Peertechz

Annals of Mathematics and Physics
OPEN ACCESS JOURNAL
ISSN: 2689-7636 Journal DOI: https://dx.doi.org/10.17352/amp

Research Article

Towards YMD (Y-Modulation Detection Algorithms and Devices) Applications in CryoSEM for Surface Studies of Superconductors: Per Aspera ad Astra

Aleksandrov PL, Filippov MK, Gradov OV* and Maklakova IA

N.N. Semenov Federal Research Center for Chemical Physics, Russian Academy of Sciences, Kosygina str., 4, 119991, Moscow, Russian Federation

Submitted : 17 March, 2026
Accepted : 26 March, 2026
Published : 27 March, 2026

***Corresponding author:** Gradov OV, N.N. Semenov Federal Research Center for Chemical Physics, Russian Academy of Sciences, Kosygina str., 4, 119991, Moscow, Russian Federation,
E-mail: o.v.gradov@gmail.com

Keywords: Superconductor; SEM; YMD; Y-modulation LTSEM; CCSEM; 3D visualization; Charge collection scanning; Wave phenomena; Autowaves

Abstract

The use of various electron microscopy techniques to study superconductors has been established since the 1980s, encompassing both high-resolution transmission electron microscopy (HRTEM) and lower magnification scanning electron microscopy (SEM). A significant challenge with these methods is the temperature dependence of imaging within the electron microscope, which necessitates noise reduction and specialized cooling systems, such as Low-Temperature Scanning Electron Microscopy (LTSEM). Programmable stages with temperature stabilization allow for analyzing temperature dependencies similar to studies on dielectric composites and semiconductors. Attempts to replace SEM and HRTEM with simpler scanning probe and tunnelling microscopy methods have not resolved the initial challenges, as they still require advanced cooling setups. The SEM benefits of scanning for large area investigations with satisfactory temporal dynamics are often overlooked. The interaction of the superconductor with the electron beam not only visualizes but can also contrast and modify samples, revealing cooperative or additive defects observable at micro- and mesoscopic levels. Therefore, it is advisable to study the charge structure of the surface of high-temperature superconductors at real temperatures. The proposed methodology involves using Y-modulated detection techniques with JEOL microscopes, applicable in both Charge Collection Scanning Electron Microscopy (CCSEM) and electronic spectroscopy methods. This approach allows for detailed 3D topographical imaging of surface charging structures/textures created by charged structures.

Introduction

The use of various electron microscopy techniques for studying superconductors has been common since the 1980s, both for high-resolution transmission electron microscopy [1,2] and for scanning electron microscopy with lower magnification and resolution [3,4]. A significant problem for such methods is dependence of the image quality on the temperature and beam parameters, which requires noise suppression and specific cooling (LTSEM – Low-Temperature Scanning Electron Microscopy) [5-7]. When using a programmable table with temperature stabilization [7], it is possible to analyze temperature dependences in the same way as in the case of studying dielectric composites and semiconductors [8]. The attempt to replace SEM and HRTEM with simpler methods of scanning probe [9,10] and tunnel [11,12] microscopy, from our point of view, did not lead to a conceptual progress, since it is still necessary to modify and use cooled tables and cryogenic modules, in particular, those that differ from the standard modules produced for cryopreservation in cryobiology, for cryochemical or cryophysical tasks [13-16].

The tasks of establishing dependencies of the microscopic structure and electronic defects [17] are solved in tunnel, probe, and atomic force microscopy extensively due to the acceleration in the kinematics of the probe/cantilever. At the same time, the advantages of scanning as a method for studying large sample areas with satisfactory time dynamics (as it has been since the advent of the TV mode in SEM) are not used in such cases. Nevertheless, it is obvious that the electron beam can not only visualize, but also contrast and modify the sample, which, from the standpoint of solid state physics, corresponds

Citation: Aleksandrov PL, Filippov MK, Gradov OV, Maklakova IA. Towards YMD (Y-Modulation Detection Algorithms and Devices) Applications in CryoSEM for Surface Studies of Superconductors: Per Aspera ad Astra. Ann Math Phys. 2026;9(2):071-077. Available from: https://dx.doi.org/10.17352/amp.000182

to a number of the possible defects of a cooperative or additive nature manifested not only at the subnanometer level, but also at the SEM-resolved micro- and mesoscopic level.

For this reason, it is advisable to study the charge structure of the superconductor surface with the subsequent analyzing of the scangrams in a mode resolving the surface texture using the selection of several isopotential lines performed by the special algorithms.

Methods

We propose to use the YMD technique and equipment ("Y-modulation mode" based on "Y-modulation device") developed for JEOL and Stereoscan (Cambridge Instrument Company) scanning electron microscopes. Y-modulated detection mode is used both in CCSEM (Charge Collection Scanning Electron Microscopy) techniques [18] and in electron spectroscopy methods based on the analysis of the energy distribution of electrons emitted during a nonradiative transition providing relaxation of the excited state, which emerged as a result of the vacancy formation in one of the inner electron shells (Auger microscopy methods [19]).

This mode can also be used in low-temperature SEM techniques [20] (including the analysis of superconductors [21]) and in conventional methods of reconstructing the topographic surface texture [22], according to the same principles as in confocal laser scanning microscopy [23]. The initial image is obtained during YMD scanning (the image sequence in Figure 1), as a result of which it is possible to observe a complete relief/bas-relief picture of the surface texture, created by the height gradient of the charged structures (for example, using the YMD technique, it is possible to distinguish between sources and drains in semiconductor devices by densitometry).

