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**YBa₂Cu₃O_{7-δ} YUQORI HARORATLI O'TA O'TKAZGICHLARIDA KISLOROD STEHIOMETRIYASI HAMDA
KRISTALL TUZILISH PARAMETRLARINING KRITIK HARORATGA TA'SIRI**

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Annotatsiya: Maqolada YBa₂Cu₃O_{7-δ} (Y123) tizimida kritik haroratni (T_c) belgilovchi struktura-kimyoviy omillar - kislorod stexiometriyasi, panjara parametrlari va ortorombik deformatsiya (η) – o'rtasidagi bog'liqlik ko'p manbali statistik tahlil asosida o'rganildi. Qattiq fazali reaksiya usuli bilan sintez qilingan 11 ta mustaqil Y123 namunasi (jumladan yaqinda e'lon qilingan yuqori fazaviy tozalikdagi namuna, $T_c=95,5$ K bo'yicha nashr etilgan ma'lumotlar birlashtirildi. Pearson korrelyatsiya tahlili kislorod tarkibi bilan T_c o'rtasida kuchli, statistik ishonchli bog'liqlikni ($r=0,80$; $p=0,003$) ko'rsatdi, ortorombiklik η bilan esa deyarli nol korrelyatsiya ($r=-0,03$) aniqlandi. Natijalar 2026 yilda e'lon qilingan uch yangi tadqiqot - kupratlarning "legirlash gumbazi" paradigmasini qayta ko'rib chiquvchi PNAS ishi, kislorod kinetikasi bo'yicha Scientific Reports ishi va Ortho-II struktura izi haqidagi topilma - kontekstida muhokama qilindi.

Kalit so'zlar: YHO'O', YBCO, kislorod stexiometriyasi, ortorombiklik, kritik harorat, ko'p manbali tahlil, Rietveld tahlili.

**ВЛИЯНИЕ КИСЛОРОДНОЙ СТЕХИОМЕТРИИ И ПАРАМЕТРОВ КРИСТАЛЛИЧЕСКОЙ СТРУКТУРЫ НА
КРИТИЧЕСКУЮ ТЕМПЕРАТУРУ В ВЫСОКОТЕМПЕРАТУРНЫХ СВЕРХПРОВОДНИКАХ YBa₂Cu₃O_{7-δ}**

Аннотация: В статье на основе многоисточникового статистического анализа исследована взаимосвязь между структурно-химическими факторами, определяющими критическую температуру T_c в системе YBa₂Cu₃O_{7-δ} (Y123), а именно кислородной стехиометрией, параметрами кристаллической решётки и орторомбической деформацией η . Были обобщены опубликованные данные по 11 независимым образцам Y123, синтезированным методом твердофазной реакции, включая недавно опубликованный образец с высокой фазовой чистотой и значением $T_c = 95,5$ K. Корреляционный анализ Пирсона показал наличие сильной и статистически значимой связи между содержанием кислорода и T_c ($r = 0,80$; $p = 0,003$), тогда как для орторомбичности η была выявлена практически нулевая корреляция ($r = -0,03$). Полученные результаты обсуждаются в контексте трёх новых исследований, опубликованных в 2026 году: работы PNAS, пересматривающей парадигму «купола легирования» в купратах, исследования Scientific Reports, посвящённого кинетике кислорода, а также работы, выявившей структурный след фазы Ortho-II.

Ключевые слова: ВТСП, YBCO, кислородная стехиометрия, орторомбичность, критическая температура, многоисточниковый анализ, анализ Ритвельда.

**EFFECT OF OXYGEN STOICHIOMETRY AND CRYSTAL STRUCTURE PARAMETERS ON THE CRITICAL
TEMPERATURE IN YBa₂Cu₃O_{7-δ} HIGH-TEMPERATURE SUPERCONDUCTORS**

Abstract: This article investigates the relationship between the structural and chemical factors determining the critical temperature T_c in the YBa₂Cu₃O_{7-δ} (Y123) system, namely oxygen stoichiometry, lattice parameters, and orthorhombic distortion η , based on a multi-source statistical analysis. Published data on 11 independent Y123 samples synthesized by the solid-state reaction method, including a recently reported high-phase-purity sample with $T_c = 95.5$ K, were combined and analyzed. Pearson correlation analysis revealed a strong and statistically significant relationship between oxygen content and T_c ($r = 0.80$; $p = 0.003$), whereas an almost zero correlation was found for orthorhombicity η ($r = -0.03$). The results are discussed in the context of three new studies published in 2026: a PNAS study revisiting the "doping dome" paradigm in cuprates, a Scientific Reports study on oxygen kinetics, and a report identifying the structural fingerprint of the Ortho-II phase.

