

APPLICATION OF ELECTROMAGNETIC ECHO EFFECT FOR CONTROL OF ATMOSPHERIC POLLUTION

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Abstract

The electromagnetic echo effect (EMEE) arises when a sample – whether a semiconductor, metal, or dielectric – is irradiated with an electromagnetic field. In response, the irradiated matter also begins to generate an alternating electrical signal whose frequency matches the modulation frequency of the incident radiation. An important feature of the effect is its high sensitivity to changes in the irradiated sample, particularly on its surface. This enables the development of control methods and sensors across a wide range of applications. One such application is the detection of atmospheric contaminants. The concept involves directing a fluid flow onto the sensor surface. If the gas flow changes due to the introduction of a new substance, this will lead to a change in the solid-fluid interface. We provide experimental evidence that such changes in the boundary surface lead to measurable changes in the EMEE signal. In this way, the presence of contaminants can be monitored.

Key words: sensor, detection, contamination, atmosphere

Introduction. Atmospheric pollution represents a global concern, characterized by the presence of deleterious particulate and gaseous pollutants in the

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troposphere [1]. This phenomenon arises from diverse emission sources, including industrial activity, natural processes, transportation, agricultural practices, and residential combustion [2]. Mitigation strategies involve the adoption of cleaner technologies and the promotion of sustainable practices [3]. Continuous monitoring of pollutant concentrations is critical for the timely assessment and management of this environmental challenge. However, current methodologies for detecting and reporting potentially hazardous airborne substances provide limited spatial coverage, necessitating the deployment of numerous systems to monitor extensive regions [4, 5]. Moreover, prediction models often extend coverage to areas lacking direct sensor presence by extrapolating data from installed sensors.

The results presented herein demonstrate the feasibility of a real-time atmospheric pollution monitoring system capable of detecting and quantifying elevated levels of specific atmospheric contaminants. A novel sensor based on the electromagnetic echo effect (EMEE), formerly known as the surface photo-charge effect (SPCE) was employed [6–8]. The fundamental mechanism of the effect is as follows: the interaction of any solid with a modulated electromagnetic field induces an electric, alternating potential difference with the same frequency as the frequency of the incident field [7, 9, 10]. The electrical signal is measured between the irradiated sample and the system’s common electrical ground, and the measurement is both contactless and rapid. A key characteristic of the effect is its significant dependence on the specific material properties of the irradiated sample. This feature presents numerous possibilities for rapid, non-contact analysis of solids, liquids, and gases [11–16]. Several mechanisms underlying the effect have been proposed and analyzed [17], although a comprehensive theoretical explanation has not yet been established. In contrast to other similar effects, the EMEE is characteristic of all solid materials, which makes it interesting from both scientific and practical perspectives.

This study aims to experimentally demonstrate the applicability of the EMEE for detection of atmospheric contaminants. A fluid stream is directed onto the sensor surface, and variations in gas flow, induced by the introduction of new chemical species, modify the solid-liquid interface. Previous research has shown that such boundary modifications result in measurable shifts in the amplitude of the EMEE signal. This enables the quantification of pollutant presence.

Materials and methods. The setup of the experimental system consists of several components. Manual pulverizers containing solutions of distilled water with various concentrations of contaminants are used to deliver the impurities to the EMEE sensor. The working surface of the sensor is irradiated by a laser module. The laser beam is modulated by a signal generator, which also sends the same reference signal to a lock-in nanovoltmeter that detects the signal after it has been amplified by a preamplifier.

The laser module is built using a standard RLDH650M-40-5 element, which supports beam modulation via a TTL signal at selectable frequencies up to 50 kHz.

Driven by the signal generator, the laser module produces a beam with a wavelength of $\lambda = 650$ nm and an intensity of $I = 20$ mW (after modulation). The beam is modulated at a frequency of 29 kHz with pulse-width modulation of 50%. The same modulation signal is supplied to the nanovoltmeter as a reference, enabling frequency-selective detection – an essential aspect of the measurement methodology. Since the detected EMEE signal typically exhibits very low amplitude, a lock-in nanovoltmeter is employed to extract it from background noise. The preamplifier boosts the sensor output feeding it to the lock-in nanovoltmeter.

