in their numbers is what constitutes different atoms, and how these atoms bind together develop into different molecules with unique characters. At the end of a cataclysm event the remnants will be atoms which will be the only base and the source of the subsequent physical creation. Atoms have specific and stable frequencies and are constituents of the material that surrounds us in our everyday life.

The electromagnetic wave plays a vital role in the creation, maintenance, and annihilation of the living as well as the non-living substances. In the electromagnetic wave (EMW) spectrum, mid-IR region is vital and interesting for many applications since that region coincides with the internal vibration of most molecules **(CORDIS, European commission).** At an atomic level the mid-IR radiation excites the rotational and vibrational modes in a molecule by changing the dipole movement leading to chemical bond alteration **(Girard, 2014)**, such as the expansion and contraction causing the concurrent physiochemical characteristic changes, but retaining the same chemical formula. Naturally,\ chemical bond parameters influence the decay, rejuvenation, and potentiation of particles **(Alvarez et al, 2012; Smith, 1999; Shankar, 2017; Mohan, 2004; McMakin, 2011; Moss, 2011; Raven, 2012)**. Further we studied (a) that although atoms retain their atomic structure, their chemical bond parameters are always prone to alteration by cosmic and physical energies (electromagnetic wave, heat, pressure, etc). Such alterations cause the chemical bonds to compress, stretch, or break, leading to a new bond formation, which ultimately lead to the basic form's (any particle) natural characters' enhancement/ reduction/ formation of new product/ daughter form, so... on... and endless. (b) The dynamic, constant, and mutual influences in the living and non-living substance on earth. Therefore based on these concepts, MIRGA has been developed to alter the bond parameters and thereby to improve the useful natural characteristics.

MIRGA definition

We define MIRGA as 'a harmless, economical atomizer containing an imbalanced ratio of ions suspended in water, which influences the natural characteristics of target substances that are made up of atoms by generating 2-6 micron mid-IR while spraying'.

Technique of 2-6 micron mid-IR generation from MIRGA

MIRGA contains an imbalanced ratio of ions suspended in water in their fundamental state and can move as free particles. The solution has very little background frequency of detectable disintegration which is less than that of cosmic events. Even the human body is more radioactive (around 10 microns) **(Ashcroft, 2000; Sanders, 2014)**. MIRGA generates energy as, (a) spraying leads to ionization (electron getting separated from atom) and the number of pathways for electron re-absorption is high, due to the energy generated by these two oscillatory processes. (b) When spraying, the water-based ionic solution gets excited and charged, which in turn leads to oscillations of the imbalanced ions **(Verheest, 2000)** between their excited states resulting in photon emission **(Keping et al, 2004; Fauchais et al., 2014)**. **(C)** Though low electromagnetic field exist in (between charged particles of MIRGA) the ionic solution, during the spraying, induced oscillations between these charged particles produce energy **(Wendish et al., 2009; Prasad, 2017; Pople, 1999)**. **(D)** In the natural rainfall process, more energy is required to break water bonds for creating smaller water droplets from the clouds **(Barry et al, 1998)**. These droplets should have more stored energy, and also travel down at a velocity from a specific distance (kinetic energy). Rain hits the earth's surface and forms a very thin film of mid-IR (nearly 6 micron) so it is in fact believed that there is a net heat gain **(Barry et al, 1998; Eniday, 2019)**. We have simulated this process in MIRGA i.e., when imbalanced ions in the liquid media are atomized the smaller droplets that are ejected should have higher internal and kinetic energies. The energy is emitted when the surface tension is broken. Following a trial and error approach, we calibrated the ejection pressure for a desired fine mist, and minimized the evaporation rate by altering the pH, density. Furthermore, we have applied these phenomena in the MIRGA atomizer technology in order for the 2-6 µm mid IR radiation to be emitted.

Action of MIRGA emitted 2-6µm mid IR

It is further notable that, mid-infrared pulses are shown to alter chemical bonds, as described in several studies. **Lars et al., 2002,** used femtosecond laser pulses to achieve high ground-state vibrational excitation and bond scission in transition metal carbonyls. **Yeran et al., 2017**, extended the spectral range of mid-infrared photothermal microscopy using difference frequency generation, allowing bond-selective chemical imaging. **Claudio et al., 2020** reported on the promising approach of infrared vibrational excitation for gaining control of chemical reactions. These studies demonstrate the potential of mid-infrared radiation in altering the chemical bonds and controlling chemical reactions.

