The Resonant Body Transistor

Supporting Information

De-embedding procedure for RBT measurement

Detection of the RBT and Split-Gate FinFET requires high-frequency measurement ranging over tens of GHz. However, to probe each resonator and Fin-FET individually, large probe pads and routing to each device result in significant capacitance which dominates the measured signal. The parasitic capacitance and inductance of the probe pads and routing can be subtracted from the measured device using de-embedding structures on-chip. Models of the de-embedding structures used for the RBT and FinFET measurements are shown in Figure S1. Finite Element Analysis (FEA) on these models in Ansoft HFSS in combination with the de-embedding method presented here result in a lowering of the capacitive floor well below the expected device signal.

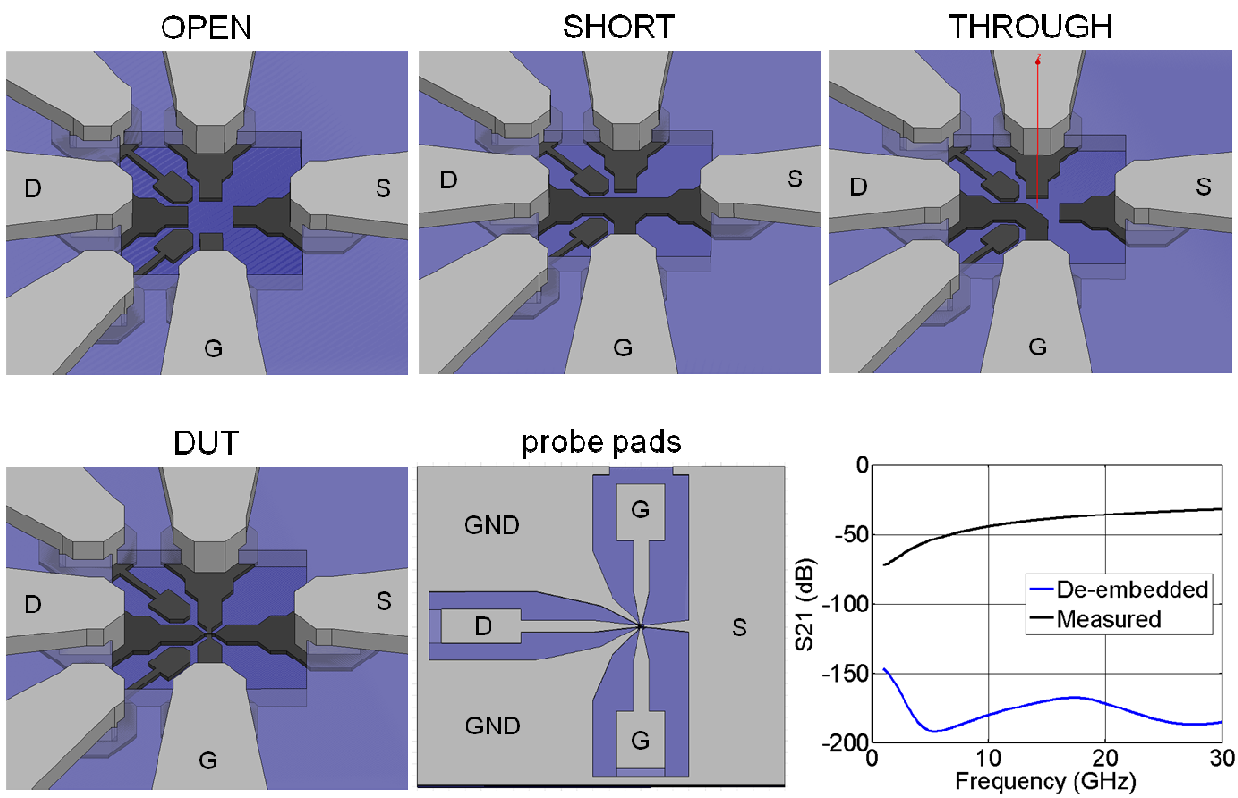

Figure S1. De-embedding structures fabricated on-chip to subtract parasitic capacitance and inductance of the probe pads and routing, lowering the measurement floor.

