Appendix

Tab. I Electrical properties of as-deposited CTO films

Deposition atmosphere	Sample	A (388 nm)	B (358 nm)	C (172 nm)	D (142 nm)
80% Ar + 20% O_2	Sheet resistance (× 10^4 Ω/□)	0.935	1.803	1.367	3.126
	Resistivity (Ω cm)	0.363	0.646	0.235	0.444
	Carrier mobility (cm^2/Vs)	19.1	15.0	18.7	9.74
	Carrier concentration (× 10^{17} /cm^3)	9.00	6.43	14.21	14.44
Ar	Sample	A′ (627 nm)	B′ (420 nm)	C′(210 nm)	D′(150 nm)
	Sheet resistance (Ω/□)	9.769	16.24	33.48	51.03
	Resistivity (× 10^{-4} Ω cm)	6.14	6.66	7.03	7.65
	Carrier mobility (cm^2/Vs)	26.4	37.6	24.4	19.2
	Carrier concentration (× 10^{20} /cm^3)	3.854	2.495	3.640	4.244

Tab. II Electrical properties of CTO films annealed at 560°C

Deposition atmosphere	Sample	A (388 nm)	B (358 nm)	C (172 nm)	D (142 nm)
80% Ar + 20% O_2	Sheet resistance (Ω/□)	113.5	48.34	26.05	28.93
	Resistivity (× 10^{-4} Ω cm)	44	17.3	4.48	4.49
	Carrier mobility (cm^2/Vs)	14.8	21	36	39.3
	Carrier concentration (× 10^{20} /cm^3)	0.958	1.718	3.867	3.544
Ar	Sample	A′ (627 nm)	B′ (420 nm)	C′ (210 nm)	D′ (150 nm)
	Sheet resistance (Ω/□)	3047	321	24.55	34.35
	Resistivity (× 10^{-4} Ω cm)	191	13.5	5.16	5.15
	Carrier mobility (cm^2/Vs)	0.149	1.16	51	43
	Carrier concentration (× 10^{20} /cm^3)	2.197	3.987	2.372	2.819

Tab. III Electrical properties of CTO films annealed at 580°C

Deposition atmosphere	Sample	A (388 nm)	B (358 nm)	C (172 nm)	D (142 nm)
80% Ar + 20% O_2	Sheet resistance (Ω/□)	32.85	31.56	23.38	26.59
	Resistivity (× 10^{-4} Ω cm)	12.75	11.3	4.02	4.12
	Carrier mobility (cm^2/Vs)	31	31.8	30.2	33.3
	Carrier concentration (× 10^{20} /cm^3)	1.581	1.734	5.145	4.545
Ar	Sample	A′ (627 nm)	B′ (420 nm)	C′ (210 nm)	D′ (150 nm)
	Sheet resistance (Ω/□)	1659	437.2	37.11	53.46
	Resistivity (× 10^{-4} Ω cm)	104	18.4	7.79	8.01
	Carrier mobility (cm^2/Vs)	0.14	1.57	43.1	27.6
	Carrier concentration (× 10^{20} /cm^3)	4.273	2.171	1.860	2.823

Tab. IV Electrical properties of CTO films annealed at 600°C

Deposition atmosphere	Sample	A (388 nm)	B (358 nm)	C (172 nm)	D (142 nm)
80% Ar + 20% O_2	Sheet resistance (Ω/□)	9.15	8.56	19.24	18.77
	Resistivity (× 10^{-4} Ω cm)	3.55	3.07	3.31	2.67
	Carrier mobility (cm^2/Vs)	37.6	45.5	32.9	37.7
	Carrier concentration (× 10^{20} /cm^3)	4.683	4.485	5.738	6.219
Ar	Sample	A′ (627 nm)	B′ (420 nm)	C′ (210 nm)	D′ (150 nm)
	Sheet resistance (Ω/□)	415.8	571.5	33.84	53.32
	Resistivity (× 10^{-4} Ω cm)	261	240	7.11	8.00
	Carrier mobility (cm^2/Vs)	0.971	1.62	51.1	46.6
	Carrier concentration (× 10^{20} /cm^3)	2.465	1.606	1.717	1.673

Tab. V Electrical properties of CTO films annealed at 620°C

Deposition atmosphere	Sample	A (388 nm)	B (358 nm)	C (172 nm)	D (142 nm)

80% Ar + 20% O_2	Sheet resistance (Ω/□)	5.07	5.34	10.90	12.21
	Resistivity (× 10^{-4} Ω cm)	1.97	1.91	1.88	1.73
	Carrier mobility (cm^2/Vs)	41.6	49.7	44.3	43.7
	Carrier concentration (× 10^{20} /cm^3)	7.616	6.596	7.516	8.245
Ar	Sample	A′ (627 nm)	B′ (420 nm)	C′ (210 nm)	D′ (150 nm)
	Sheet resistance (Ω/□)	487	534	68.29	28.79
	Resistivity (× 10^{-4} Ω cm)	305	225	14.3	7.32
	Carrier mobility (cm^2/Vs)	1.29	2.36	22.8	45.2
	Carrier concentration (× 10^{20} /cm^3)	1.852	1.178	1.913	1.887