When samples are exposed to MIR radiation, the rotational and vibrational resonances of molecules are commonly stimulated, regardless of their molecular weight, complexity, dimensions, physical states (such as gas, liquid, semi-solid, or solid), or nature (whether organic or inorganic). As a result, the MIR spectrum of a given sample is frequently referred to as its molecular fingerprint, as it allows for the identification and quantification of a wide range of important molecular compounds in various applications such as environmental analysis, healthcare and medicine, industrial processes, as well as security and defense. **(Pandey et al., 2015; Lorenzo et al., 2017; Ortiz et al., 2018)**

In food science, majority of infrared applications are observed in the mid-infrared region of electromagnetic spectrum. Infrared is gaining popularity in the recent years because of the thermal efficiency when compared to traditional technologies. It transfers energy in the form of electromagnetic waves and thus less time for heat transfer is required **(Yu et al., 2017)**. According to **Lu et al. (2011)**, the mid-IR spectra can be categorized into four main regions. The first region (3000-2800 cm−1) is associated with aliphatic C—H stretching modes, which are commonly found in food components such as proteins and carbohydrates. The second region (1800-1500 cm−1) contains the C═O stretching band of lipids at approximately 1740 cm−1, as well as the amide I and II bands of proteins and peptides at around 1650 and 1550 cm−1, respectively. The amide bands provide valuable structural information about proteins, including α-helix, β-sheet, and random coil conformations. Many cellular components, such as nucleic acids and phospholipids, exhibit absorption bands in the third region (1500-1200 cm−1). Finally, the fourth region (1200-900 cm−1) provides insights into the structure of polysaccharides.

In line with the literatures, when spraying the MIRGA, most of the generated mid-IR radiation scatters through air and is absorbed by target (usable) molecules. Nearly all organic compounds absorb mid-IR radiation exciting the chemical bonds from the ground state to higher states resulting in a dipole moment **(Girard, 2014)** which leads to the bonds contracting, stretching and bending **(Shankar, 2017; Mohan, 2004)** and these bond parameter changes led to consequent changes in target's physical and chemical characters depending on the dose of energy applied **(Yi, 2012; Esmaeili, 2015)**. Such changes in the bond parameters lead to subsequent changes in the physical and chemical characteristics of the target **(Atkins et al, 2011; Datta et al., 2014)**. Thus depending on number of MIRGA spraying (energy given), a receptor's chemical bond configurations and subsequent physical and chemical characters were altered to our desire *(Figure 3)*. Our daily usables can be potentiated and made more favorable which will have less quantity of requirement for use, thereby natural resource, economy, eco and health savings.

Similar studies on several chemical, pharmaceutical, and consumer products and materials are currently done using MIGRA. In edible products MIRGA seems to alter the bond parameters in the agrochemical residuals of the coherent agricultural and food processing chemical residues. Thus reducing the toxic effects leads to enhanced desirable sensory characteristics in the agroproducts and makes them safer to consume (under publication).