The EMEE sensor uses a thin liquid layer over the interface. This layer consists of distilled water (DW). It generates a signal of very small amplitude, proportional to the amount of liquid inside. When a contaminant enters the liquid layer, it dissolves and comes into uniform contact with the entire interface, thereby altering it. For this reason, the EMEE signal also changes. It is possible to automate flushing of the sensor and refilling it with clean water before the next measurement.

Employing such a liquid layer of identical composition to that used during contaminant generation presents several advantages. Under these conditions, the sensing element exhibits no response to the predominant carrier fluid regardless of its type – clean air or water droplets. It only reacts to the contaminants, where signal fluctuations arise. Variable volumes of contaminants engaging with the sensor will correspondingly result in inconsistent quantities of impurities interacting with the sensor's active surface. These fluctuations are temporally averaged by the liquid layer over a defined period. This layer also serves additional functions. It effectively mitigates condensation, which often obstructs sensor readings. It also prevents surface fouling caused by particulate and chemical deposition – a common challenge that can degrade measurement accuracy. Moreover, the liquid layer zeroes the dominant signal from the carrier phase, thereby enhancing the sensor's sensitivity to the impurities. This is particularly important given that the pollutant concentrations are much lower than those of the carrier fluid. The only minor drawback is the need to periodically flush and refill the sensor with small liquid volumes, a task that can be readily automated using micro pumps.

A large number of specimens (mainly semiconductor materials) have been investigated for use as sensing elements in the sensor structures. All of them have been tested and confirmed to respond to the presence of fluid contaminants, generating distinct signals for clean and contaminated air. Because the EMEE signal is inherently weak, it is crucial to identify locations on the semiconductor wafers where the generated signal is strongest.

Several chemicals at varying concentrations were used to simulate contaminants in these experiments – Axetin (cefuroxime sodium), potassium dihydrogen phosphate (PDP), iodine, and acetone. These substances were selected because they are easily accessible, inexpensive, and considered relatively non-toxic. Initially, the signal from pure water (used as a base value) was measured. Then,

measurements were performed to determine the maximum amplitude deviations produced by varying contaminant concentrations. For each concentration of each contaminant, a series of independent measurements was carried out, and the percentage deviation for each measurement was calculated. When constructing a graph, each data point (i.e., each concentration) was measured multiple times, and the arithmetic mean was used. The procedure was then repeated to generate a new graph for the same or a different contaminant. Each graph for a given pollutant was reproduced several times in this manner.

Results and discussion. Four graphs are presented for each contaminant (Fig. 1a–d), illustrating the EMEE response to varying concentrations. The results clearly demonstrate that the signal amplitude changes with the concentration of the pollutant.

