cmIPCS: Compact Model of Four-Terminal, Inline, Indirectly Heated Phase Change RF Switches

cmIPCS is a compact model of Four-Terminal, Inline, Indirectly Heated Phase Change RF Switches (IPCSs). The model accurately predicts the thermal and electrical dynamics of the device by considering the changes in heater resistance, contact resistance, and parasitic capacitance. The thermal dynamics are modeled using a thermal-equivalent RC model, based on the physical dimensions and thermal properties of the device. The temperature feeds a behavioral model that determines if a phase transition occurs. The parasitic OFF capacitance is obtained from RF measurements. The model is validated using FEM simulations and experimental electrical thermometry of GeTe IPCS devices with different physical dimensions.

The complete model is implemented in Verilog-A, thus it enables rapid device optimization, and the design and simulation of large-scale circuits and systems composed of IPCS with varying substrates, dielectrics and PCM materials. The threshold voltages and the temperature of the heater are predicted within 92% accuracy by this model.

Modules of the cmIPCS

The model consists of four electrical ports: two RF ports (RF_P and RF_N) and two actuation ports (DC_P and DC_N). The change in the resistance of the IPCS (R_{IPCS}), and the parasitic C_{OFF} are probed between the RF ports, while the programming pulse is applied to the actuation ports. The input resistance of the latter ports is the resistance of the heater (R_H). The model is subdivided in: a) a behavioral model that determines the variation in R_{IPCS} and R_H accordingly to the temperature of the PCM (T_{PCM}) and the heater (T_H), and b) an equivalent lumped thermal-impedance RC model that predicts T_H and T_{PCM}.

Physical Dimensions and Electrical Parameters

Parameter	Description	Nominal Value	Units
WH	Width of the heater	2u	m
LH	Length of the heater	20u	m
WRF	Width of the RF gap	20u	m
LRF	Length of the RF gap	2u	m
t_W	Thickness of the heater	100n	m
t_GeTe	Thickness of GeTe	100n	m
t_TB	Thickness of SiNx (dielectric 2)	50n	m

t_capping	Thickness of capping/passivation layer	30n	m
t_SiOx	Thickness of SiOx (dielectric 1)	100n	m
t_Si	Thickness of Si substrate	500u	m
t_contacts	Thickness of the contacts	150n	m
Rsh_heater0	Sheet resistance of heater at RT	3.6	Ω/sq
Rc_heater	Contact resistance of the heater	13e-6	Ω.m
Rsh	Crystalline phase sheet resistance	33	Ω/sq
Roff	Amorphous phase resistance	100e3	Ω
C_RF	Parallel plate capacitance between contacts	8.82e-12*3.9*WRF*t_contacts/LRF	F
C_H_coupling	Coupling capacitance between heater and contacts	8.82e-12*7*WRF*(0.77+1.06*(LRF/t_TB)^0.25+1.06*(tW/t_TB)^0.5)	F
C_OFF	Total OFF-capacitance	C_RF+C_H_coupling/2+CF	F
init_state	Initial state of the device	0 (OFF) or 1 (ON)	
Ta	Amorphization temperature	998	K
Tc	Crystallization temperature	773	K

Thermal Properties

Parameter	Description	Nominal Value	Units
k_W	Thermal conductivity of Tungsten	20.3	$WK^{-1}m^{-1}$
cv_W	Heat capacity of Tungsten	2.58M	$Jm^{3}K^{-1}$
k_SiOx	Thermal conductivity of SiOx (dielectric 2)	ln(T**0.52)-1.5737	$WK^{-1}m^{-1}$
cv_SiOx	Heat capacity of SiOx(dielectric 2)	2.27M	$Jm^{3}K^{-1}$
k_Si	Thermal conductivity of Si	4e4/T	$WK^{-1}m^{-1}$
cv_Si	Heat capacity of Si	1.657M	$Jm^{3}K^{-1}$

k_SiNx	Thermal conductivity of SiNx (dielectric 2)	2.2	$WK^{-1}m^{-1}$
cv_SiNx	Heat capacity of SiNx (dielectric 2)	2.28M	Jm^3K^{-1}
k_GeTe	Thermal conducitivity of GeTe	2.2	$WK^{-1}m^{-1}$
cv_GeTe	Heat capacity of GeTe	3.07M	Jm^3K^{-1}
TCR	Thermal coeficient of resistance of Tungsten	0.0013	K^{-1}
TBR	Thermal boundary resistance of SiOx-W interface	1.3	

Running Transient Simulations

1. Import the Verliog-A file of the cmIPCS to SPICE or Cadence Virtuoso.
2. Create a symbol of the cmIPCS.
3. Add a cmIPCS instance to a new schematic.
4. Connect a voltage pulse generator with an output resistance of $50\,\Omega$ between the DC ports of the cmIPCS.
5. Choose the desired pulses and create a simulation environment.
6. The IPCS resistance and capacitance can be probed from the RF ports, while the resistance of the heater can be probed from the DC ports
7. The temperature of the heater and the PCM are probed from the T_heater and T_GeTe ports.

Running S-Parameters Simulations

1. Import the Verliog-A file of the cmIPCS to SPICE or Cadence Virtuoso.
2. Create a symbol of the cmIPCS.
3. Add a cmIPCS instance to a new schematic.
4. Connect ports to the RF ports.
5. Create an S-parameter simulation.
6. Select the state of the IPCS by changing init_state parameter.