COMPARISON AND EVOLUTION OF GATE OXIDE TBD MODELS

http://www.leapcad.com/Other_Tech/Comparison_TDDB_Models.MCD

PHYSICAL CONSTANTS: $k := 8.62 \cdot 10^{-5} \cdot ev$ $\quad ev \equiv 1.6 \cdot 10^{-19} \cdot joul$ $\quad q := 1.6 \cdot 10^{-19} \cdot coul$

DEVICE DATA: $thick_{SiO2} := 600 \cdot A$ $\quad X_{eff} := 79 \cdot A$ $\quad t_{ox} := 107 \cdot A$ $\quad V_{gate} := 1$

VARIABLES: $Tk := 300 .. 400$ $\quad V := 5 .. 60$ $\quad \Delta Xox := 1 .. 70$ $\quad V_{ox} := 11.2 \cdot volt$

1985, K. Yamabe, "Time dependent dielectric breakdown ... SiO2 films", SC 20, pg. 343:
TBD has a Thickness dependent Field Acceleration Factor, β =d(log(tbd)/dEox

$$\beta(Tox) := (4.2 \cdot \log(Tox) - 6.95) \cdot \frac{cm}{MV} \qquad \beta(200) = 2.714 \frac{cm}{MV}$$

The time to fail for 200A oxide is shortened by 10^ -2.7 with an increase of the stress field by 1MV/cm.

1988, Qp Model, J. Lee, "Modeling and Char of Gate Oxide Relibility", ED 35, pg. 2268:

INTRINSIC BREAKDOWN MODEL, **Critical Hole Fluence, Qp**:
Oxide lifetime is is the time required for the hole fluence Qp, to reach a critical value.
Qp ~ J α t, where J is the FN current ~ e(-B/Eox) and α is the hole generation coefficient ~ e(-H/Eox). Then Qp ~ e(-G/Eox) t, where G = B + H.

DEFECT RELATED BREAKDOWN MODEL (Oxide thinning = ΔXox): Xeffective = tox - ΔXox .

$V_{oxPos} := V_{gate} - 0.2$ $\qquad V_{oxNeg} := V_{gate} - 1.3$

$\tau_o := 10^{-11} \cdot sec$ $\quad B := 240 \cdot 10^{6} \cdot \frac{volt}{cm}$ $\quad G_o := 320 \cdot 10^{6} \cdot \frac{volt}{cm}$ $\quad tbd_{Lee}(V) := \tau_o \cdot \exp\left(\frac{G_o \cdot X_{eff}}{V \cdot volt}\right)$

$J_{FN}(V) := 3 \cdot 10^{8} \cdot \exp\left(-\frac{B \cdot X_{eff}}{V \cdot volt}\right) \cdot \frac{amp}{cm^2}$ $\quad J_{FN}(7.9) \cdot tbd_{Lee}(7.9) = 8.943 \frac{coul}{cm^2}$ $\quad Qbd := 10 \cdot \frac{coul}{cm^2}$

$c := 0.7$ $\quad slope := \dfrac{-70^{c}}{\ln\left(\dfrac{3 \cdot 10^{-1}}{4 \cdot 10^{5}}\right)}$

TWK Approx for Defect Density, D(ΔX) $D(\Delta Xox) := 4 \cdot 10^{5} \cdot \exp\left(\frac{-\Delta Xox^{c}}{slope}\right)$
tox = 107A, A = 500 x 500 um

$a1 := 13.1$ $\quad a2 := 6.3$
$b1 := -0.26$ $\quad b2 := -0.175$ $\qquad Df(\Delta Xox) := (a1 \cdot \exp(b1 \cdot \Delta Xox) + a2 \cdot \exp(b2 \cdot \Delta Xox)) \cdot 10^{4}$

Note: Article says b2 = -0.11. Added 10^4 above. This is a bi-Poisson Defect Distribution. See Yugami 1994

For a fixed Vox, the distribution D(ΔX) of ΔX can be extracted from the tbd distribution, i.e. ΔX =ΔX(tbd). $\quad \Delta X(tbd) := t_{ox} - \frac{V_{ox}}{G_o} \cdot \ln\left(\frac{tbd \cdot sec}{\tau_o}\right)$

PREDICTING RELIABILITY FROM **GAMMA** DEFECT DISTRIBUTION:

$tbmin := 10^{-5} \quad tbmax := 1000 \quad n := 200 \quad r := \ln\left(\frac{tbmax}{tbmin}\right) \qquad i := 1..n \quad tbd_i := tbmin \cdot e^{i \cdot \frac{r}{n}} \qquad s := 0.6$

$$CumFail(tbd, Area) := 100 \cdot \left[1 - \frac{1}{\left(1 + \frac{Area \cdot mm^2}{cm^2} \cdot D\left(\Delta X(tbd) \cdot A^{-1}\right) \cdot s\right)^{\frac{1}{s}}}\right]$$

Assume the defect distribution is clustered, i.e. gamma distribution with cluster factor, s = 0.6.