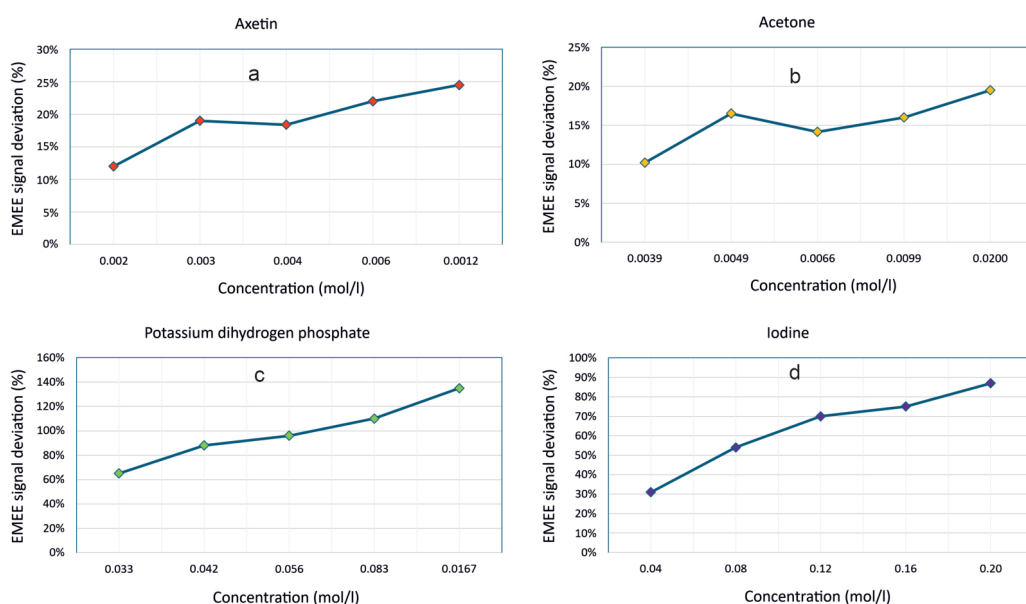


Fig. 1. Contaminant reaction with: a) 0.100 g Axetin dissolved into 20 ml, 40 ml, 60 ml, 80 ml, 100 ml of DW; b) 40 μ l acetone dissolved into 20 ml, 40 ml, 60 ml, 80 ml, 100 ml of DW; c) 0.455 g of PDP dissolved into 20 ml, 40 ml, 60 ml, 80 ml, 100 ml of DW; d) 0.04 ml, 0.08 ml, 0.12 ml, 0.16 ml, 0.20 ml of iodine dissolved into 20 ml of DW

An important observation that can be made is that the addition of any of the four contaminants changes the EMEE signal. As expected, higher pollutant concentrations generally lead to larger signal deviations, although all graphs clearly show that this relationship is not strictly linear. The pulverization of chemical solutions in distilled water involves a complex interplay of physicochemical and hydrodynamic nonlinearities. During pulverization, high-pressure conditions can induce cavitation and turbulence, leading to the formation of microdroplets with unpredictable trajectories and interactions. These droplets may undergo

nonlinear wave propagation, vortex formation, and pressure fluctuations, all of which strongly influence their dispersion and mixing behaviour [18]. Furthermore, the confined collapse of cavitation bubbles within droplets can generate localized energy spikes, affecting both droplet morphology and chemical reactivity [19]. When active compounds are present, chemical reactions within droplets are governed by nonlinear kinetics, often exhibiting autocatalytic behaviour, concentration gradients, and surface-mediated transformations [20]. Such processes may lead to the formation of secondary products or phase transitions. The combination of droplet-scale transport phenomena and reaction-diffusion dynamics results in emergent behaviours that cannot be predicted by linear models alone. These nonlinear effects are particularly relevant in applications such as aerosol synthesis, environmental dispersion modelling, and reactive spray technologies.

Nonlinear effects, similar to those described above, are presumably responsible for the observed deviations in the curves describing the dependence of the EMEE signal on impurity concentration. This indicates that the studied fluid should be supplied to the sensor not by pulverization but by a uniform flow. In the future, we plan to acquire a chamber that will allow us to work with such contaminant-bearing fluid flows without posing a risk to the people conducting the experiments.

Also, additional studies can be carried out for specific contaminants of interest in order to optimize the operating parameters of the measuring system. These parameters include the wavelength and intensity of the irradiating light, the type of the sensor's working surface, its mechanical structure, the modulation frequency, and others. Such investigations will help improve the sensor's sensitivity and the stability of its readings. In this direction, there is considerable potential for achieving even better performance.

Conclusion. In conclusion, the EMEE demonstrates strong potential for the development of new techniques for detecting and quantifying air pollution. This method offers significant advantages by combining optical probing of the sample with electrical detection of the generated signal. It enables instantaneous measurements and requires virtually no consumables. Devices based on this principle can be produced at low cost and in compact form, making them suitable for field applications. The use of a laser as the light source does not increase the size or weight of the system, as modern laser modules are quite small and can even incorporate internal intensity modulation. Another important observation is that the EMEE signal is sensitive to variations in contaminant concentrations, and each pollutant produces a characteristic change in the signal. This highlights the feasibility of using such sensors for air-quality monitoring. Although absolute repeatability is not always achieved, relative repeatability is consistently observed, and clear distinction between pure and contaminated fluid is always present. Future work will focus on improving the stability and robustness of the entire system.