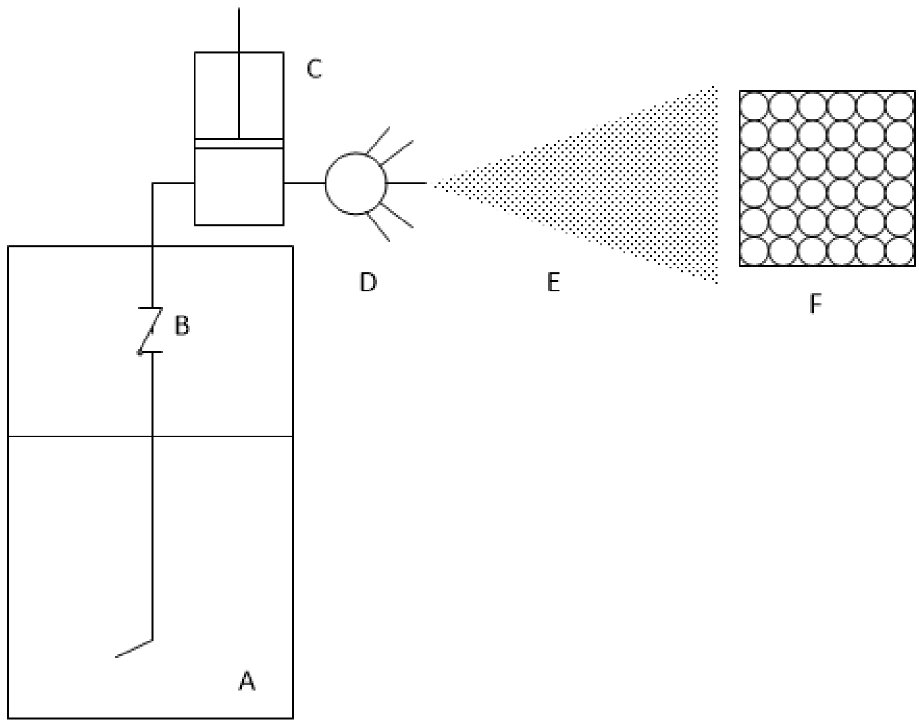

Figure 3. Schematic diagram of MIRGA's action during spraying (A) Spraying solution tank; (B) Valve; (C) Pressure Pump; (D) Nozzle; (E) Ions in the solution spray mist oscillate and generate 2–6 µm mid-infrared; (F) incidence of 2–6 µm mid-infrared on the target material and action at atomic/molecular/ chemical bond level

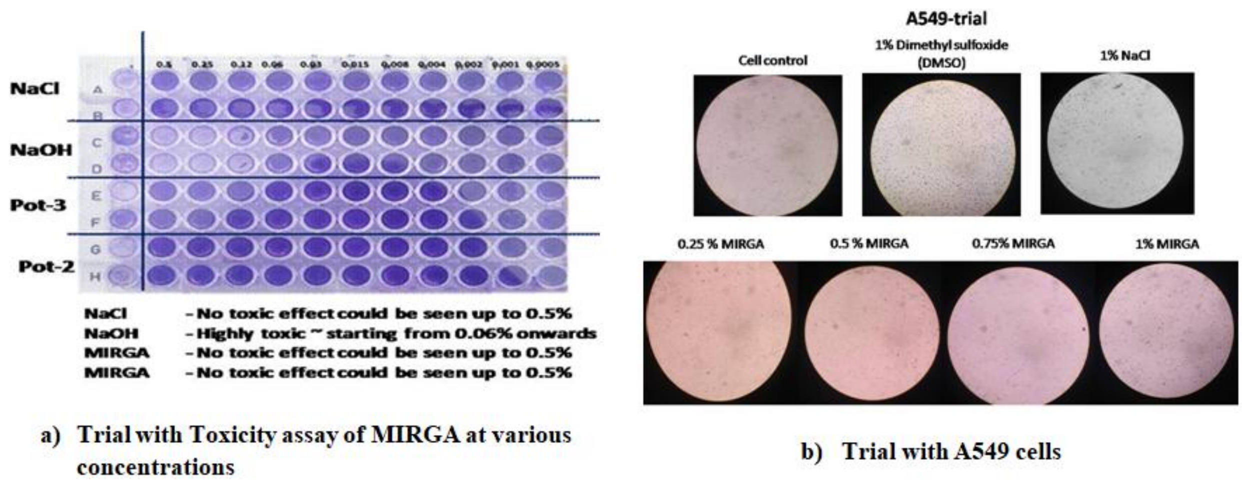

Figure 4. MIRGA's toxicological studies

Recent achievements using MIRGA

MIRGA has proven to altered the chemical bonds and thereby enhanced the sensory attributes of coffee, tea, cocoa and edible salts **Umakanthan *et al*., 2022a; Umakanthan *et al*., 2022b; Umakanthan *et al*., 2023c**. Also in cocoa it was found to have reduced the alkaloid and heavy metals concentration **(Umakanthan *et al*., 2022b)**. In siddha medicine system the efficacy of terminalia has been potentiated using MIRGA **(Umakanthan *et al*., 2023d)**. In rubber, MIRGA as an additive has enhanced the cross-linkage **(Umakanthan *et al*., 2023e)**. In cocoa and furnace oil their calorific value improved **(Umakanthan *et al*., 2023f)**, thus rendering the usables desirable for various defined purposes.