Materials

We have studied the samples of superconductor ceramics, which are not subject to disclosure as "know-how" in this methodological article. Due to this, in the test experiments, we did not cool the samples up to cosmic cryovacuum temperatures. However, as a motivation for the analysis and visualization of superconductors at lower temperatures (literally simulating cosmic cryovacuum conditions), we can refer to the works on the detection of superconductors and superconductivity phenomena in micrometeorites, as well as in the fragments of large meteorites that fell to Earth [24-27].

Results

Several negative and positive image series of the field disturbances and charge wandering in the form of travelling waves and solitary waves in a potential superconductor, registered by SEM with a Y-modulating device without cooling, are shown in Figures 2 and 3. It can be seen that not only single waves are observed, but also fine modulations of the charge distribution surface profile, varying significantly in time. There are both stationary and regular or repeating components of the wave behaviour (depending on the surface structure or texture), and modulated spontaneous bursts and wave

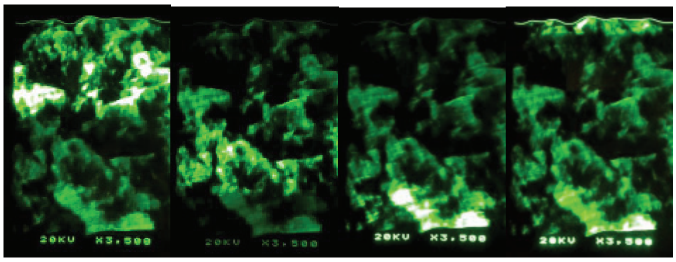

Figure 1: The scanning process of a superconductor surface in the Y-modulation detection mode before any processing and decoding. One can see the change in the positions of the luminance maxima ("3D Luminance Surface"), corresponding to the line scanning.

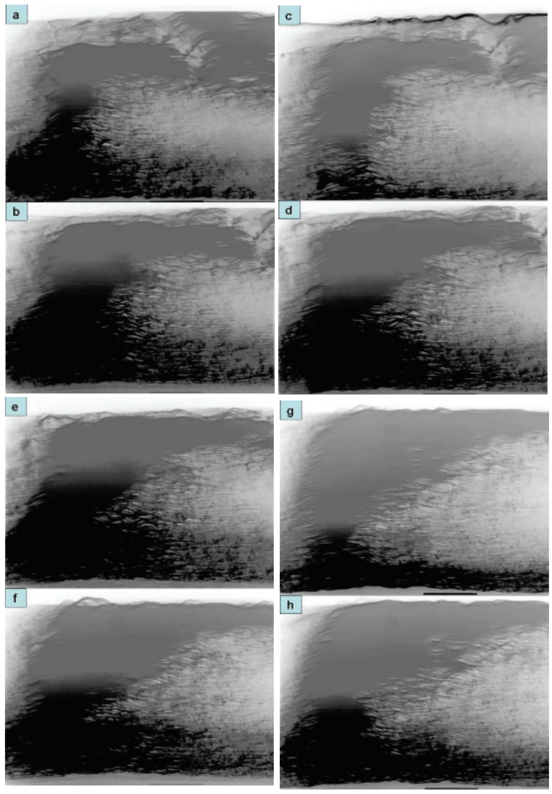

Figure 2: Positive images of YMD visualizations for the possible superconductor material.

fronts. This pool of wave phenomena for an uncooled potential superconductor material (before the phase transition) can be characterized by cumulative dynamics, i.e. an increase in their amplitude, a change in the frequency of bursts and dissipation phenomena until the transition to the superconducting state, in which, according to the definition of superconductivity (the property of some materials to conduct electric current without dissipation with the simultaneous expulsion of a magnetic field), dissipation is not observed. In the verification experiments, the equivalent circuit of a sample with a table or a foil substrate behaves incompatibly with the superconducting state, which confirms the correctness of our approach.

Discussion

The application of this 3D visualization method is possible in several aspects, including modeling of non-classical effects in photosynthesis and tunnelling reactions (including

Citation: Aleksandrov PL, Filippov MK, Gradov OV, Maklakova IA. Towards YMD (Y-Modulation Detection Algorithms and Devices) Applications in CryoSEM for Surface Studies of Superconductors: Per Aspera ad Astra. Ann Math Phys. 2026;9(2):071-077. Available from: https://dx.doi.org/10.17352/amp.000182

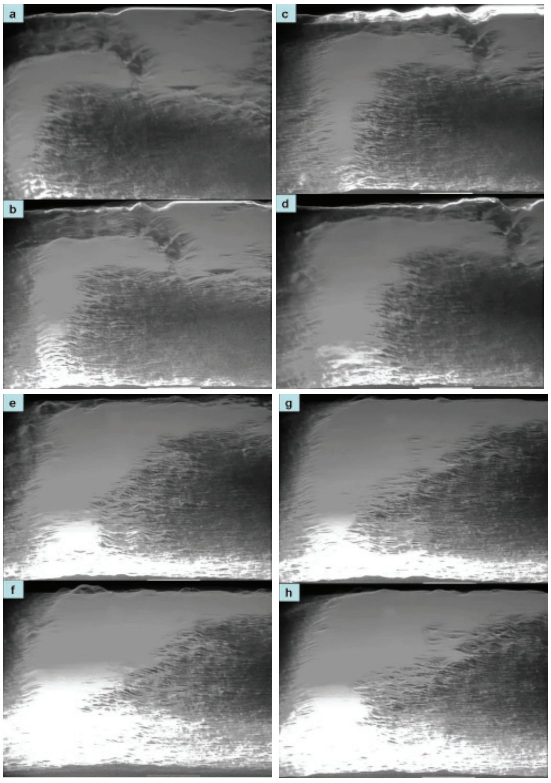

Figure 3: Negative images of YMD visualizations for the possible superconductor material.

prebiological synthesis in cryogenic media proposed by V.I. Goldansky) in mineral samples [28-30], even in space conditions [31-35]. Accordingly, this method can also be applied in cryoelectron microscopy for validating Goldansky's hypotheses and experimental verification of the possibility of templating processes on cosmic bodies, including templating processes on superconducting minerals [36,37]. Therefore, if the development of the proposed YMD visualization technology allows to analyze in real time (in a dynamic or time-lapse / time-resolved mode) the electrophysical state of the natural superconductor surface, this will be a significant contribution to the development and testing of new devices based on superconducting elements using traveling waves - such as, for example, traveling-wave amplifiers [38-42], traveling-wave photodetectors [43-47], traveling wave cavity prototypes [48,49], traveling-wave antennas [50-52], traveling-wave-type optical modulators or optomechanical traveling wave phonon–photon translators [53,54], etc. However, for such a primary communication as this propositional work, it does not seem rational to talk much about the future applications of the proposed technique.