REFERENCES

- [1] BROOK R. D., J. R. BROOK, S. RAJAGOPALAN (2003) Air pollution: the “Heart” of the problem, *Curr. Hypertens. Rep.*, **5**(1), 32–39.
- [2] GOEL A. K. (2015) Anthrax: a disease of biowarfare and public health importance, *World J. Clin. Cases*, **3**(1), 20–33.
- [3] TSUJITA W., S. KANEKO, T. UEDA et al. (2003) Sensor-based air-pollution measurement system for environmental monitoring network. In: *TRANSDUCERS’03. 12th Int. Conf. on Solid-State Sensors, Actuators and Microsystems, Digest of Technical Papers* (Cat. No. 03TH8664), Boston, IEEE, 544–547.
- [4] SOMA S., C. PATIL, M. A. BAIG, J. D. AMOL (2022) Multi-sensor system for air and water quality monitoring, *Int. J. Eng. Res. Technol.*, **11**(8), 350–353, <https://doi.org/10.5281/zenodo.18410149>.
- [5] KABILAN M., R. KISHORE, R. MAGESH (2024) Air quality monitoring system: a comprehensive overview of an advanced air quality monitoring system using Arduino, *Asian J. Appl. Sci. Technol.*, **8**(2), 1–6.
- [6] BORISSOV M., O. IVANOV, V. KOVACHEV, V. LOVCHINOV (1988) Transverse acoustoelectronic effect in piezoelectric configuration: metal conductive sample, *Acoust. Lett.*, **11**(12), 229–232.
- [7] PUSTOVOIT V. I., M. BORISSOV, O. IVANOV (1989) Surface photo-charge effect in conductors, *Solid State Commun.*, **72**(6), 613–619.
- [8] IVANOV O., P. TODOROV, I. GULTEPE (2020) Investigations on the influence of chemical compounds on fog microphysical parameters, *Atmosphere*, **11**(3), 225, <https://doi.org/10.3390/atmos11030225>.
- [9] IVANOV O., L. KONSTANTINOV (2000) Application of the photo-induced charge effect to study liquids and gases, *Surf. Rev. Lett.*, **7**(3), 211–212.
- [10] IVANOV O., M. KUNEVA (2011) Quality control methods based on electromagnetic field-matter interactions. In: *Application and Experience of Quality Control* (ed. O. Ivanov), Vienna, InTech, 509–536.
- [11] IVANOV O., A. VASEASHTA, L. STOICHEV (2008) Rapid, contactless, and non-destructive testing of chemical composition of samples. In: *Functionalized Nanoscale Materials, Devices and Systems for Chem.-bio Sensors, Photonics, and Energy Generation and Storage* (eds A. K. Vaseashta, I. N. Mihailescu), Springer, 331–334.
- [12] IVANOV O., A. VASEASHTA (2013) A method for fast and contactless control of raw materials, *Ceram. Int.*, **39**(3), 2903–2907.
- [13] IVANOV O., L. KONSTANTINOV (2002) Investigations of liquids by photo-induced charge effect at solid-liquid interfaces, *Sens. Actuators B*, **86**(2–3), 287–289.
- [14] IVANOV O., S. RADANSKI (2009) Application of surface photo charge effect for milk quality control, *J. Food Sci.*, **74**(7), R79–R83.
- [15] IVANOV O., S. KARATODOROV, J. L. P. DÍAZ (2017) Novel electromagnetic sensor for contaminations in fog based on the laser-induced charge effect. In: *Proc. IEEE Sensors, Glasgow, IEEE*, 1–3, <https://doi.org/10.1109/ICSENS.2017.8234379>.
- [16] TODOROV P., O. IVANOV, I. GULTEPE et al. (2024) Optimization of the air cleaning properties of fog, *Aerosol Sci. Eng.*, **8**, 241–248, <https://doi.org/10.1007/s41810-024-00220-0>.
- [17] IVANOV O. (2006) Sensor applications of field–matter interactions. In: *Encyclopedia of Sensors* (eds C. A. Grimes, E. C. Dickey, M. V. Pishko), vol. 9, Stevenson Ranch, American Scientific Publishers, 165–197.

- [18] GANIEV S. R., Y. S. KUZNETSOV, O. V. SHMYRKOV (2019) Nonlinear wave and cavitation processes and their effect on the mechanical properties of viscous solutions, *Dokl. Phys.*, **64**(2), 49–52, <https://doi.org/10.1134/S1028335819020010>.
- [19] QIN Y., Z. WANG, L. ZOU (2024) Theoretical investigation of the nonlinear dynamics for cavitation bubbles inside liquid drops, *Phys. Fluids*, **36**(12), 122017, <https://doi.org/10.1063/5.0244809>.
- [20] DANAILA I., P. JOLY, S. M. KABER, M. POSTEL (2023) Nonlinear differential equations: application to chemical kinetics. In: *An Introduction to Scientific Computing*, Cham, Springer, https://doi.org/10.1007/978-3-031-35032-0_2.

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