Note: Added - sign to Area

$$\lambda(tbd, Area) := \frac{-Area \cdot \frac{V_{ox}}{tbd \cdot G_o}}{1 + \frac{Area \cdot mm^2}{cm^2} \cdot Df\left(\Delta X(tbd) \cdot A^{-1}\right)} \cdot \left(a1 \cdot b1 \cdot exp\left(b1 \cdot \frac{\Delta X(tbd)}{A}\right) + a2 \cdot b2 \cdot exp\left(b2 \cdot \frac{\Delta X(tbd)}{A}\right)\right) \cdot \frac{10^4}{A}$$

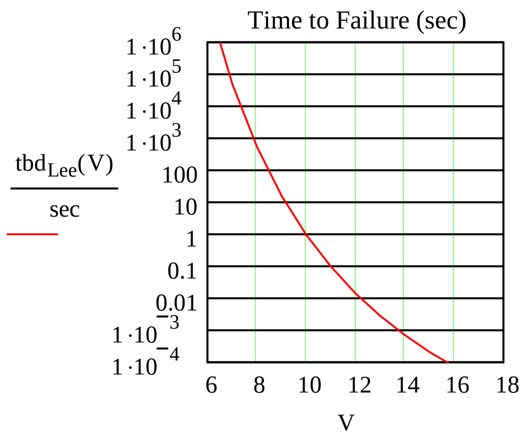


Fig. 1. 79A Gate

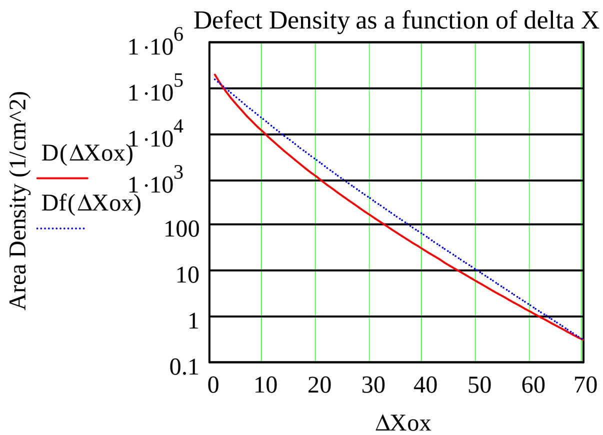


Fig 9. Oxide Thinning (A) for 107A Gate

Area: 4, 0.25, 0.01 mm^2, **Xox = 107A**, Vgate = 11V

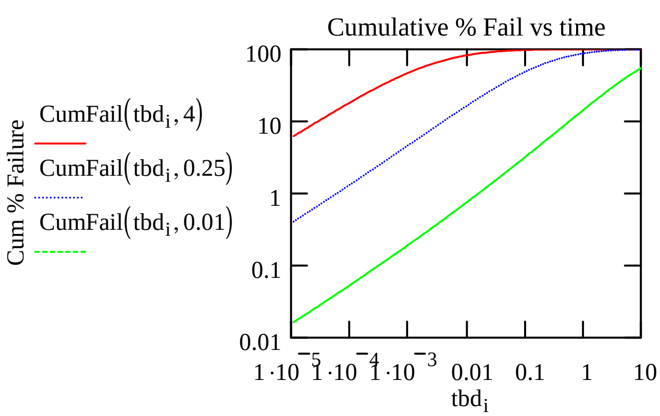


Fig. 10a. Time (sec)

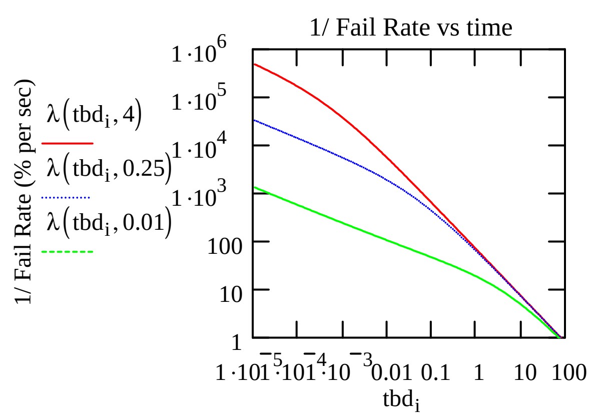


Fig. 11a. Time (sec)

The Temperature Variation is modeled the same as R. Moazzami, which follows.