Tab. VI Electrical properties of CTO films annealed at 635°C

Deposition atmosphere	Sample	A (388 nm)	B (358 nm)	C (172 nm)	D (142 nm)
80% Ar + 20% O_2	Sheet resistance (Ω/□)	9.08	8.542	15.8	14.87
	Resistivity (× 10^{-4} Ω cm)	3.52	3.06	2.59	2.11
	Carrier mobility (cm^2/Vs)	41.2	38.9	40.9	38.7
	Carrier concentration (× 10^{20} /cm^3)	4.302	5.248	5.876	7.638
Ar	Sample	A′ (627 nm)	B′ (420 nm)	C′ (210 nm)	D′ (150 nm)
	Sheet resistance (Ω/□)	705.5	1321	32.69	46.43
	Resistivity (× 10^{-4} Ω m)	443	555	6.87	6.96
	Carrier mobility (cm^2/Vs)	0.77	0.63	43.0	40.2
	Carrier concentration (× 10^{20} /cm^3)	1.831	1.780	2.133	2.232

Tab. VII Some annealing research works about CTO

Deposition atmosphere and target	Anneal atmosphere	Anneal temperature and time	Resistivity ρ (lowest), carrier mobility μ, and carrier concentration n.	Reference
Ar/O_2, Cd-Sn alloy target.	Ar	400-500°C，40 min.	ρ = ～10^{-4} Ω cm	[3]
Ar/O_2, Cd-Sn alloy target.	Ar	500°C，2 hour.	ρ = 1.74 × 10^{-4} Ω cm, n = 4.46 × 10^{20} /cm^3	[4]

Ar/O_2, Cd_2SnO_4 ceramic target.	Ar/CdS	600-700°C , 10 min.	$\rho = 1.54 \times 10^{-4}$ Ω cm, n = ～10^{21} /cm^3	[5]
O_2, Cd_2SnO_4, ceramic target.	Ar, Ar/CdS	580-700°C ,10-30 min.	$\rho = 1.28 \times 10^{-4}$ Ω cm, n = 8.94×10^{20} /cm^3, μ = 54.5（cm^2/Vs）	[7]
Ar/O_2, ceramic target.	Ar/CdS	450-700°C , 30 min.	$P = 1.6 \times 10^{-4}$ Ω cm, n = 7.4×10^{20} /cm^3, μ = 52（cm^2/Vs）	[8]
Ar, (cosputtering) CdO target and SnO_2 target.	He, H_2	500-700°C , 20 min.	$P = 2.01 \times 10^{-4}$ Ω cm, n = 5.8×10^{20} /cm^3, μ = 29.2.（cm^2/Vs）	[9]
Ar/O_2, ceramic target.	Air	600°C , 30 min.	ρ = ～6.6×10^{-2} Ω cm	[10]
Ar/O_2, ceramic target.	He/CdS (low pressure)	650°C , 700°C , 15 min.	$\rho = 1.9 \times 10^{-4}$ Ω cm, n = 5.9×10^{20} /cm^3, μ = 54（cm^2/Vs）	[11]
Ar/O_2, ceramic target.	CdS	600°C , 1 hour.	$\rho = 2.8 \times 10^{-4}$ Ω cm, n = 5.5×10^{20} /cm^3, μ = 40（cm^2/Vs）	[12]
N_2	620	620°C, 30 min.	$\rho = 1.73 \times 10^{-4}$ Ω cm, n = 8.2×10^{20} /cm^3, μ = 43.7（cm^2/Vs）	This work

Tab. VIII Electrical properties of CTO films after both 1st N_2 annealing and 2nd chloride treatment

Sample	N_2 gas annealing temperature (°C)	560	580	600	620	635
A (388 nm)	Sheet resistance（Ω/□）	225.5	354.3	9.59	8.43	10.72
	Resistivity（× 10^{-4} Ω cm）	87.5	137.5	3.72	3.27	4.16
	Carrier mobility（cm^2/Vs）	6.1	5.85	40.9	49.9	38.4
	Carrier concentration（× 10^{20} /cm^3）	1.169	1.776	4.095	3.822	3.528
C (172 nm)	N_2 gas annealing temperature (°C)	560	580	600	620	635
	Sheet resistance（Ω/□）	41.16	1021.9	14.83	12.67	17.73
	Resistivity（× 10^{-4} Ω m）	7.08	175.8	2.55	2.18	3.05

	Carrier mobility（cm^2/Vs）	31.9	6.56	48.2	59.7	37
	Carrier concentration（$\times 10^{20}$ $/cm^3$）	2.76	0.541	5.081	4.79	5.546