Western European Journal of Modern Experiments and Scientific Methods
Volume 4, Issue 11 November 2026
https://westerneuropeanstudies.com/index.php/1
ISSN (E): 2942-1896 Open Access| Peer Reviewed
This article/work is licensed under CC Attribution-Non-Commercial 4.0

THICKNESS-DEPENDENT ELECTRICAL TRANSPORT IN THERMALLY EVAPORATED AND OXIDIZED SNO_2 THIN FILMS: A CRITICAL REASSESSMENT OF TEMPERATURE-DEPENDENT RESISTANCE

Madrakhimov Muminjon Moydinovich,
Tuychibayev Baxodir Kurbonaliyevich,
Sherzod Shukhrat oglu Abdullayev
Fergana State Technical University, Fergana, Uzbekistan *Corresponding Author e-mail: madrahimovmuminjon43@gmail.com

Abstract
The thickness dependence of electrical transport in polycrystalline tin dioxide (SnO_2) is important for the reproducible development of oxide-electronic and sensing devices. This manuscript critically reassesses temperature-dependent electrical data reported in a doctoral dissertation for nominal SnO_2 films produced by vacuum thermal evaporation of metallic tin followed by oxidation. The source document describes resistance measurements across 300–500 K and provides trends for log R versus 1000/T, apparent activation energy versus thickness, log conductivity versus $T^{-1/4}$, and a thickness-dependent transport crossover temperature. The reported activation-energy trends decrease with increasing nominal film thickness, while an approximately linear log conductivity–$T^{-1/4}$ representation suggests that localized-state hopping deserves further evaluation. Rather than assigning a unique conduction mechanism on the basis of graph shape alone, we assess the assumptions underlying Arrhenius and three-dimensional Mott variable-range hopping (VRH) descriptions, discuss grain boundaries and oxide stoichiometry as competing explanations, and identify missing measurements needed for quantitative model selection. The analysis indicates that a thickness-dependent evolution of transport barriers is plausible, but reliable activation energies, hopping parameters, and crossover temperatures cannot be established without traceable pointwise data and sample-level uncertainty estimates. The resulting framework provides a reproducible route for assessing transport in thermally fabricated SnO_2 films.
Keywords: tin dioxide; SnO_2; thermal evaporation; oxidation; film thickness; electrical transport; grain boundaries; activation energy; variable-range hopping.

1. Introduction

Tin dioxide is a wide-bandgap oxide semiconductor used in transparent conducting architectures, chemical sensors, and electronic heterostructures. Its macroscopic conductivity reflects coupled contributions from carrier density, mobility, point defects, surface adsorption, and microstructure. In polycrystalline layers, the density and electrostatic state of grain boundaries may substantially modify transport [1,2]. As thickness evolves, incomplete coverage, grain coalescence and defect distributions can alter the dominant conduction path. These effects complicate comparison between films characterized only by nominal thickness or two-terminal resistance.

Vacuum evaporation of Sn followed by controlled oxidation provides one route to tin-oxide films. The oxidation step requires explicit verification because the resulting layer can contain

Western European Journal of Modern Experiments and Scientific Methods
Volume 4, Issue 11 November 2026
https://westerneuropeanstudies.com/index.php/1
ISSN (E): 2942-1896 Open Access| Peer Reviewed
This article/work is licensed under CC Attribution-Non-Commercial 4.0

Sn, SnO and SnO_2 in proportions that depend on atmosphere, temperature, time, and starting thickness. Consequently, any transport interpretation presupposes phase identification and reproducible sample preparation. The dissertation by Madraximov reports a family of thickness-dependent electrical graphs that motivate a systematic evaluation [3].

The present paper asks whether the reported resistance and conductivity trends support a consistent thickness-dependent transport picture and which measurements are necessary to distinguish thermally activated, grain-boundary-limited and hopping processes. Its contribution is a critical, transparent synthesis of the available data rather than an independent claim of newly acquired measurements.