1990, R. Moazzami, "Projecting Gate Oxide Rel", ED 37, pg 1643):

Temp Variation on Qbd/Qp Model:

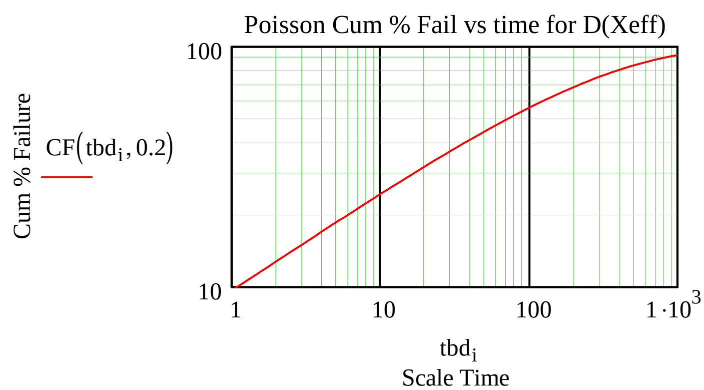
$V_{ox} := 8 \cdot volt$

$\tau_o := 10^{-11} \cdot sec$ $\delta := 0.0167 \cdot ev$ $E_b := 0.28 \cdot ev$ $X_{eff} := 100 \cdot A$ $Go := 300 \cdot 10^6 \cdot \frac{volt}{cm}$

$G(T) := Go \cdot \left[1 + \frac{\delta}{k} \cdot \left(\frac{1}{T} - \frac{1}{300}\right)\right]$ $\tau(T) := \exp\left[\frac{-E_b}{k} \cdot \left(\frac{1}{T} - \frac{1}{300}\right)\right]$ $tbd_{Mz}(V,T) := \tau(T) \cdot \tau_o \cdot \exp\left(\frac{G(T) \cdot X_{eff}}{V \cdot volt}\right)$

$\Delta X(tbd) := X_{eff} - \frac{V_{ox}}{G_o} \cdot \ln\left(\frac{tbd \cdot sec}{\tau_o}\right)$ $CF(tbd, Area) := 100 \cdot \left(1 - \exp\left(-\frac{Area \cdot mm^2}{cm^2} \cdot D\left(\Delta X(tbd) \cdot A^{-1}\right)\right)\right)$

RELIABILITY PROJECTION, CUMULATIVE FAILURE PROBABILITY, CF:
Assume that defects are distributed randomly across the wafer. Poisson Distribution.



1997, J. W. McPhearson, "Field enhanced Si-Si bond breakage", AP Phys Let, Aug, p.1101

Low Field TBD data reveals that TBD had field dependence ~ E and not 1/E.

Warranty 2000 hr = 7.2M sec. For 0.1ppm Failures,
need factor of 0.5/0.0000001 ==> t_{50} of 1.4 E14 sec.

Enthalpy of Activation for Si-Si Breakage: Ho $Ho := 1.15 \cdot ev$ $Ao := 1 \cdot sec$

$Q(V) := \frac{Ho - 7.2 \cdot q \cdot A \cdot V \cdot \frac{volt}{thick_{SiO2}}}{ev}$ Time to 50% Failure, TF: $tbd_{.McP}(V,T) := Ao \cdot e^{\frac{Q(V) \cdot ev}{k \cdot T}}$

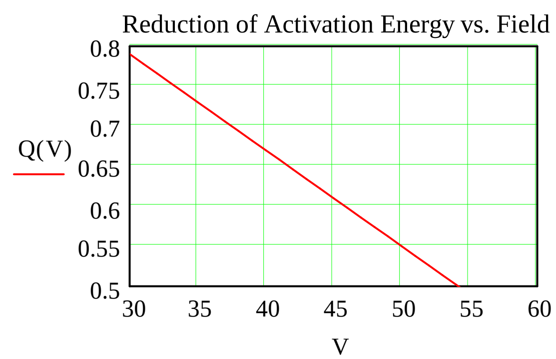


Fig. 3.