Supplement: What is YMD-EM?

The development of Y-modulation methods in electron microscopy began with the introduction of the first Y-modulated scanning systems (Y-modulation detection and scan-modulation displays) in SEMs in the late 1960s [55-57]. In the pioneering work [55], the authors state:

"*In scanning electron microscopy (reviewed by Oatley, Nixon, and Pease, 1965), the signal from the specimen is generally used to modulate the brightness of a cathode ray tube (c.r.t) to give a television-type display. This display has the advantage of giving a picture similar in appearance to one that would be obtained with an optical microscope, and its information is therefore much easier to interpret. However, the contrast observed relies on the differences in brightness levels seen on the face of a cathode ray tube, and the number of distinguishable levels is limited. Moreover, the relationship between these distinguishable levels or "shades of grey" is qualitative. It is sometimes desirable to be able to study the information in a scanning electron micrograph in a quantitative manner, and for this purpose, a special display technique has been developed. The microscope signal is displayed by deflecting the scanning c.r.t beam a distance proportional to the amplitude of the signal, and hence it is known as scan-modulation display. Other descriptive terms that have been used are Deflection, Frame or y-Modulation*".

An example of an electronic block diagram for a Y-modulation imaging device or scan-modulation display (SMD) from the paper [55] is shown in Figure 4.

An explanation of "how Y-modulation operates at the hardware level, specifically at the electron beam control level" for the "Stereoscan" SEM system is provided in Figure 5 from the paper [56] ("Y-modulation: an improved method of revealing surface detail using the scanning electron microscope") from the "Science" journal.

According to the above-cited paper [56]:

"*As in normal scanning electron microscopy, a finely focused beam of electrons is deflected across the surface under investigation. The number of electrons back-scattered and emitted is a function of the topography and composition of the specimen...; such electrons are accelerated by a wire grid biased to + 12 kV and allowed to strike the surface of a phosphor screen. The scintillation produced is viewed and amplified by a photomultiplier, and the output of the photomultiplier is applied to a cathode-ray tube scanning in synchronization. The scan size of the cathode-ray tube remains fixed at 10.5 cm², but the area of scan on the specimen may be successively decreased, thus*

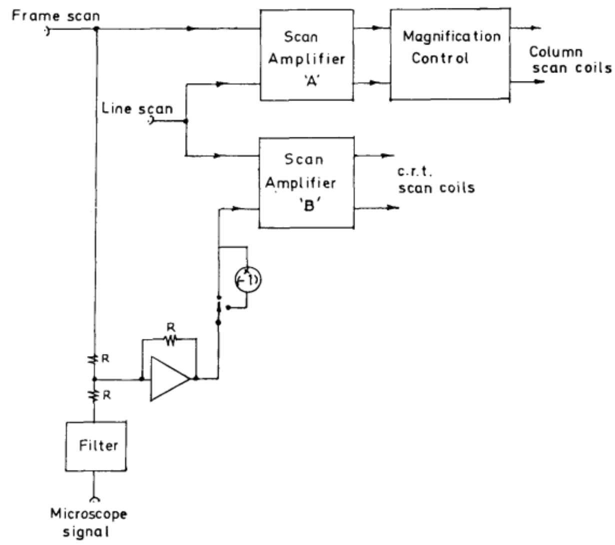

Figure 4: Scheme of scan-modulation display (SMD) from the paper [55].

Citation: Aleksandrov PL, Filippov MK, Gradov OV, Maklakova IA. Towards YMD (Y-Modulation Detection Algorithms and Devices) Applications in CryoSEM for Surface Studies of Superconductors: Per Aspera ad Astra. Ann Math Phys. 2026;9(2):071-077. Available from: https://dx.doi.org/10.17352/amp.000182

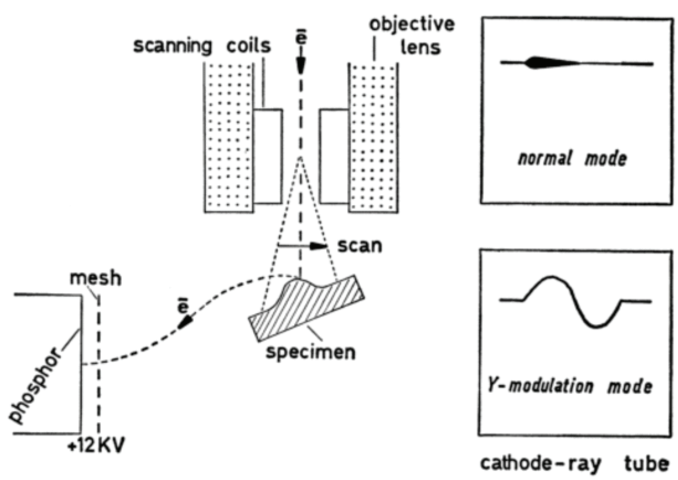

Figure 5: Comparison between standard SEM scanning mode and Y-modulation mode from the paper [56].

giving an apparent step-up of magnification within the range of x 20 to X 100,000 at the normal working distance of 11 mm. These values may be varied either by changing the working distance or by utilizing the zoom magnification factor on the scan rotation unit. "The clarity with which the step-by-step growth features can be observed … is further exemplified at a magnification which, in the normal mode …, is clearly unusable. Taken at lower power …, the Y-shift effect can be seen to introduce considerable difficulties in interpretation if complex morphology or topographical relief is present. Using a lower amount of modulation will reduce this effect…, but, taken in conjunction with the normal mode photograph, the Y-modulation mode photograph permits detailed examination of the fine structure of selected areas. We thus deduce that this method becomes increasingly important as higher and higher magnifications are employed, especially with magnetic materials or on surfaces with low or moderate relief, and that at lower magnification the Y-modulation photographs provide valuable information supplementing normal mode photographs".