2. Materials and methods

2.1. Film preparation reported in the source

According to the dissertation [3, Chapter III, §3.2], metallic Sn films of different thicknesses were deposited onto glass substrates by vacuum thermal evaporation and were subsequently oxidized to obtain tin-oxide films. Film thicknesses were assessed by gravimetry and optical interference. A quantitative evaporation pressure, Sn source temperature, deposition rate, oxidation temperature, oxidation duration and per-sample identification table are not consistently provided for the exact transport series used here; these quantities must be reconstructed from laboratory records before submission.

2.2. Electrical measurements and data provenance

The dissertation reports resistance/conductivity measurements over 300–500 K under reduced pressure (approximately 10^{-2} Torr), using electrical contacts on the layers [3]. Its Figures 3.1–3.4 display transport trends. The digital source files, individual voltage-current pairs, electrode separation, contact resistance and sample-specific geometric factors were not available for this manuscript. Accordingly, the present figures are explicitly qualitative redrawing aids. They cannot be used to calculate fit coefficients, uncertainty bounds or statistically defensible activation energies.

2.3. Transport analysis

For a simple thermally activated process, conductivity may be modeled as $\sigma(T)=\sigma_0 \exp[-E_a/(kBT)]$. Thus, $\ln \sigma$ plotted against $1/T$ has slope $-E_a/kB$; where resistance is used as a proxy, constant sample geometry and negligible temperature-dependent contact effects must be demonstrated. For three-dimensional Mott VRH, $\sigma(T)=\sigma_0 \exp[-(T_0/T)^{1/4}]$. A visually linear plot against $T^{-1/4}$ is insufficient to uniquely establish VRH because alternative stretched exponentials and composite conduction regimes can produce similar behavior over finite temperature windows [4].

A defensible model comparison should fit the same raw $\sigma(T)$ points to activated conduction, three-dimensional VRH, two-dimensional VRH and Efros–Shklovskii-type hopping where relevant, then compare residual structure and model-selection statistics. Only models with physically interpretable parameters and adequate temperature coverage should be retained.

3. Results

3.1. Temperature-dependent resistance

The reported log R–1000/T profiles increase toward lower temperatures, consistent with semiconducting behavior. The change of apparent slope described in the dissertation could indicate two transport regimes; however, contact contributions or temperature-dependent geometrical effects cannot yet be excluded. Figure 1 provides a reconstructed overview of the qualitative profile, not measured datapoints.

Western European Journal of Modern Experiments and Scientific Methods
Volume 4, Issue 11 November 2026
https://westerneuropeanstudies.com/index.php/1
ISSN (E): 2942-1896 Open Access| Peer Reviewed
This article/work is licensed under CC Attribution-Non-Commercial 4.0