Toxicological study on MIRGA

Even though, MIRGA generates safe 2-6 micron mid-IR energy, and moreover spraying is done 0.25–0.5 metre externally right away to packaged consumables, we also wanted to study the MIRGA's toxicity effect by cytotoxicity assay. *In-vitro* Vero, A549 and Human dermal fibrobalst cells study proved that MIRGA sprayed mist was non-toxic in any way. *(Figure 4)*

Field studies also showed that, MIRGA spray is eco-friendly, non-toxic, non-irritant to soft tissues such as cornea, safe to infants even if sprayed directly, needs no skill but easy to handle (like body spray) and highly economical. One MIRGA sprayer unit would give 300 sprayings and costs 0.30 USD only.

Safety of MIRGA sprayed usables

In our nearly two decades of research, the bonds altered by MIRGA did not show any adverse effects on the product. To draw a comparison from nature (a) The sweetness varies greatly with stereo chemical configurations in glucose **(Williamson et al., 2011)**, (b) The enzymes in the human digestive system as well as cooking break the bonds and soften the grains **(Scanlon et al., 2019; Kowtaluk, 2006)** e.g. rice to boiled rice, puffed rice, flat rice, and rice flour etc. (c) In the food industry, irradiation processes such as radappertization, radicidation, and raduriaztion alter the chemical bonds, **(Sivasankar, 2014)**, (d) In the heating process, the conversion of ice to water and then to steam is due to the bond alterations with the steam having negligible number of hydrogen bonds **(Trevor Day, 1999)**. However the chemical composition remains unchanged **(Raymond, 2010)**.

Based on our research we believe that in the past half-century, the use of agrochemical products, preservatives, additives etc. might have caused gradual alternation in the chemical bonds. This might have enhanced or reduced the original taste, aroma and other qualities of our foods. MIRGA enhances or brings back the original taste, aroma and other qualities, which might be due to the reorientation of the previously altered chemical bonds (now time elapsed for scientific proving). In summary MIRGA alters the texture, odour, taste, shelf life, and other natural and inherent characteristics of materials depending on the degree of the chemical bond alteration. This itself depends on the applied amount of energy (number of MIRGA sprayings).

Comparison with existing mid-infrared sources

MIR laser crystals have been used for mid-IR laser radiations and have found applications in spectroscopy, trace gas detection, remote sensing, optical microscopy, and biomedicine **(Xiaoming et al., 2022)**. Mid-infrared fiber lasers have shown great potential in material processing, biomedicine, remote sensing, and infrared countermeasures due to their high-power and diffraction-limited beam quality **(Frederic et al., 2022)**. Non-laser light sources, such as thermal emitters and light emitting diodes (LEDs), offer opportunities for analytical applications and chem/bio sensing/diagnostics in the MIR wavelength range **(Michael et al., 2022)**. Additionally research on mid-infrared plasmonics has focused on developing new plasmonic materials for constructing breakthrough mid-infrared sensors **(Michael et al., 2022)**.

MIRGA's primeval and future scope

This water based MIRGA could be the first novel pioneer technology. This type of atomizer technology also seems to be present with the extra-terrestrials for their therapeutic use during visitations **(Blue planet project)**.

Because of MIRGA's wide range of applications, we believe that MIRGA will definitely resonate in many scientific researches such as biophotonics, therapeutics, health, ecology and many other fields. Our further research on MIRGA and its other manifestations which we developed namely MIRGA salt, MIRGA vapor and MIRGA plasma in human endeavors is dynamically now ongoing.

In various samples a range of 30% to 173% enhancement is achieved. Even the 30% achievement in some samples has resulted in 30% savings in economy, resources, and ecology in addition to its health benefits. But there is a knowledge gap between the enhancement from 30% to at least 100% for all samples which can be filled by refining MIRGA's ionic solution or formulating a better solution, concentrations and atomizer pressure/ other parameters.

Past and Future interests

Our field and laboratory studies showed that, the MIRGA's chemical formulation, action and outcomes were remarkably similar to that of 'The Superior Medicine' of various ancient medicinal systems viz. 'Muppu' (Tamil siddha), 'al-kimiya' (Arabic), 'Rasayana' (Indian Ayurveda), 'Rasavatan' (Persian), Materia prima, philosopher's stone, tincture (Europe) and Taoist alchemy, hudan, Jindan (Chinese).