Subsequently, Y-modulation techniques were standardized for various detector types, including backscattered electron detectors (BEI) and transmitted electrons, and later for cathodoluminescence as well as for mapping elemental distributions via energy-dispersive X-ray spectroscopy and microprobe analysis [58-60]. This enabled cross-correlation and colocalization of 3D profiles not only for sample topography but also for spatial distributions of their chemical components. Furthermore, quantitative Y-modulated detection and colocalization/correlation of profiles became possible for both STEM (scanning transmission electron microscopy) and conventional TEM within a single instrument without sample removal [61,62]. By this time (the 1985 - 1990s), fully digital signal processing from various detectors and digital implementation of the YMD mode were already available [63], and state-of-the-art electron microscopes were equipped with microcomputer-based imaging systems (e.g., in "new" JEOL JSM models).

Initially (from the 1960s), YMD was implemented using analogue instrumentation—various oscilloscopes with camera attachments and delay lines, followed by storage oscilloscopes. In the 1970s, although equipment from the late 1960s remained functional, there was a shift toward computer-assisted 3D visualization techniques and computer-mediated YMD. The first developers and users of these technologies were "microelectronics specialists," i.e., experts working with photomasks and photoresists, who required regular, reproducible, and automated measurements of photoresist thickness, photomask features, and etched grooves [64,65]. By the 1990s, YMD was widely applied in both digital and analogue microelectronics (for quality control of integrated circuits), as well as in semiconductor physics and engineering (e.g., for profiling heterojunctions in field-effect transistors) [66,67].

Following the implementation of digital methods that enabled the colocalization of data from any type of scanning on a single image and the construction of 3D profiles / "bas-relief" representations / visualizations of arbitrary data sources related to surface texture and micro-roughness, it became possible to use YMD in synchronized systems of atomic force microscopy and scanning electron microscopy, as well as in tunneling microscopy and scanning electron microscopy; a similar statement holds for synchronized and correlative systems of scanning tunneling (or atomic force) and reflection electron microscopy [68]. The latter assertion seems trivial, since, by definition, Y-modulation scanning in scanning electron microscopy pertains to deflection and reflection scan modes.

In the semiconductor industry and semiconductor physics, YMD visualization is actively employed for visualizing the spatial distribution of defects in semiconductors using a scanning probe and electron beam to excite defects [69] (SDTLS = Scanning Deep-Level Transient Spectroscopy); however, in this case, additional measurements of transient capacitance and current after excitation are used, depending on temperature, which yields quantitative data on the energy levels, concentration, and other characteristics of defects (such as carrier capture cross-sections or activation barriers) in the semiconductor. Papers on YMD visualization in scanning electron microscopy of charging effects on semiconductors are well known since 1970 [70].

To our knowledge, before our unfulfilled proposal (which formed the basis of this article), there were no studies utilizing YMD for cryo-SEM of superconductors.

Author contributions

Aleksandrovsk P.L. – Automation of the JEOL JSM scanning electron microscope with YMD; 3D fabrication of an adapter for a digital camera. Designing and soldering electronic circuits and connecting cables (2018-2019, 2025-2026) [71-74].

Filippov M.K. – Restorations of the vacuum systems of the JEOL JSM scanning electron microscope with YMD mode, cleaning of the scanning electron microscope column, design of a new power supply source, replacement of technical oils (2018-2025). Memoirs about old SEM instruments with Y modulation devices (1970-1990).

Gradov O.V. – YMD experiment design, Cryo-SEM instrumentation development and modernization

Citation: Aleksandrov PL, Filippov MK, Gradov OV, Maklakova IA. Towards YMD (Y-Modulation Detection Algorithms and Devices) Applications in CryoSEM for Surface Studies of Superconductors: Per Aspera ad Astra. Ann Math Phys. 2026;9(2):071-077. Available from: https://dx.doi.org/10.17352/amp.000182

(unfortunately, destroyed now) [75-77]. Conceptualization and writing of the review text | introduction part. Time-resolved SEM and time-resolved SEM-YMD experiments on JEOL JSM-based setups (for example, see [78-82], etc.).

Maklakova I.A. – Time-resolved SEM and time-resolved SEM-YMD experiments on JEOL JSM-based setups (for example, see [78-82] etc.). Primary image processing (monochrome mode; contrast; brightness; cropping; etc.).

Conflict of interests: The authors declare that they have no conflict of interest.

Acknowledgements

We sincerely thank the late Professor Trusevich for the opportunity to attempt SEM studies of the superconductors (he created). We are deeply concerned about not knowing the composition and are unable to interpret the data or complete the study of charge effects using machine learning methods. Therefore, we are forced to publish only preliminary results demonstrating that our YMD method is, in principle, viable. Unfortunately, due to strict sanctions, we are currently unable to complete the setup and finalize the instrumentation and software developments. Due to the sudden death of the aforementioned co-author, we have not yet developed cryo-electron microscopy techniques with machine learning for these materials.

