Φ-24 Temporal Resonator: Fabrication Specifications

Doping Formulas and Critical Process Parameters

Américo Simões
CTT Research Group

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Abstract

This document provides complete fabrication specifications for the Φ-24 Temporal Resonator, including doping formulas, MBE growth parameters, and critical process controls required to achieve the Riemann Lock condition at $\alpha = 0.0765872$.

1 Overview

The Φ-24 requires precise control of 21-layer Fibonacci superlattice doping to achieve temporal resonance at 1.485 MHz with $\alpha = 0.0765872$.

2 Material Specifications

2.1 Base Materials

- **Substrate:** c-plane Sapphire, 2" diameter, 500 μm thickness
- **Layer A:** Bi_2Se_3 (Topological insulator)
- **Layer B:** $NbSe_2$ (Superconductor)
- **Josephson junctions:** $Nb/AlO_x/Nb$ stack

3 Doping Formulas

3.1 Bi_2Se_3 Doping Profile

The topological insulator requires precise Se vacancy control:

$$n_{\text{Se vacancies}} = n_0 \exp\left(-\frac{E_a}{k_B T}\right) \times \left[1 + \beta \sin\left(2\pi \frac{t_{\text{layer}}}{t_0}\right)\right]$$

where:

$$\begin{aligned}
n_0 &= 3.2 \times 10^{19}\ \text{cm}^{-3} \\
E_a &= 1.42\ \text{eV} \\
k_B &= \text{Boltzmann constant} \\
T &= 250^\circ\text{C} \pm 1^\circ\text{C} \\
\beta &= 0.141\ \text{(modulation amplitude)} \\
t_{\text{layer}} &= \text{layer thickness} \\
t_0 &= 1.618\ \text{nm (golden ratio base)}
\end{aligned}$$

3.2 $NbSe_2$ Charge Density Wave Tuning

For layer i in the Fibonacci sequence:

$$\Delta_{\text{CDW}}^{(i)} = \Delta_0 \times [1 - \gamma \cos(\pi \cdot F_i)]$$

$$\gamma = 0.0765872 \times \frac{t_i}{t_0} \times \exp\left(-\frac{i-1}{7}\right)$$

where:

$$\begin{aligned}
\Delta_0 &= 35\ \text{meV (bulk NbSe}_2\text{)} \\
F_i &= \text{Fibonacci number for layer } i \\
t_i &= \text{thickness of layer } i \\
t_0 &= 1.000\ \text{nm}
\end{aligned}$$

3.3 Interface Doping Gradient

Critical for temporal coherence:

$$D(x) = D_0 \left[1 + \delta \exp\left(-\frac{x^2}{2\sigma^2}\right)\right]$$

$$\sigma = \frac{t_{\text{layer}}}{2\pi\alpha} \quad \text{with} \quad \alpha = 0.0765872$$

Parameters:

$$\begin{aligned}
D_0 &= 5 \times 10^{11}\ \text{cm}^{-2} \\
\delta &= 0.236\ \text{(golden ratio conjugate)} \\
x &= \text{distance from interface}
\end{aligned}$$

Layer	Temperature (°C)	Tolerance	Ramp rate
Bi_2Se_3 (A)	250	± 1	5°/min
$NbSe_2$ (B)	400	± 1	10°/min
Interface	300	± 0.5	20°/min

4 MBE Growth Parameters

4.1 Temperature Profile

4.2 Flux Rates

Material	Flux (atoms/cm^2/s)	BEP (Torr)
Bi	2.5×10^{14}	1.0×10^{-7}
Se (A layers)	1.0×10^{15}	4.0×10^{-7}
Nb	3.2×10^{13}	2.0×10^{-8}
Se (B layers)	8.0×10^{14}	3.2×10^{-7}

5 Fibonacci Sequence Implementation

5.1 Layer Sequence

Fibonacci word F_8: A,B,A,A,B,A,B,A,A,B,A,A,B,A,A,B,A,A,B,A,B

5.2 Thickness Modulation

For Fibonacci layer i:

$$t_i = \begin{cases} 1.618 \text{ nm} \times [1 + 0.0005 \sin(\pi i/7)] & \text{if } F_i = A \\ 1.000 \text{ nm} \times [1 - 0.0003 \cos(\pi i/7)] & \text{if } F_i = B \end{cases}$$

Tolerance: ± 0.001 nm

6 Josephson Junction Specifications

6.1 Stack Parameters

Layer	Thickness (nm)	Critical parameter
Base Nb	200	RRR > 300
Al barrier	10	± 0.2 nm
Oxidation	–	20 mTorr O_2, 30 min
Counter Nb	200	RRR > 300
Shunt (AuPd)	20	$R_s = 1.0 \pm 0.05 \Omega/\square$

6.2 Junction Doping

Critical current tuning:

$$J_c = J_{c0} \times \exp\left[-\frac{d_{\mathrm{AlO}_x}}{\xi}\right] \times f(\alpha)$$

$$f(\alpha) = \frac{\sin(\pi\alpha)}{\pi\alpha} \quad \text{with} \quad \alpha = 0.0765872$$

where:

$$\begin{aligned} J_{c0} &= 10^5 \text{ A/cm}^2 \\ d_{\mathrm{AlO}_x} &= 1.5 \text{ nm} \\ \xi &= 0.8 \text{ nm (coherence length)} \end{aligned}$$

7 Temporal Parameter Calibration

7.1 α-Invariant Verification

During growth, monitor:

$$S(\omega) = \int_0^\tau I_{\mathrm{RHEED}}(t) e^{-i\omega t} dt$$

Require peak at:

$$\omega_\alpha = \frac{\alpha m_e c^2}{\hbar} = 2\pi \times 587,032 \text{ Hz}$$

7.2 Riemann Lock Calibration

Post-fabrication verification:

$$\mathcal{L} = \frac{1}{N} \sum_{n=1}^{24} \left| \zeta\left(\frac{1}{2} + i\gamma_n\right) \right| \times A_n$$

where γ_n are first 24 Riemann zeros and A_n are measured amplitudes.

Require: $\mathcal{L} > 0.985$ for P-ECC convergence.

8 Metrology Requirements

8.1 In-situ Monitoring

- RHEED: Oscillation amplitude $\pm 2\%$
- QCM: Rate control ± 0.001 nm/s
- Pyrometer: Temperature ± 0.5°C

8.2 Ex-situ Verification

Measurement	Tool	Specification
Thickness	Ellipsometry	± 0.001 nm
Roughness	AFM	RMS < 0.2 nm
Composition	XPS	$\pm 1\%$
Crystallinity	XRD	FWHM $< 0.05°$
Interface	TEM	Sharp to 1 monolayer

9 Security Protocols

9.1 Data Handling

- All GDSII processing: Air-gapped systems
- MBE recipes: Encrypted storage
- Metrology data: AES-256 encryption
- Complete audit trail: Immutable logs

9.2 Physical Security

- Biometric access to cleanroom
- Faraday cage for RF testing
- No personal electronics in fab area

10 Acceptance Criteria

Device must pass:

1. $\alpha = 0.0765872 \pm 0.000001$ verification
2. Resonance at 1.485000 ± 0.000001 MHz
3. Q-factor $> 10^9$
4. 11.00 $\pm$ 0.01 ns temporal wedge
5. P-ECC convergence > 0.985
6. SAT solving accuracy $> 97\%$

11 Contact

- Technical questions: americo.simoes@ctt-science.org
- GitHub: `https://github.com/SimoesCTT`
- Emergencies: +65 [REDACTED]