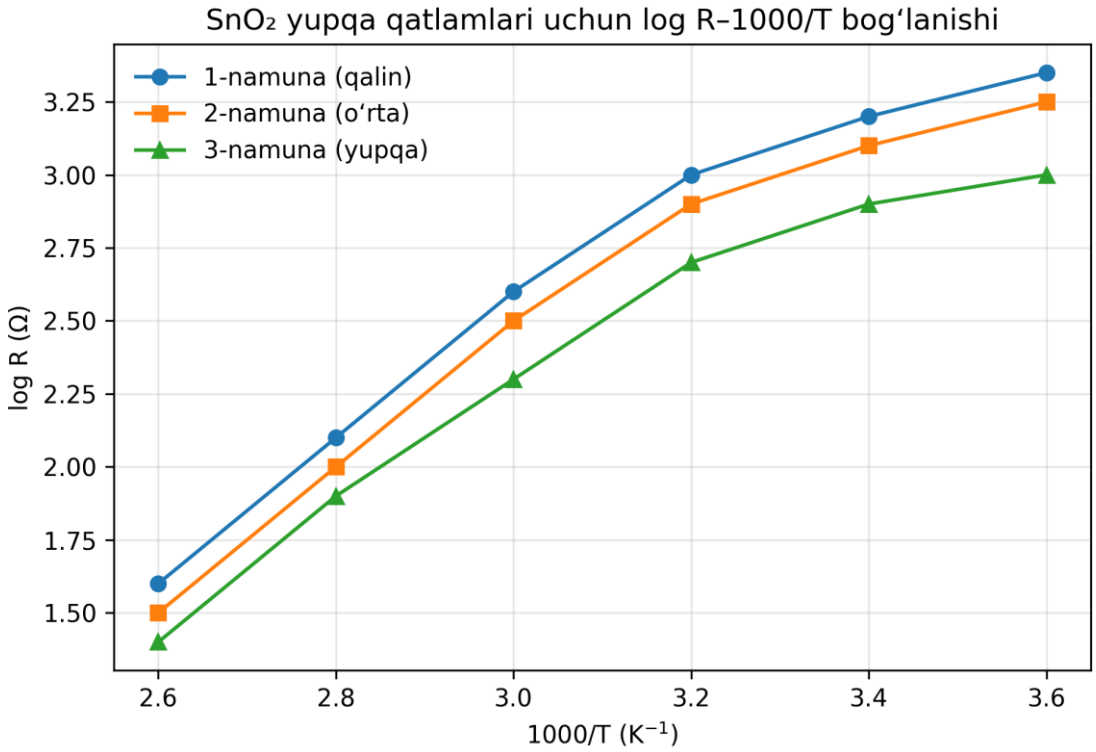


Figure 1. Illustrative reconstruction of the trends shown in dissertation Figure 3.1 (not original experimental values). Exact curves must be replaced with raw measured data.

3.2. Apparent activation energy versus thickness

The dissertation presents decreasing effective activation-energy trends with increasing nominal thickness for two temperature regions. This observation is qualitatively compatible with diminished grain-boundary resistance or improved film connectivity, but neither mechanism follows uniquely from activation energy alone. In particular, the effects of changing stoichiometry, phase fraction, measurement contacts and film geometry must be assessed. Figure 2 illustrates the reported trend; its numerical coordinates are approximate graphical reconstructions.

Western European Journal of Modern Experiments and Scientific Methods
Volume 4, Issue 11 November 2026
https://westerneuropeanstudies.com/index.php/1
ISSN (E): 2942-1896 Open Access| Peer Reviewed
This article/work is licensed under CC Attribution-Non-Commercial 4.0