References

1. Marks LD, Li DJ, Shibahara H, Zhang JP. High-resolution electron microscopy of high-temperature superconductors. J Electron Microsc Tech. 1988;8(3):297–306. Available from: https://doi.org/10.1002/jemt.1060080308

2. Zhao YJ, Chu WK, Liu JR, Kulik J, Zandbergen H, Tao YK. High-resolution transmission electron microscopy study of the radiation damage defects in high temperature superconductors. Appl Phys Lett. 1992;61(16):1968–1970. Available from: https://doi.org/10.1063/1.108332

3. Sasov A. Local studies in SEM of high-temperature superconductors. J Microsc. 1988;152(1):RP1–RP2.

4. Obst B, Nast R, Schlachter S, de Boer B, Holzapfel B, Nemetschek R, Prusseit W. Application of electron backscatter diffraction in the SEM to textural problems of coated high-temperature superconductors. Int J Mater Res. 2003;94(5):580–586. Available from: https://doi.org/10.1515/ijmr-2003-0101

5. Gerber R, Nissel T, Wener HG, Willmann A, Keil S, Hansel H, et al. Low-temperature scanning electron microscopy for low noise studies of high-Tc superconductors. IEEE Trans Appl Supercond. 1997;7(2):3231–3234. Available from: https://pascal-francis.inist.fr/vibad/index.php?action=getRecordDetail&idt=2819631

6. Huebener RP, Gross R, Bosch J. Low-temperature scanning electron microscopy for studying inhomogeneities in thin-film high-Tc superconductors. Z Phys B Condens Matter. 1988;70:425–430. Available from: https://link.springer.com/article/10.1007/BF01312115

7. Gross R, Bosch J, Wener HG, Fischer J, Huebener RP. Temperature stabilized sample stage for the investigation of high Tc superconductors by scanning electron microscopy. Cryogenics. 1989;29(7):716–719. Available from: https://doi.org/10.1016/0011-2275(89)90137-9

8. Xu Z. Electron microscopy studies in electrical ceramics: dielectric composites and high critical temperature superconductors. Urbana-Champaign (IL): University of Illinois at Urbana-Champaign; 1991.

9. de Lozanne A. Scanning probe microscopy of high-temperature superconductors. Supercond Sci Technol. 1999;12(4):R43. Available from: https://iopscience.iop.org/article/10.1088/0953-2048/12/4/001

10. De Lozanne AL, Edwards HL, Yuan C, Markert JT. Scanning probe microscopy and spectroscopy of high temperature superconductors. Acta Phys Pol A. 1998;93(2):333–342. Available from: https://doi.org/10.12693/APHYSPOLA.93.333

11. Wang X, Yuan Y, Xue QK, Li W. Charge ordering in high-temperature superconductors visualized by scanning tunneling microscopy. J Phys Condens Matter. 2019;32(1):013002. Available from: https://doi.org/10.1088/1361-648x/ab41c5

12. Shih CK, Feenstra RM, Chandrashekhar GV. Scanning tunneling microscopy and spectroscopy of Bi-Sr-Ca-Cu-O 2:2:1:2 high-temperature superconductors. Phys Rev B. 1991;43(10):7913. Available from: https://journals.aps.org/prb/abstract/10.1103/PhysRevB.43.7913

13. Hudson E. Low temperature scanning tunneling microscopy of high temperature superconductors: what we gain by taking a closer look. Bull Am Phys Soc. 2009;54(1):Abstract ID A27.00007. Available from: https://meetings-archive.aps.org/mar/2009/a27/7/

14. Hug HJ, van Schendel PJ, Stiefel B, Kafue O, Hoffmann R, Martin S, et al. Scanning force microscopy at low temperatures: vortices in high transition temperature superconductors. Verh Dtsch Phys Ges. 1999;34(5):1011.

15. Minami M. Cryogenic scanning tunneling microscopy and spectroscopy on high temperature superconductors [dissertation]. Tokyo: University of Tokyo; 1995. Available from: https://cultural.jp/en/item/dignl-3115392

16. Go K. Local electronic properties of high Jc oxide superconductors studied by low temperature scanning tunneling microscopy/spectroscopy [dissertation]. Tokyo: University of Tokyo; 2003.

17. Zeljkovic I. Visualizing the interplay of structural and electronic disorders in high-temperature superconductors using scanning tunneling microscopy [dissertation]. Cambridge (MA): Harvard University; 2013. Available from: https://hoffman.physics.harvard.edu/theses/2013-05-14-Ilija-Zeljkovic-thesis.pdf

18. Leamy HJ. Charge collection scanning electron microscopy. J Appl Phys. 1982;53(6):R51–R80. Available from: https://doi.org/10.1063/1.331667

19. Venables JA, Janssen AP, Harland CJ, Joyce BA. Scanning Auger electron microscopy at 30 nm resolution. Philos Mag. 1976;34(3):495–500. Available from: https://doi.org/10.1080/14786437608222040

20. Huebener RP. Applications of low-temperature scanning electron microscopy. Rep Prog Phys. 1984;47(2):175. Available from: https://doi.org/10.1088/0034-4885/47/2/002

21. Gross R, Doderer T, Huebener RP, Kober F, Koelle D, Kruelle C, et al. Low-temperature scanning electron microscopy studies of superconducting thin films and Josephson junctions. Physica B. 1991;169(1-4):415–421. Available from: https://publikationen.bibliothek.kit.edu/1000078001

22. Kelly TK, Lindqvist WF, Muir MD. Y-modulation: an improved method of revealing surface detail using the scanning electron microscope. Science. 1969;165(3890):283–285.