1993, N. Shiono, "A lifetime projection method using series ...TDDB...", IRPS, p. 1

!/E overestimates low field lifetime.   log(MTF Eox2) vs. !/Eox fits low fields.

Use full FN, J_{FN} = A. E_{ox}^2 exp(-B/E_{ox}), then MTF ~ exp(G/E_{ox})/E_{ox}^2. Note τos Differences

$mp := 4$

$EaPlus := 0.63 \cdot ev$ $G_{sp} := 150 \cdot \frac{MV}{cm}$ $t_{ox} := 110 \cdot A$ $\tau os := 1 \cdot hr \cdot \left(\frac{volt}{cm}\right)^2$ $S := 0.01 \cdot mm^2$ $Area := 0.09 \cdot mm^2$

$EaMinus := 0.56 \cdot ev$

$G_{sn} := 125$

$mn := 3$

$$tbd_{Shi}(V,T) := \tau os \cdot \exp\left(\frac{EaPlus}{k \cdot T}\right) \cdot \exp\left(G_{sp} \cdot \frac{t_{ox}}{V \cdot volt}\right) \cdot \left(\frac{V \cdot volt}{t_{ox}}\right)^{-2} \cdot \left(\frac{S}{Area}\right)^{-\frac{1}{mp}}$$

Plot Inverse of E = 1/Eox: $InvE := 0.8, 0.82 .. 1.54$ $Vi(InvE) := t_{ox} \cdot \left(InvE \cdot 10^{-7} \cdot \frac{cm}{volt}\right)^{-1} \cdot volt^{-1}$

$hmin := 1$ $hmax := 2 \cdot 10^4$ $n := 200$ $i := 1 .. n$ $r := \ln\left(\frac{hmax}{hmin}\right)$ $h_i := hmin \cdot e^{i \cdot \frac{r}{n}}$

$$\eta(MTF) := \frac{MTF}{\ln(2)^{\frac{1}{mp}}}$$

$$CF(h, MTF) := 1 - \exp\left[-\left(\frac{h}{\eta(MTF)}\right)^{mp}\right]$$

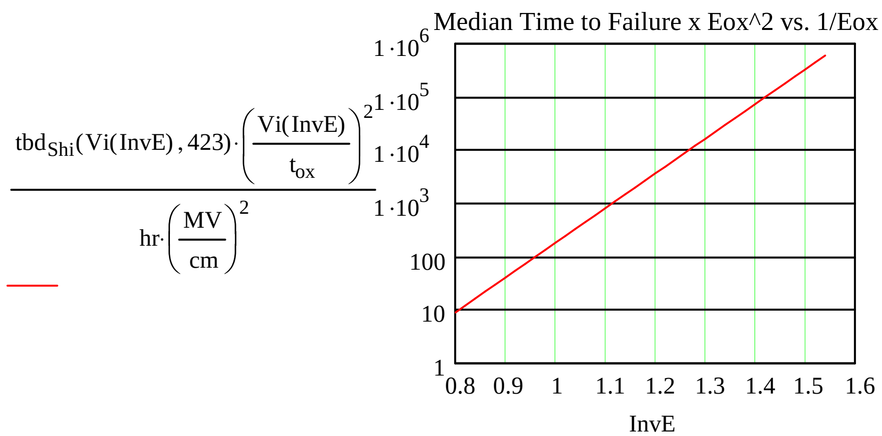


Fig. 4 1/Eox (10^-7 cm/V)

MODEL FOR TDDB STATISTICS: The Weibull is the extreme distribution for minimum value. TDDB breakdown is min value. Therefore the Weibull is a more suitable statistical distribution model than log normal. DMOS is composed of many cells, the failure of any one causes device failure. This is a series model. Normalized Cumulative Failure CF(t) = 1- exp(-(t/η)^{m}), $\eta = \eta i/(\eta^{1/m})$ η is the characteristic lifetime, m is the dispersion of lifetime, and n is the number of elements which is proportional to Area. Then MTF~ Area$^{1/m}$ Let $m_p = \beta$ and $\eta = \alpha$.