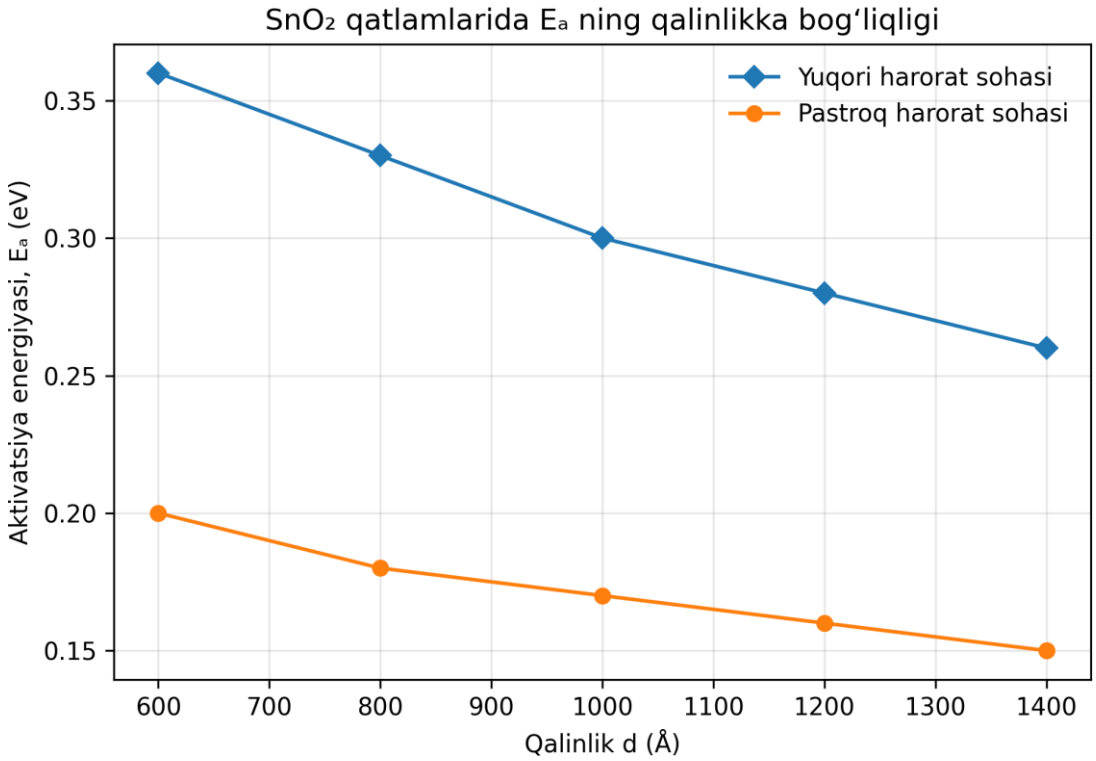


Figure 2. Illustrative reconstruction of activation-energy trends from dissertation Figure 3.2; numerical values are not independently remeasured or fitted.

3.3. Conductivity versus $T^{-1/4}$

The approximately linear log σ–$T^{-1/4}$ trend described in the source is qualitatively compatible with a three-dimensional Mott VRH representation. Nevertheless, the underlying low-temperature range is ambiguous because the measurement section specifies 300–500 K, while adjacent interpretation refers to regimes below 300 K. This inconsistency prevents assigning a low-temperature VRH interval without resolving the experimental temperature log. Figure 3 should therefore be regarded as a visual hypothesis rather than definitive evidence for hopping.

Western European Journal of Modern Experiments and Scientific Methods
Volume 4, Issue 11 November 2026
https://westerneuropeanstudies.com/index.php/1
ISSN (E): 2942-1896 Open Access| Peer Reviewed
This article/work is licensed under CC Attribution-Non-Commercial 4.0