23. Brakenhoff GJ. Imaging modes in confocal scanning light microscopy (CSLM). J Microsc. 1979;117(2):233–242. Available from: https://doi.org/10.1111/j.1365-2818.1979.tb01179.x

24. Wampler J, Thiemens M, Cheng S, Zhu Y, Schuller IK. Superconductivity found in meteorites. Proc Natl Acad Sci U S A. 2020;117(14):7645–7649. Available from: https://doi.org/10.1073/pnas.1918056117

25. Feder T. Minerals and meteorites: searching for new superconductors. Phys Today. 2014;67(5):20. Available from: https://physicstoday.aip.org/news/minerals-and-meteorites-searching-for-new-superconductors

26. Guénon S, Ramírez JG, Basaran AC, Wampler J, Thiemens M, Schuller IK. Search for new superconductors: an electromagnetic phase transition in an iron meteorite inclusion at 117 K. J Supercond Nov Magn. 2017;30:297–304. Available from: https://arxiv.org/pdf/1509.04452

27. Guénon S, Ramírez JG, Basaran AC, Wampler J, Thiemens M, Taylor S, et al. Search for superconductivity in micrometeorites. Sci Rep. 2014;4(1):7333. Available from: https://doi.org/10.1038/srep07333

28. Mostame S, Rebentrost P, Eisfeld A, Kerman AJ, Tsomokos DI, Aspuru-Guzik A. Quantum simulator of an open quantum system using superconducting qubits:

Citation: Aleksandrov PL, Filippov MK, Gradov OV, Maklakova IA. Towards YMD (Y-Modulation Detection Algorithms and Devices) Applications in CryoSEM for Surface Studies of Superconductors: Per Aspera ad Astra. Ann Math Phys. 2026;9(2):071-077. Available from: https://dx.doi.org/10.17352/amp.000182

exciton transport in photosynthetic complexes. New J Phys. 2012;14(10):105013. Available from: https://doi.org/10.48550/arXiv.1106.1683