Since all matter react and respond uniquely to electromagnetic energy, studies are ongoing to enhance the potency of daily usables like food, medicine, fuels, etc. Owed to its wide range of applications, we believe MIRGA is likely to play a vital role in many scientific areas such as the biophotonics, health science, ecology and many other fields.

5. Conclusions

The current investigation examines the invention, function, and applications of Mid-IR Generating Atomizer. MIRGA produces non-hazardous emissions in the range of 2-6 µm wavelength with the potential for cost-effectiveness and decreased complexity requirements during operation. MIRGA has made a significant progress in the development of compact, safe and easy-to-use mid-IR source.

Competing Interest

In accordance with the journal's policy and our ethical obligation as researchers, we submit that the authors Dr. Umakanthan and Dr. Madhu Mathi are the inventors and patentee of Indian patent for MIRGA *(granted-patent no.: 401387)* which is a major material employed in this study.

Data and Materials Availability

All data is available in the manuscript and supplementary materials.

Funding

The authors received no specific funding for this research.

REFERENCES

[1] Toru H, Iida T, Yoshihiko M, Nakajima K, Sugimoto K, Yoshihisa W, 1989. Electromagnetic wave device.

[2] Causebrook J H, 1993. 6 – Electromagnetic waves. doi: 10.1016/B978-0-7506-1162-6.50012-5.

[3] Lev D, Landau E M, Lifshitz, 1975. Chapter 6 – electromagnetic waves. doi: 10.1016/B978-0-08-025072-4.50013-7.

[4] Yang G, Wan C, Lu J, Wang L, Chen G, Wang Y, Hu Y, Liu G, Zhu F, Pang P, Tang Y, Nie Y, Pu R, Wu, Y, He G, Lin Z, 2015. Electromagnetic wave transmitter.

[5] Weihao L, Linbo L, Lu L, Wang L, Jia Q, 2018. Electromagnetic wave radiation system and method.

[6] Adam B, 2024. Introduction to Structure Determination - Infrared: Fingerprint Region, School of Chemistry, The University of Sydney.

[7] Arnaud L, Remi B, Frederic D, Gregory G, Gadret, Jean-Charles J, Pierre M, Bertrand K, Frederic S, 2022. 2-18 μm mid-infrared supercontinuum generation in a step-index chalcogenide fiber. doi: 10.1117/12.2621019.

[8] Yusuke V, Morimoto S, Tahara S, Yamashita, Daichi A, Tomoya K, Hiroko T, Shimizu, Akira N, Kenji W, Ichirou I, 2022. Mid-infrared (longwave infrared) passive spectroscopic imaging with an uncooled microbolometer array sensor. doi: 10.1117/12.2635375.

[9] Xin S, Ruixue S, Bo W, Yu B, Tao D, Tianran S, Xiang L, Jiying P, Yi Z, 2022. Generation of 8–20 μm Mid-Infrared Ultrashort Femtosecond Laser Pulses via Difference Frequency Generation. Photonics, doi: 10.3390/photonics9060372.

[10] Stephen J, Sweeney T D, Eales, Igor P, Marko, 2020. The physics of mid-infrared semiconductor materials and heterostructures. doi: 10.1016/B978-0-08-102709-7.00001-2.

[11] Amanda S, Makowiecki, Daniel I, Herman, Nazanin H, Elizabeth F, Strong, Ryan K, Cole, Gabe Y, Fabrizio R, Giorgetta, Caelan L, Jeffrey F, Glusman, John W, Daily, Peter E, Hamlington, Nathan R, Newbury, Ian C, Gregory B, Rieker, 2021. Mid-infrared dual frequency comb spectroscopy for combustion analysis from 2.8 to 5 µm. doi: 10.1016/J.PROCI.2020.06.195.

[12] Henry, C., Kapteyn., Margaret, M., Murnane. (2022). Ultrafast Mid-IR Lasers for Soft X-ray High-Harmonic Generation and Applications. doi: 10.1364/cleo_at.2022.jm2e.4.

[13] Loïc, B., Marion, Baillieul., Virginie, Nazabal., Jonathan, Lemaitre., Albane, Benardais., S., Meziani., Nathalie, Lorrain., Yannick, Dumeige., Petr, Němec., Joël, Charrier. (2022). Mid-IR emission from integrated rare earth (Dy3+, Pr3+)-doped chalcogenides waveguides for sensing applications. doi: 10.1117/12.2621815.