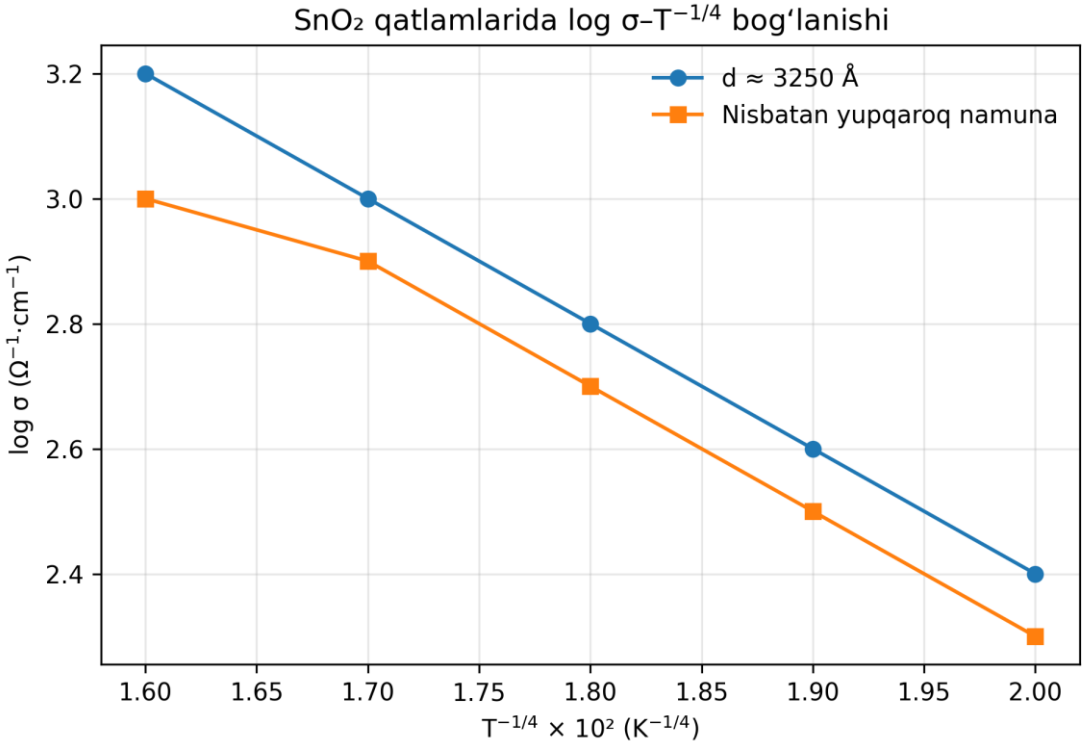


Figure 3. Illustrative reconstruction of the log σ versus $T^{-1/4}$ profiles reported in dissertation Figure 3.3; visual linearity alone does not establish VRH.

3.4. Thickness-dependent crossover behavior

A downward trend in characteristic crossover temperature with increasing thickness is also presented in the dissertation. Such a change may indicate a reduction of disorder-controlled transport with increasing continuity of the film. However, a crossover temperature extracted from the intersection of fitted branches must not be confused with a structural phase-transition temperature. Figure 4 communicates only the reported directional relationship.

Western European Journal of Modern Experiments and Scientific Methods
Volume 4, Issue 11 November 2026
https://westerneuropeanstudies.com/index.php/1
ISSN (E): 2942-1896 Open Access| Peer Reviewed
This article/work is licensed under CC Attribution-Non-Commercial 4.0