29. Norris G, Potočnik A, Collodo M, Akin A, Gasparinetti S, Eichler C, et al. Time-resolved measurements of energy transport in a system of coupled superconducting qubits inspired by simulations of photosynthetic processes. Bull Am Phys Soc. 2019;64(2):Abstract ID B27.00012. Available from: https://ui.adsabs.harvard.edu/abs/2019APS..MARB27012N/abstract
30. McDevitt JT, Jurbergs DC, Eames S, Zhao J. Novel optical switches and devices based on metalloporphyrin/superconductor assemblies. Washington (DC): American Chemical Society; 1995 Dec 31.
31. Ball P. Cosmic superconductivity. Nat Mater. 2020;19(5):490.
32. Goldanskii VI. Interstellar grains as possible cold seeds of life. Nature. 1977;269(5629):583–584. Available from: https://ui.adsabs.harvard.edu/abs/1977Natur.269..583G/abstract
33. Goldanskii VI. Revival of the concept of the cold prehistory of life. Eur Rev. 1993;1(2):137–147. Available from: https://doi.org/10.1017/S106279870000048X
34. Goldanskii VI. Revival of the concept of cold prehistory of life. Orig Life Evol Biosph. 1994;24(2):283–294. Available from: https://ideas.repec.org/a/cup/eurrev/v1y1993i02p137-147_00.html
35. Goldanskii VI. Quantum chemical reactions in the deep cold. Sci Am. 1986;254(2):46–53. Available from: https://www.scientificamerican.com/article/quantum-chemical-reactions-in-the-d/
36. Gradov OV, Gradova MA. From systems to synthetic biology through cryoelectron microscopy. In: Russian International Conference on Cryoelectron Microscopy 2017 (MSU, Moscow); p. 17.
37. Gradov OV, Gradova MA. Cryoelectron microscopy as a functional instrument for system biology, structural analysis and experimental manipulations with living cells. Probl Cryobiol Cryomed. 2014;24(3):193–210. Available from: https://arxiv.org/abs/1501.04337
38. Chaudhuri S, Gao J, Irwin K. Simulation and analysis of superconducting traveling-wave parametric amplifiers. IEEE Trans Appl Supercond. 2014;25(3):1–5. Available from: https://arxiv.org/abs/1412.2372
39. Erickson RP, Pappas DP. Theory of multiwave mixing within the superconducting kinetic-inductance traveling-wave amplifier. Phys Rev B. 2017;95(10):104506. Available from: https://journals.aps.org/prb/abstract/10.1103/PhysRevB.95.104506
40. Planat L, Ranadive A, Dassonneville R, Puertas Martínez J, Léger S, Naud C, et al. Photonic-crystal Josephson traveling-wave parametric amplifier. Phys Rev X. 2020;10(2):021021. Available from: https://journals.aps.org/prx/abstract/10.1103/PhysRevX.10.021021
41. Popescu VA. Absorption efficiency of traveling wave photodetectors in superconducting fiber plasmon–polariton optical waveguides. J Supercond Nov Magn. 2012;25:1413–1419. Available from: https://link.springer.com/article/10.1007/s10948-012-1592-3
42. Di Gioacchino D, Enrico E, Falters P. Detector array readout with traveling wave amplifiers. J Low Temp Phys. 2022;209(3):658–666. Available from: https://arxiv.org/abs/2111.01512
43. Ghamsari BG, Majedi AH. Superconductive traveling-wave photodetectors: fundamentals and optical propagation. IEEE J Quantum Electron. 2008;44(7):667–675. Available from: https://doi.org/10.1109/JQE.2008.922409
44. Ghamsari BG, Majedi AH. Superconductive traveling-wave photodetectors. IEEE Trans Appl Supercond. 2009;19(3):371–375. Available from: https://www.researchgate.net/publication/224563886_Superconductive_Traveling-Wave_Photodetectors
45. Majedi AH, Ghamsari BG. THz signal generation/propagation in an integrated traveling-wave superconductive/photoconductive heterodyne photodetector. Proc SPIE. 2006;6373:173–180. Available from: https://doi.org/10.1117/12.686284
46. Stöhr A, Malcoci A, Sauerwald A, Mayorga IC, Güsten R, Jäger DS. Ultra-wide-band traveling-wave photodetectors for photonic local oscillators. J Lightwave Technol. 2003;21(12):3062. Available from: https://doi.org/10.1109/JLT.2003.822257
47. Popescu VA. Very high absorption of traveling wave photodetectors in superconducting fiber plasmon–polariton optical waveguides. J Supercond Nov Magn. 2013;26:243–250. Available from: https://doi.org/10.1007/S10948-012-1823-7
48. Kostin R, Avrakhov P, Didenko A, Kanareykin A, Solyak N, Yakovlev V, et al. A tuner for a superconducting traveling wave cavity prototype. J Instrum. 2015;10(10):P10038. Available from: https://iopscience.iop.org/article/10.1088/1748-0221/10/10/P10038
49. Kostin R, Avrakhov P, Kanareykin A, Yakovlev V, Solyak N. Progress towards 3-cell superconducting traveling wave cavity cryogenic test. J Phys Conf Ser. 2017;941:012100. Available from: https://iopscience.iop.org/article/10.1088/1742-6596/941/1/012100
50. Kuris VV, Vdovicheva NK, Shereshevskii IA. Josephson traveling-wave antennas. Radiophys Quantum Electron. 2017;59:922–936. Available from: https://link.springer.com/article/10.1007/s11141-017-9762-6
51. Galin MA, Shereshevsky IA, Vdovicheva NK, Kurin VV. Coherent radiation of active Josephson traveling-wave antennas. Supercond Sci Technol. 2021;34(7):075005. Available from: https://ui.adsabs.harvard.edu/abs/2021SuScT..34g5005G/abstract
52. Sakai S, Ustinov AV, Kohlstedt H, Petraglia A, Pedersen NF. Theory and experiment on electromagnetic-wave-propagation velocities in stacked superconducting tunnel structures. Phys Rev B. 1994;50(17):12905. Available from: https://journals.aps.org/prb/abstract/10.1103/PhysRevB.50.12905
53. Yoshida K, Kanda Y, Kohjiro S. A traveling-wave-type LiNbO3 optical modulator with superconducting electrodes. IEEE Trans Microw Theory Tech. 1999;47(7):1201–1205. Available from: https://doi.org/10.1109/22.775458
54. Giachero A, Barone C, Borghesi M, Carapella G, Caricato AP, Carusotto I, et al. Proposal for an optomechanical traveling wave phonon–photon translator. New J Phys. 2011;13(1):013017. Available from: https://doi.org/10.1088/1367-2630/13/1/013017
55. Chang T, Nixon WC. Scan-modulation display in scanning electron microscopy. J R Microsc Soc. 1968;88(2):143–149. Available from: https://doi.org/10.1111/j.1365-2818.1968.tb00603.x
56. Kelly TK, Lindqvist WF, Muir MD. Y-modulation: an improved method of revealing surface detail using the scanning electron microscope. Science. 1969;165(3890):283–285. Available from: https://doi.org/10.1126/science.165.3890.283
57. Joy DC. A simple and inexpensive fast scan system for a scanning electron microscope. Micron. 1970;2(2):187–191. Available from: https://doi.org/10.1016/0047-7206(70)90008-7
58. Lebiedzik J. Multiple electron detector method for quantitative microtopographic characterization in the SEM. University Park (PA): The Pennsylvania State University; 1975. Available from: https://www.proquest.com/openview/2de7d19b181cb6a55f41991efd103ad5/1?pq-origsite=gscholar&cbl=18750&diss=y
59. Autrata R, Walther P, Kriz S, Müller M. A BSE scintillation detector in the (S)TEM. Scanning. 1986;8(1):3–8. Available from: https://doi.org/10.1002/sca.4950080103
60. Basu S. Deflection modulation imaging of elements in the scanning electron microscope with energy-dispersive X-rays. J Comput Assist Microsc. 1990;2:25–45.
61. Browne MT, Ward JF. Detectors for STEM, and the measurement of their detective quantum efficiency. Ultramicroscopy. 1982;7(3):249–262. Available from: https://doi.org/10.1016/0304-3991(82)90172-3
62. Crewe AV, Ohtsuki M. A “stand alone” image processing system for STEM images. Ultramicroscopy. 1982;9(1-2):101–108. Available from: https://doi.org/10.1016/0304-3991(82)90232-7
63. Niemietz A, Reimer L. Digital image processing of multiple detector signals in scanning electron microscopy. Ultramicroscopy. 1985;16(2):161–173. Available from: https://doi.org/10.1016/0304-3991(85)90071-3
64. Herzog RF, Greeneich JS, Everhart TE, Van Duzer T. Computer-controlled resist exposure in the scanning electron microscope. IEEE Trans Electron Devices. 1972;19(5):635–641. Available from: https://ieeexplore.ieee.org/document/1476936
65. Newbury DE. Image formation in the scanning electron microscope. In: Practical

Citation: Aleksandrov PL, Filippov MK, Gradov OV, Maklakova IA. Towards YMD (Y-Modulation Detection Algorithms and Devices) Applications in CryoSEM for Surface Studies of Superconductors: Per Aspera ad Astra. Ann Math Phys. 2026;9(2):071-077. Available from: https://dx.doi.org/10.17352/amp.000182

scanning electron microscopy: electron and ion microprobe analysis. 1975. p. 95–148.