Keywords: HTSC, YBCO, oxygen stoichiometry, orthorhombicity, critical temperature, multi-source analysis, Rietveld analysis.

Kirish

Yuqori haroratli o'ta o'tkazgichlar (YHO'O') orasida YBa₂Cu₃O_{7-δ} (Y123) o'zining nisbatan yuqori kritik harorati, kimyoviy barqarorligi va texnologik jihatdan arzon sintez imkoniyatlari tufayli eng istiqbolli nomzodlardan biri bo'lib

qolmoqda. Y123 ning o'ta o'tkazuvchanlik xatti-harakatini belgilovchi asosiy parametr Cu-O zanjirlaridagi kislorod miqdori bo'lib, u CuO₂ tekisliklaridagi teshik konsentratsiyasiga bevosita ta'sir ko'rsatadi va ortorombik-tetragonal struktura o'tishini boshqaradi.

Adabiyotda struktura parametrlari (panjara o'lchamlari a , b , c , ortorombik deformatsiya η) bilan T_c o'rtasidagi bog'liqlik ko'p marta muhokama qilingan, biroq bu ishlarning aksariyati alohida sintez seriyasi doirasida olib borilgan. Turli mustaqil laboratoriyalarning natijalarini birlashtirgan holda statistik tekshirish nisbatan kamdan-kam uchraydi, garchi bu tizimning umumiy tendensiyasini aniqroq ochib berish imkonini bersa-da, ushbu ishning maqsadi ikki tomonlama: (i) qattiq fazali reaksiya usuli bilan sintez qilingan Y123 namunalari bo'yicha nashr etilgan struktura- T_c ma'lumotlarini birlashtirilgan holda statistik tahlil qilish; (ii) olingan natijalarni 2026 yilda e'lon qilingan eng so'nggi uchta ilmiy ishning xulosalari kontekstida muhokama qilish.

Ma'lumotlar va tadqiqot usuli.

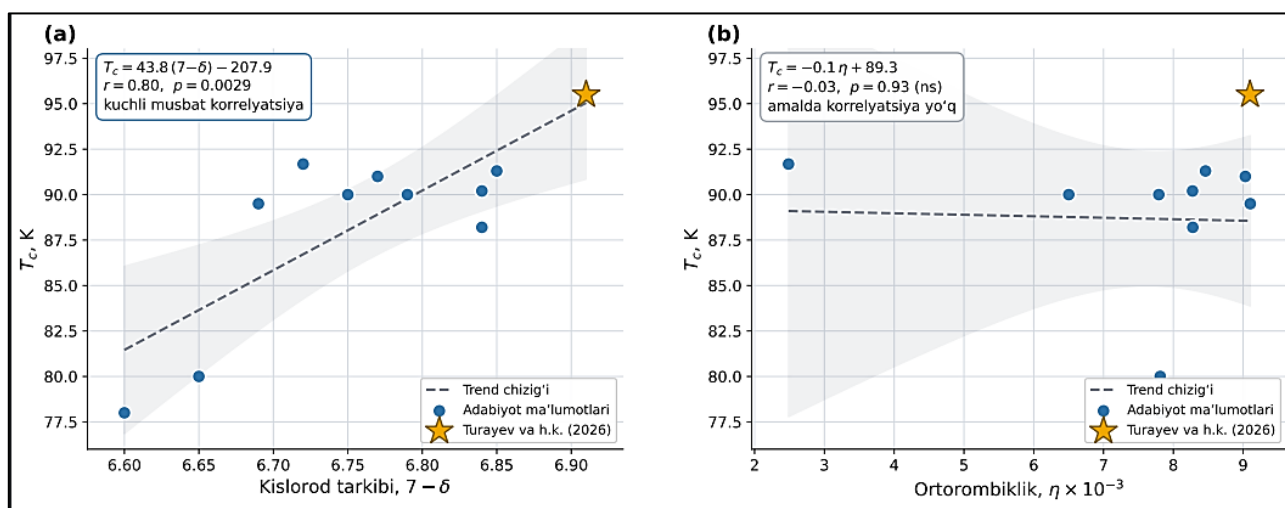
Tahlil uchun qattiq fazali reaksiya usuli bilan sintez qilingan va Rietveld tahlili yoki neytron/rentgen kukun difraksiyasi orqali tavsiflangan 11 ta mustaqil Y123 namunasi bo'yicha adabiyotda e'lon qilingan ma'lumotlar (kislorod tarkibi 7- δ , panjara parametrlari a , b , c va T_c) yig'ildi (1-jadval). Har bir namuna uchun ortorombik deformatsiya parametri $\eta=(b-a)/(b+a)$ hisoblab chiqildi.