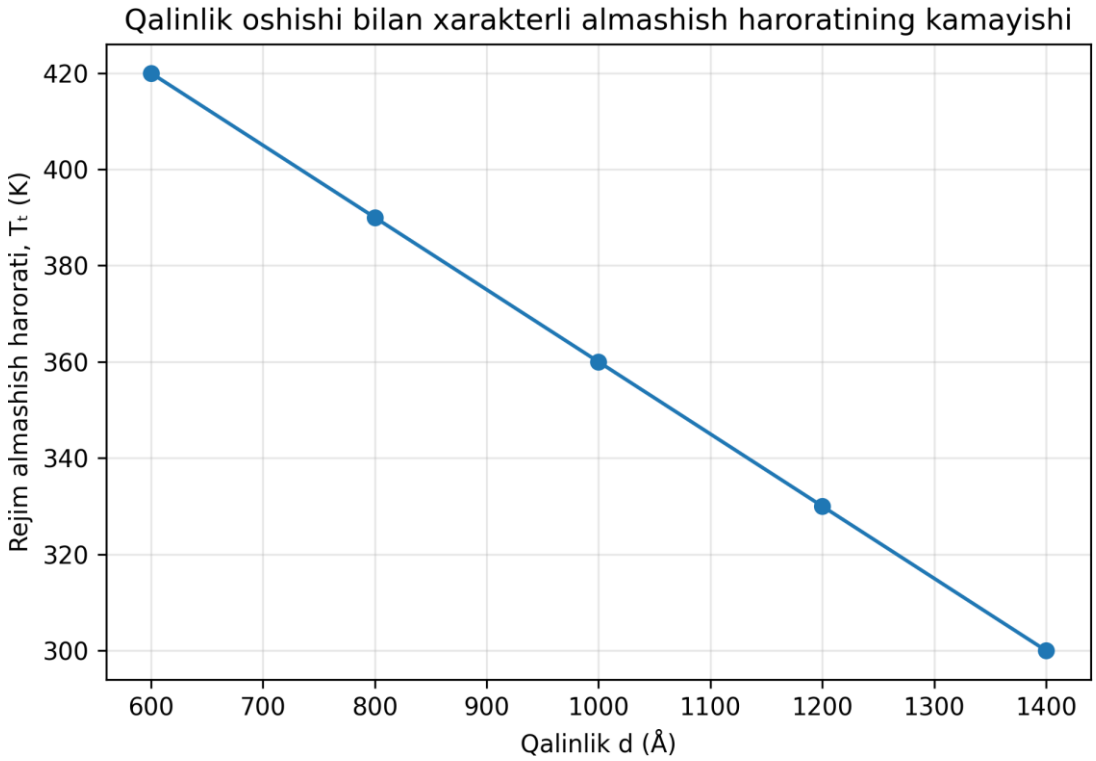


Figure 4. Schematic reconstruction of the reported thickness dependence of the characteristic transport crossover; plotted values are illustrative.

4. Discussion. A physically coherent interpretation must link thickness, microstructure, defect chemistry and the measured electrical pathway. Grain coarsening and increased percolation can decrease effective transport barriers. Conversely, changes in oxygen stoichiometry, trapped charge, roughness, surface adsorption and electrical-contact geometry can produce competing thickness trends. The classic grain-boundary electrostatic framework is useful as a hypothesis but cannot be transferred directly from silicon to SnO_2 without materials-specific constraints [2].

The source figures do not establish whether the same specimens were used for each transport characterization. The resistance ranking in the reconstructed thickness series also requires reconciliation with the conductivity comparison. For identical material and measurement geometry, resistance and conductivity must be related through the exact electrode configuration; comparing uncorrected two-terminal resistance against nominal bulk conductivity may otherwise lead to an apparent contradiction.

The plotted trends support a falsifiable research program: obtain source R(T) files; extract σ(T) using measured specimen dimensions and contact resistance; determine activation energies with confidence intervals; test VRH exponents and residuals; and correlate transport parameters with phase-pure SnO_2 identified by X-ray diffraction and morphology resolved by SEM or AFM. If these checks reproduce the trends, the thickness-dependent barrier interpretation would be substantially strengthened.

Western European Journal of Modern Experiments and Scientific Methods
Volume 4, Issue 11 November 2026
https://westerneuropeanstudies.com/index.php/1
ISSN (E): 2942-1896 Open Access| Peer Reviewed
This article/work is licensed under CC Attribution-Non-Commercial 4.0