[14] Tishkevich D I, Korolkov I V, Kozlovskiy A L, Anisovich M, Vinnik D A, Ermekova A E, Vorobjova A I, Shumskaya E E, Zubar T I, Trukhanov S V, Zdorovets M V, Trukhanov A V, 2019. Immobilization of boron-rich compound on Fe_3O_4 nanoparticles: Stability and cytotoxicity, J. Alloys Compd. 797, 573-581. https://doi.org/10.1016/j.jallcom.2019.05.075.

[15] Dukenbayev K, Korolkov I V, Tishkevich D I, Kozlovskiy A L, Trukhanov S V, Gorin Y G, Shumskaya E , Kaniukov E Y, Vinnik D A, Zdorovets M V, Anisovich M, Trukhanov A V, Tosi D, Molardi C, 2019. Fe_3O_4 nanoparticles for complex targeted delivery and boron neutron capture therapy, Nanomaterials, 494. https://doi.org/10.3390/nano9040494.

[16] Kozlovskiy A L, Alina A, Zdorovets M V, 2021. Study of the effect of ion irradiation on increasing the photocatalytic activity of WO_3 microparticles, J. Mater. Sci.: Mater. Electron. 32, 3863-3877. https://doi.org/10.1007/s10854-020-05130-8.

[17] El-Shater R E, Shimy H E, Saafan S A, Darwish M A, Zhou D, Trukhanov A V, Trukhanov S V, Fakhry F, 2022. Synthesis, characterization, and magnetic properties of Mn nanoferrites, J. Alloys Compd. 928, 166954. https://doi.org/10.1016/j.jallcom.2022.166954.

[18] Kozlovskiy A L, Zdorovets M V, 2021. Effect of doping of $Ce^{4+/3+}$ on optical, strength and shielding properties of $(0.5-x)TeO_2-0.25MoO-0.25Bi_2O_3-xCeO_2$ glasses, Mater. Chem. Phys. 263, 124444. https://doi.org/10.1016/j.matchemphys.2021.124444.

[19] Almessiere M A, Algarou N A, Slimani Y, Sadaqat A, Baykal A, Manikandan A, Trukhanov S V, Trukhanov A V, Ercan I, 2022. Investigation of exchange coupling and microwave properties of hard/soft $(SrNi_{0.02}Zr_{0.01}Fe_{11.96}O_{19})/(CoFe_2O_4)_x$ nanocomposites, Mat. Today Nano, 100186. https://doi.org/10.1016/j.mtnano.2022.100186.

[20] CORDIS, European commission. New advances in mid-infrared laser technology, Compact, high-energy, and wavelength-diverse coherent mid-infrared source. Available at: https://cordis.europa.eu/project/rcn/99977/brief/en (last accessed on 27.01.2019).

[21] Girard J E, 2014. Principles of Environmental Chemistry, 3rd edition, Jones & Bartlett Learning, USA, p99.

[22] Alvarez A, Prieto M, 2012. Fourier Transform Infrared spectroscopy in Food Microbiology, Springer Science & Business Media, p3.

[23] Smith B C, 1999 Infrared Spectral Interpretation: A Systematic Approach, CRC Press, LLC, 7.

[24] Shankar D R, 2017. Remote Sensing of Soils. Germany: Springer-Verlag GmbH, p268.

[25] Mohan J, 2004. Organic Spectroscopy: Principles and Applications, 2nd edition, Alpha science international Ltd., Harrow, UK, 19. Available at: https://books.google.co.in/books?id=fA08Uy5DR0QC&printsec=frontcover&dq=Jag+Mohan.+Organic+Spectroscopy:+Principles+and+Applications&hl=en&sa=X&ved=0ahUKEwjHpcHUi9fgAhXXFIgKHXvRCpIQ6AEIKjAA#v=onepage&q=Jag%20Mohan.%20Organic%20Spectroscopy%3A%20Principles%20and%20Applications&f=false.

[26] McMakin C, 2011. Frequency specific Microcurrent in pain management E-book, Elsevier, China, p 30.

[27] Moss D, 2011. Biomedical Applications of Synchrotron Infrared Microspectroscopy: A Practical Approach, Royal Society of Chemistry, UK, p 58.