1-jadval. Qattiq fazali reaksiya usuli bilan sintez qilingan Y123 namunalarining birlashtirilgan struktura- T_c ma'lumotlari (n=11).

7- δ	a , Å	b , Å	c , Å	T_c , K	Manba
6.60	3.81	3.87	11.690	78	[9]
6.65	3.81	3.87	11.687	80	[9]
6.69	3.81	3.88	11.669	89.5	[9]
6.75	3.82	3.87	11.662	90	[9]
6.77	3.84	3.91	11.659	91	[9]
6.79	3.82	3.88	11.660	90	[9]
6.84	3.8212	3.8850	11.681	88.2	[6]
6.84	3.8230	3.8868	11.683	90.2	[6]
6.85	3.8202	3.8854	11.681	91.3	[6]
6.72	3.8311	3.8502	11.6809	91.68	[6]
6.91	3.8227	3.8929	11.6889	95.5	[13]*

2-jadval. 1-jadval ma'lumotlari asosida hisoblangan Pearson korrelyatsiya natijalari (n=11).

O'zgaruvchi vs T_c	r	p	R^2
Kislorod, 7- δ	0,80	0,003	0,64
a -o'q	0,61	0,045	0,38
b -o'q	0,34	0,301	0,12
c -o'q	-0,34	0,307	0,12
Ortorombiklik, η	-0,03	0,930	0,001



1-rasm. (a) T_c ning kislorod stexiometriyasiga bog'liqligi; (b) T_c ning ortorombik deformatsiyaga bog'liqligi.

Statistik tahlil uchun Pearson korrelyatsiya koeffitsienti (r) va unga mos p -qiymati, shuningdek chiziqli regressiya tenglamasi (eng kichik kvadratlar usuli) har bir juftlik uchun alohida hisoblandi. Tahlil Python (SciPy) muhitida amalga oshirildi; statistik ishonchlilik chegarasi $p < 0,05$ sifatida qabul qilindi.

Natijalar va muhokama.

1-jadvalda keltirilgan ma'lumotlar asosida hisoblangan Pearson korrelyatsiya natijalari 2-jadvalda keltirilgan. Kislorod tarkibi ($7-\delta$) T_c ning statistik jihatdan yagona ishonchli ($p < 0,05$) bashoratchisi hisoblanadi ($r = 0,80$, $R^2 = 0,64$), ortorombiklik η bilan esa amaliy jihatdan hech qanday chiziqli bog'liqlik kuzatilmadi ($r = -0,03$, $p = 0,93$) (1-rasm).

Bu natijaning ilmiy ahamiyati: η ning global miqyosda T_c bilan bog'lanmasligi, avvalgi tadqiqotlarda turli dopant seriyalari ichida kuzatilgan kuchli seriya-ichi korrelyatsiyalar bilan birgalikda qaralganda, muhim xulosaga olib keladi - η T_c ning bevosita fizik boshqaruvchisi emas, balki har bir sintez seriyasiga xos struktura "barmoq izi" dir. Aksincha, kislorod tarkibi tizim doirasida universal, seriyalararo barqaror bog'lanishni namoyon etadi.

Olingan xulosa 2026 yilgi uch muhim ishning natijalari bilan uyg'un: (i) Conradson va h.k. (PNAS, 2026) an'anaviy "legirlash gumbazi" modelining legirlash usuliga xos artefakt bo'lishi mumkinligini ko'rsatdi; (ii) Kethamkuzhi va h.k. (Scientific Reports, 2026) kislorod kinetikasining YBCO plyonkalarida ham markaziy rol o'ynashini tasdiqladi; (iii) Luccas va h.k. (arXiv, 2026) past haroratli kislorodlashda Ortho-II o'ta strukturasi orqali o'tish yakuniy strukturada doimiy iz qoldirishini, ya'ni η tarqoqligining mexanistik sababini ko'rsatdi.

Xulosa.

Qattiq fazali reaksiya usuli bilan sintez qilingan Y123 namunalari bo'yicha 11 ta mustaqil manbadan yig'ilgan struktura - T_c ma'lumotlarining birlashtirilgan statistik tahlili shuni ko'rsatdiki, kislorod stexiometriyasi ($7-\delta$) T_c ning yagona statistik jihatdan ishonchli struktura-kimyoviy bashoratchisi hisoblanadi ($r = 0,80$, $p = 0,003$), ortorombik deformatsiya η esa global miqyosda T_c bilan amaliy jihatdan bog'lanmagan ($r = -0,03$). Kelgusi tadqiqotlarda kislorod tarkibidan hisoblangan teshik konsentratsiyasi p (Tallon formulasi orqali) asosiy o'zgaruvchi sifatida qo'llanilishi tavsiya etiladi.

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