The de-embedding algorithm implemented in these measurements was developed by Cho *et al*[S1], and is outlined below.

1. Measure S-parameters of the device under test (DUT), open, short, and through structures $[S^{DUT}]$, $[S^{OPEN}]$, $[S^{SHORT}]$, $[S^{THRU}]$.

2. Convert $[S^{OPEN}] \rightarrow [Y^{OPEN}]$, $[S^{SHORT}] \rightarrow [Y^{SHORT}]$.

3. Subtract $[Y^{S-O}] = [Y^{SHORT} - Y^{OPEN}]$.

4. Convert $[Y^{S-O}] \rightarrow [Z^{S-O}]$.

5. Calculate ABCD matrices of the input and output pads (PAD1 and PAD2, respectively) to the device:

$$[A^{PAD1}] = \begin{bmatrix} 1 & Z_{PAD} \\ Y_{PAD} & 1 + Y_{PAD}Z_{PAD} \end{bmatrix}$$

$$[A^{PAD2}] = \begin{bmatrix} 1 + Y_{PAD}Z_{PAD} & Z_{PAD} \\ Y_{PAD} & 1 \end{bmatrix}$$

where $Y_{PAD} = Y_{11}^{OPEN} + Y_{12}^{OPEN}$ and $Z_{PAD} = Z_{11}^{S-O} - Z_{12}^{S-O}$.

6. Convert $[S^{THRU}] \rightarrow [A^{THRU}]$.

7. Calculate

$$[A^{INT}] = [A^{PAD1}]^{-1}[A^{THRU}][A^{PAD2}]^{-1}$$

$$[A^{INT}] \rightarrow [S^{INT}]$$

$$Z_C \equiv \pm Z_0 \sqrt{\frac{(1 + S_{11}^{INT})^2 - (S_{21}^{INT})^2}{(1 - S_{11}^{INT})^2 - (S_{21}^{INT})^2}}$$

$$\gamma = -\frac{1}{\ell} ln\left[\left(\frac{1 - (S_{11}^{INT})^2 + (S_{21}^{INT})^2}{2S_{21}^{INT}} \pm \kappa\right)^{-1}\right]$$

$$\kappa = \sqrt{\frac{(1 - (S_{21}^{INT})^2 + (S_{11}^{INT})^2)^2 - (2S_{11}^{INT})^2}{(2S_{21}^{INT})^2}}$$

8. Calculate ABCD matrices $[A^{INT1}]$, $[A^{INT2}]$ using input and output interconnect lengths ℓ_1, ℓ_2.

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} cosh(\gamma\ell) & Z_C sinh(\gamma\ell) \\ \frac{1}{Z_C} sinh(\gamma\ell) & cosh(\gamma\ell) \end{bmatrix}$$

9. Calculate

$$[A^{IN}] = [A^{PAD1}][A^{INT1}]$$

$$[A^{OUT}] = [A^{INT2}][A^{PAD2}]$$

10. Convert $[S^{DUT}] \rightarrow [A^{DUT}]$.

11. Calculate $[A^{D}] = [A^{IN}]^{-1}[A^{DUT}][A^{OUT}]^{-1}$

12. Convert $[A^{D}] \rightarrow [S^{D}]$.

The resulting $[S^{D}]$ matrix corresponds to the 2-port frequency response of the device de-embedded from the probe pads and routing. It should be noted that de-embedding using the through structure does not remove the series resistance of the suspension beams to the RBT or the FinFET, but does eliminate the contact resistance between the metal and silicon layers.

References

[S1] Cho, M.-H.; Huang, G.-W.; Chiu, C.-S.; Chen, K.-H.; Peng, A.-S.; Teng, Y.-M. *IEICE Transactions on Electronics* **2005**, *E88-C* (5), 845–850.