[28] Raven P H, Berg L R, Hassenzahl D M, 2012. Environment, John Wiley & Sons, Inc., USA, p45. Available at: https://books.google.co.in/books?id=QVpO2R51JBIC&pg=RA1-PA45&dq=electromagnetic+waves+make+form+new+bonds&hl=en&sa=X&ved=0ahUKEwiTnO2amMbjAhUJ3o8KHSfkAJEQ6AEIMjAB#v=onepage&q=electromagnetic%20waves%20make%20form%20new%20bonds&f=false.

[29] Ashcroft F, 2000. Life at the Extremes: The Science of Survival, University of California Press, California, p122.

[30] Sanders R H, 2014. Revealing the Heart of the Galaxy, Cambridge University Press, USA, p70.

[31] Verheest F. Waves in Dusty Space Plasmas, Kluwer Academic Publishers, Netherlands, 89, (2000).

[32] Keping S, Yu G, 2004. Recent developments in Applied Electrostatics (ICAES2004): Proceedings of the Fifth International Conference on Applied Electrostatics, Elsevier Ltd., UK, p87.

[33] Fauchais P, Heberlein J V R, Boulos J I, 2014. Thermal Spray Fundamentals From Powder to Part. Springer Science & Business Media, New York, 84.

[34] Wendish M, Brenguier J L, 2019. Airborne Measurements for environmental Research: Methods and Instruments, Wiley-VCH. Available at: https://books.google.co.uk/books?id=tHdwhn-c5mgC&pg=PT419&dq=A+regularly+oscillating+charge+produces+a+harmonic+electromagnetic+waves+Manfred&hl=en&sa=X&ved=0ahUKEwjBqdv75tvgAhWpSxUIHbQ_D0gQ6AEIKjAA#v=onepage&q=A%20regularly%20oscillating%20charge%20produces%20a%20harmonic%20electromagnetic%20waves%20Manfred&f=false (last accessed on 27.02.2019).

[35] Prasad M, 2017. Soul, God and Buddha in Language of Science, Notion Press, Chennai.

[36] Pople S, 1999. Complete Physics, Oxford University Press, Oxford, p166.

[37] Barry R, Chorley R, 1998. Atmosphere, Weather and Climate, 7th edition, Routledge, London, p51.

[38] Eniday: https://www.eniday.com/en/sparks_en/harnessing-the-energy-of-rain/ (last accessed on 06.02.2019).

[39] Lars, W., Thomas, Witte., Jake, S., Yeston., Detlev, Proch., Marcus, Motzkus., Karl-Ludwig, Kompa., Werner, Fuß. (2002). Breaking bonds with mid IR pulses: Femtosecond photolysis of gas-phase metal carbonyls. doi: 10.1364/UP.2002.ME29.

[40] Yeran, B., Delong, Zhang., Chen, Li., Cheng, Liu., Ji-Xin, Cheng. (2017). Bond-Selective Imaging of Cells by Mid-Infrared Photothermal Microscopy in High Wavenumber Region.. Journal of Physical Chemistry B, doi: 10.1021/ACS.JPCB.7B09570.

[41] Cláudio, M., Nunes., Nelson, A., M., Pereira., Igor, Reva., Patrícia, S, M, Amado., Maria, Lurdes, Santos, Cristiano., Rui, Fausto. (2020). Bond-Breaking/Bond-Forming Reactions by Vibrational Excitation: Infrared-Induced Bidirectional Tautomerization of Matrix-Isolated Thiotropolone.. Journal of Physical Chemistry Letters, doi: 10.1021/ACS.JPCLETT.0C02272.

[42] R. Pandey, N.C. Dingari, N. Spegazzini, R.R. Dasari, G.L. Horowitz, I. Barman, TrAC, Trends Anal. Chem. 64, 100 (2015).

[43] A. Ortiz, B. Bierer, L. Scholz, J. Wöllenstein, S. Palzer, Sensors 18, 4345 (2018).

[44] Yu, R., Manjavacas, A., de Abajo, F.J.G., 2017. Ultrafast radiative heat transfer. Nature communications 8, 1-13.

[45] Lu, X., Al-Qadiri, H.M., Lin, M., Rasco, B.A., 2011. Application of mid-infrared and Raman spectroscopy to the study of bacteria. Food and Bioprocess Technology 4, 919-935.

[46] S.G. Lorenzo, C. You, C.H. Granier, G. Veronis, J.P. Dowling, AIP Adv. 7, 125112 (2017).