$$\eta_i := 1 \quad \eta := \frac{\eta_i}{n^{\frac{1}{mp}}}$$

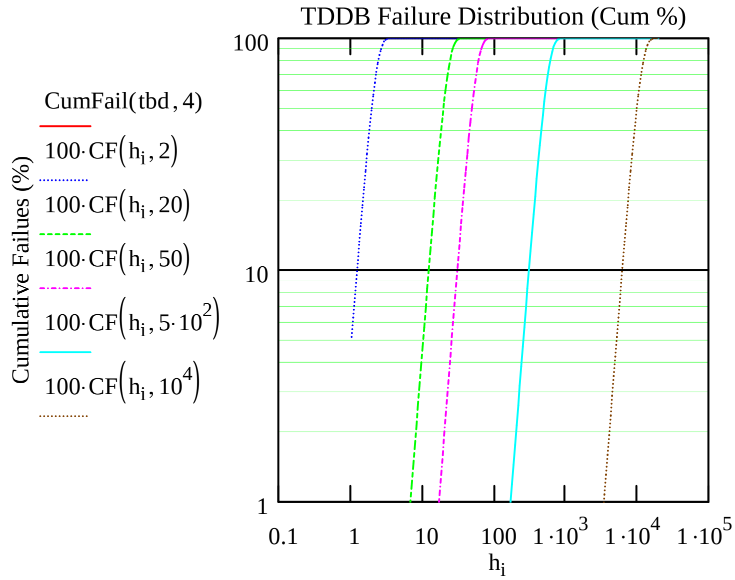


Fig. 2b Aging Time (hours)

$$\mathrm{LLCF}(h, \mathrm{MTF}) := \ln\left[\ln\left[(1 - \mathrm{CF}(h, \mathrm{MTF}))^{-1}\right]\right]$$

FAILURE RATE PROJECTIONS:

Shiono's definition of acceptable failure rate Spec (FIT)

Failure Rate, λ(t): $\lambda(t, MTF) := \frac{mp}{\eta(MTF)^{mp}} \cdot t^{mp-1}$

$FailSpec := 0.001$

$\tau oss := 1.9 \cdot 10^{-12} \cdot hr \cdot \left(\frac{MV}{cm}\right)^2$

$tbd_{ShiE}(E, T) := \tau oss \cdot \exp\left(\frac{EaPlus}{k \cdot T}\right) \cdot \exp\left(G_{sp} \cdot \frac{cm}{E \cdot MV}\right) \cdot \left(E \cdot \frac{MV}{cm}\right)^{-2} \cdot \left(\frac{S}{Area}\right)^{-\frac{1}{mp}}$

$$\lambda_E(t, E) := \frac{mp}{\eta\left(\frac{tbd_{ShiE}(E, 358)}{hr}\right)^{mp}} \cdot t^{mp-1}$$

$t25yr := 25 \cdot 365 \cdot 24 \qquad E := 3, 3.1 .. 6$

Ta = 85C, Area = 10 mm^2

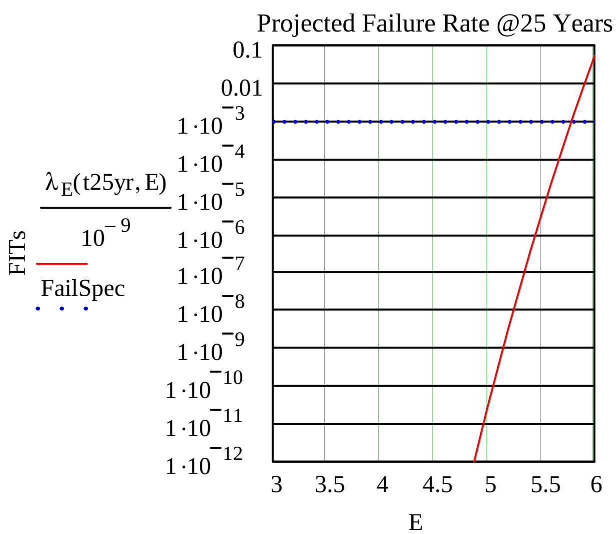


Fig 11. Eox (MV/cm)

COMPARISON OF E AND 1/E MODELS

$$AF(T) := \exp\left[\frac{0.4 \cdot ev}{k} \cdot \left(\frac{1}{T} - \frac{1}{423}\right)\right]$$

$TenYears := 10$ $\quad$ $WarrantyMiles := 50000 \cdot \frac{mi \cdot hr}{25 \cdot mi}$ $\quad$ $WarrantyMiles = 0.228\,yr$

$UseFullLifeMiles := 2 \cdot 10^{5} \cdot mi$ $\quad$ $UseFullLife := \frac{UseFullLifeMiles}{20 \cdot mi \cdot hr^{-1}}$ $\quad$ $UseFullLife = 1.141\,yr$

Projected **LOG NORMAL** Plot
for Median Time to Fail vs.Vgate
from Power DMOS Data Sheet.
Gate oxide thickness unknown.