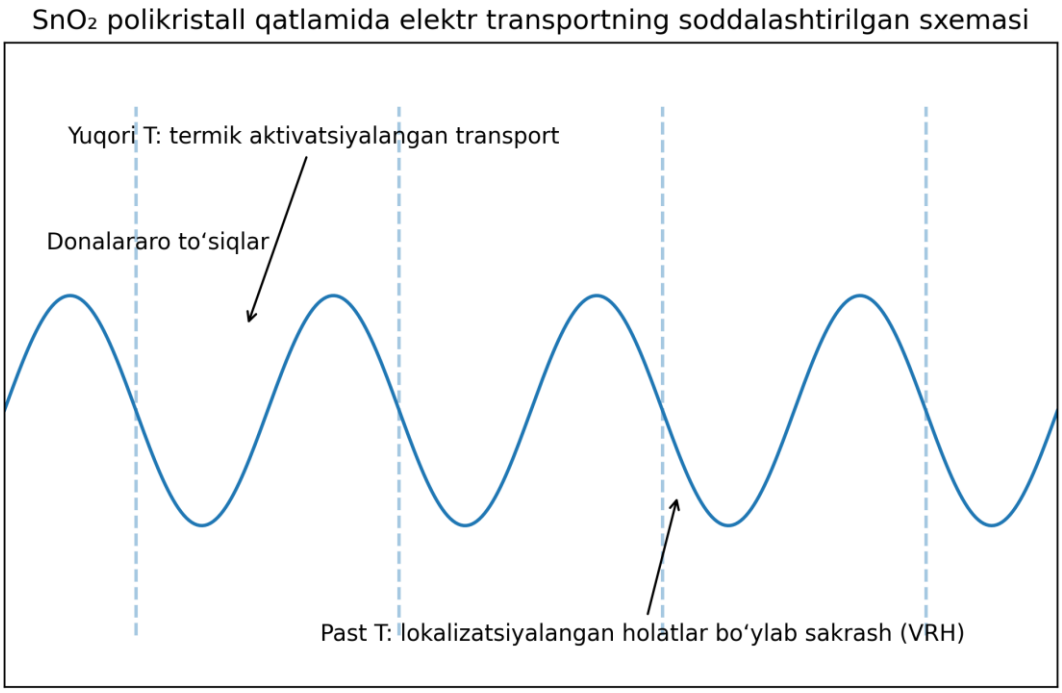


Figure 5. Conceptual diagram only: possible activated and localized transport pathways in a polycrystalline oxide. Not an experimental figure.

5. Limitations and reproducibility

The principal limitation is the absence of the original numerical measurements and detailed sample records. Neither statistical significance nor unique carrier-transport parameters can be inferred from illustrative reconstructions. The figures included here are not publication-ready experimental evidence; they must be replaced with plots built from archived datasets. Phase identification (SnO_2 versus other Sn–O phases), oxidation conditions, electrode geometry, replicate sample count, measurement uncertainty and raw-data availability also require confirmation.

6. Conclusions. The dissertation presents a consistent qualitative picture of thermally sensitive resistance and a decrease in apparent transport activation energy with increasing SnO_2-film thickness. The conductivity trends motivate consideration of localized-state transport, while the thickness dependence of characteristic crossover temperature suggests evolving disorder or connectivity. These observations are promising but do not on their own identify a unique microscopic mechanism. Reanalysis of the original data, comparison among transport models, and direct structural characterization of the same specimens are essential prerequisites for a quantitative research article suitable for external peer review.

Western European Journal of Modern Experiments and Scientific Methods
Volume 4, Issue 11 November 2026
https://westerneuropeanstudies.com/index.php/1
ISSN (E): 2942-1896 Open Access| Peer Reviewed
This article/work is licensed under CC Attribution-Non-Commercial 4.0

Declarations. Funding: To be confirmed by the author. Conflicts of interest: To be declared by the author. Data availability: Original pointwise R(T) and σ(T) datasets were not provided for manuscript preparation; raw measurements and metadata must be deposited or made available according to the selected journal's policy. Author contributions: To be confirmed. Ethics approval: Not applicable to conventional materials characterization (subject to journal policy).

References.

[1] Batzill M, Diebold U. The surface and materials science of tin oxide. Progress in Surface Science. 2005;79(2–4):47–154. doi:10.1016/j.progsurf.2005.09.002.
[2] Seto JYW. The electrical properties of polycrystalline silicon films. Journal of Applied Physics. 1975;46(12):5247–5254. doi:10.1063/1.321593.
[3] N.A. Sultanov, Z. Mirzajonov, M.M. Madrakhimov, T.I. Rakhmonov A study of the production technology and electrical characteristics of silicon-based SnO2 heterojunctions.
[4] Madraximov MM. Development of Technologies for Obtaining Silicon-Based Heterostructures from Tin Oxide Layers and Investigation of Their Electrophysical and Optical Properties. PhD dissertation manuscript. Fergana State Technical University; 2026. (Original in Uzbek; title translated.)
[5] Mott NF, Davis EA. Electronic Processes in Non-Crystalline Materials. 2nd ed. Oxford: Clarendon Press; 1979.