66. Tollkamp-Schierjott C, Windsor-Martin J. The SEM as inspection and testing tool in the IC industry. Microelectron Eng. 1986;5(1-4):581–586. Available from: https://doi.org/10.1016/0167-9317(86)90093-6

67. Glück M, König U, Winter W, Brunner K, Eberl K. Modulation-doped Si1−x−yGexCy p-type hetero-FETs. Physica E. 1998;2(1-4):768–771. Available from: https://doi.org/10.1016/S1386-9477(98)00157-X

68. Spence JH. A scanning tunneling microscope in a side-entry holder for reflection electron microscopy in the Philips EM400. Ultramicroscopy. 1988;25(2):165–169. Available from: https://doi.org/10.1016/0304-3991(88)90224-0

69. Breitenstein O. SCANNING-DLTS. J Phys Colloques. 1989;50(C6):C6-101. Available from: https://doi.org/10.1051/jphyscol:1989609

70. Kato T, Matsukawa T, Koyama H, Fujikawa K, Shimizu R. Scanning electron microscopy of charging effect on silicon. J Appl Phys. 1975;46(5):2288–2292. Available from: https://doi.org/10.1063/1.321823

71. Aleksandrov PL, Gradov OV, Gradova MA, Maklakova IA, Popov AA, Ratnovskaya AV, et al. Biocompatible structured materials for tissue engineering based on ethylene–vinyl acetate copolymers: From controllable waviness and microroughness to spatially modulated electrostatics and diffusion programmable by electron beam modifications. Adv Struct Mater. 2025;221:13-41. Available from: https://doi.org/10.1007/978-3-031-75626-9_2

72. Aleksandrov PL, Buryanskaya EL, Gradov OV, Iordansky AL, Maklakova IA, Olkhov AA, et al. Towards the design of electron beam-controlled (optical) fiber microelectromechanical systems based on piezoelectric and ferroelectric polymers and composites. J Radio Electron. 2025;(8):1-46. Available from: https://doi.org/10.30898/1684-1719.2025.8.1

73. Alexandrov PL, Filippov MK, Orekhov TK. Technical notes on the applicability of SEM and EPMA (microprobe analysis) for reconstructing biogeographical and paleoclimatic factors of taphonomic alterations of elasmobranch teeth. Eur Geogr Stud. 2025;12(1):9-25. Available from: https://doi.org/10.13187/egs.2025.1.9

74. Alexandrov PL, Filippov MK, Orekhov TK. Methodological notes on the possibility of electron microscopic study of fossil elasmobranch teeth in ultra-low-budget laboratories. Russ J Biol Res. 2017;12(1):34-59.

75. Anshin SM, Biryukov VP, Gradov OV, Prince AN. Thermoplastic polyurethane (TPU) and nitrile butadiene rubbers (NBR) as promising materials for elastomeric microfluidics and cryomicrofluidics. In: Advances in Machinery, Materials Science and Engineering Application X 2024. IOS Press; 2024;306-313. Available from: https://doi.org/10.3233/ATDE240639

76. Gradov OV. Cryoconveyor protocols in correlative light and electron microscopy: From multilevel imaging to modeling the biophysical effects and "cryotheranostics". Mosc Univ Biol Sci Bull. 2023;78(Suppl 1):S64-S68. Available from: https://doi.org/10.55959/MSU0137-0952-16-78-3S-10

77. Gradov OV. Novel perspectives for CLEM techniques in multiparametric morphology protocols. Int J Biomedicine. 2019;9(Suppl 1):35-P39. Available from: https://doi.org/10.21103/IJBM.9.Suppl_1.P39

78. Buryanskaya EL, Gradov OV, Gradova MA, Kochervinskii VV, Maklakova IA. Time-resolved multifractal analysis of electron beam induced piezoelectric polymer fiber dynamics: Towards multiscale thread-based microfluidics or acoustofludics. Adv Struct Mater. 2023;195:35-58. Available from: https://doi.org/10.1007/978-3-031-28744-2_3

79. Buryanskaya EL, Gradov OV, Gradova MA, Iordanskii AL, Maklakova IA, Olkhov AA. Visualization and quantitative estimation of ferroelectric polymer fiber motility in time-resolved SEM using Gabor atoms. In: Applied Mathematics, Modeling and Computer Simulation 2024. IOS Press; 2024;689-696. Available from: https://doi.org/10.3233/ATDE240821

80. Buryanskaya EL, Gradov OV, Gradova MA, Iordanskii AL, Kochervinskii VV, Maklakova IA, et al. Time-resolved estimation of multifractal spectra of ferroelectric/piezoelectric polymer dynamics and neuromimetic fiber orientation: Towards electric-field-and electron-beam-controllable scaffolds and tissue-engineering constructs with dynamic beads. Adv Struct Mater. 2025;221:97-119. Available from: https://doi.org/10.1007/978-3-031-75626-9_6

81. Elfimov AB, Gradov OV, Gradova MA, Maklakova IA, Sergeev AI. Field-driven and electron beam-driven discrete multi-stable microrotators based on modified HPLC sorbents. Adv Struct Mater. 2025;221:157-189. Available from: https://doi.org/10.1007/978-3-031-75626-9_8

82. Gradov OV, Maklakova IA, Sergeev AI. Time-resolved scanning electron microscopy, time-resolved 2D FFT analysis and high-speed line scanning oscilloscopic measurements in electrostatic sand saltation registration. Aspects Min Miner Sci. 2025;14(3):1745-1748. Available from: https://doi.org/10.31031/AMMS.2025.14.000840

Citation: Aleksandrov PL, Filippov MK, Gradov OV, Maklakova IA. Towards YMD (Y-Modulation Detection Algorithms and Devices) Applications in CryoSEM for Surface Studies of Superconductors: Per Aspera ad Astra. Ann Math Phys. 2026;9(2):071-077. Available from: https://dx.doi.org/10.17352/amp.000182