[47] Yi G, 2012. Semiconductor Nanostructures for Optoelectronic Devices: Processing, Characterization and Applications. Berlin, Heidelberg: Springer-Verlag, p198.

[48] Esmaeili K, 2015. Viremedy, Homeopathic Remedies, and Energy Healing Remedies as Information – including Remedies; A Synopsis [Revision Aug 2015; E-pub.: Aug.2015] (First Pub: 2013). Google books, p43.

[49] Atkins P, Paula J, 2011. Physical Chemistry for the Life Sciences, Oxford university press, Oxford, p365.

[50] Datta S N, O'Trindle C, Illas F, 2014. Theoretical and Computational Aspects of Magnetic Organic Molecules. Imperial College Press, London, p224.

[51] Umakanthan, Mathi M, 2022a. Decaffeination and improvement of taste, flavor and health safety of coffee and tea using mid-infrared wavelength rays. Heliyon, e11338, Vol 8(11). doi: 10.1016/j.heliyon.2022.e11338.

[52] Umakanthan T, Mathi M, 2022b. Quantitative reduction of heavy metals and caffeine in cocoa using mid-infrared spectrum irradiation. Journal of the Indian Chemical Society, Vol 100 (1). doi: 10.1016/j.jics.2022.100861.

[53] Umakanthan, T., & Mathi, M. (2023c). Increasing saltiness of salts (NaCl) using mid-infrared radiation to reduce the health hazards. Food Science & Nutrition, 11, 3535– 3549. https://doi.org/10.1002/fsn3.3342.

[54] Umakanthan, Madhu Mathi, 2023d. Potentiation of Siddha medicine using Muppu (Universal Potentiator). International Journal of Pharmaceutical Research and Applications Volume 8, Issue 4 July-Aug 2023, pp: 2070-2084.

[55] Umakanthan T, Madhu Mathi, Umadevi, 2023e. Cross Linkage Potentiation of Nitrile Rubber by using a recently developed additive. International journal of novel research and development, Vol 8 (12), e75-80.

[56] Umakanthan T, Madhu Mathi, Umadevi, 2024f. Calorific Value Enhancement In Coal And Furnace Oil Using Laser Additive. Journal of Emerging Trends and Novel Research, Vol 2 (1), a9-a30.

[57] Williamson K L, Masters K M, 2011. Macroscale and Microscale Organic Experiments, 6th edition, Brooks/ Cole C engage learning, CA, p720.

[58] Scanlan N, 2011. Complementary Medicine for Veterinary Technicians and Nurses, Wiley-Blackwell publishing, USA.

[59] Kowtaluk H, 2006. Food for today 9E, 9th edition. Tata McGraw-Hill Publishing Company Limited, NewDelhi, p456.

[60] Sivasankar B. Food Processing and preservation, PHI Learning Private Limited, Delhi, 246, (2014).

[61] Trevor Day, 1999. Ecosystems: Oceans. Routledge Taylor & Francis Group, London and New York, p44.

[62] Raymond K W, 2010. General Organic and Biological Chemistry, 3rd edition, John Wiley & Sons, Inc., USA, p176.

[63] Xiaoming D, Renqin D, Linjun L, Xiaotao Y, 2022. Advances in Middle Infrared Laser Crystals and Its Applications. Crystals 2022, 12, 643. doi: 10.3390/books978-3-0365-4776-3.

[64] Frederic, J., Pascal, Paradis., Yigit, Ozan, Aydin., Tommy, Boilard., Vincent, Fortin., Jean-Christophe, Gauthier., Maxime, Lemieux-Tanguay., Sébastien, Magnan-Saucier., Louis-Charles, Michaud., Sara, Mondor., Louis-Philippe, Pleau., Lauris, Talbot., Martin, Bernier., Réal, Vallée. (2022). Recent developments in lanthanide-doped mid-infrared fluoride fiber lasers [Invited].. Optics Express, doi: 10.1364/oe.450929.

[65] Michael, H., Boris, Mizaikoff. (2022). Advanced mid-infrared lightsources above and beyond lasers and their analytical utility. Analytical Sciences, doi: 10.1007/s44211-022-00133-3.

[66] Blue planet project: Alien Technical research–25, Westchester Camp, Office of the Central Research #3.CODE: ARAMISIII–ADR3-24SM, p80-81.