$G_{accel} := 0.112 \cdot \frac{MV}{cm}$

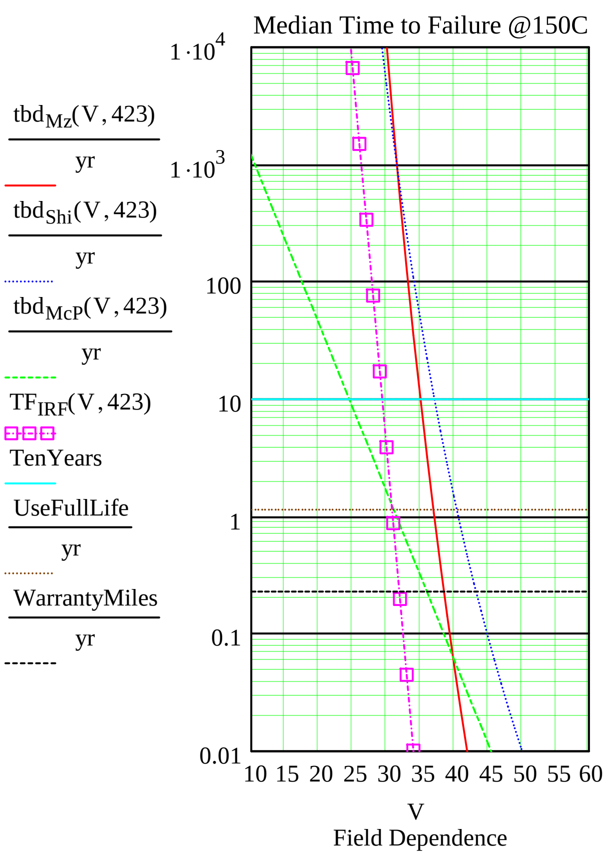
$$TF_{IRF}(V, T) := 7 \cdot 10^{28} \cdot e^{\frac{-V \cdot volt}{G_{accel} \cdot thick_{SiO2}}} \cdot \frac{sec}{yr \cdot \tau(T)}$$

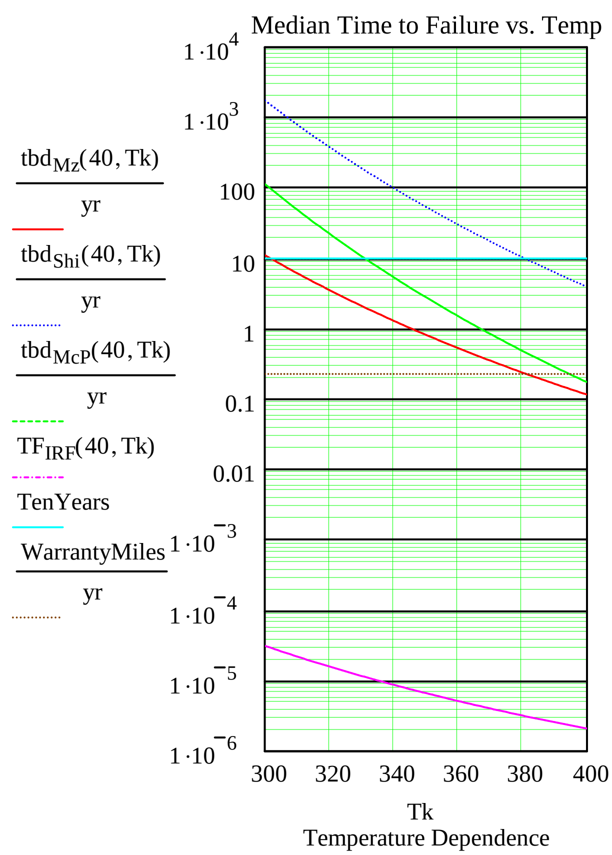
$M7 := 1300 \cdot mil^{2}$

$$tbd_{Shi}(V, T) := \tau os \cdot \exp\left(\frac{EaPlus}{k \cdot T}\right) \cdot \exp\left(G_{sp} \cdot \frac{thick_{SiO2}}{V \cdot volt}\right) \cdot \left(\frac{V \cdot volt}{thick_{SiO2}}\right)^{-2} \cdot \left(\frac{S}{M7}\right)^{-\frac{1}{mp}}$$

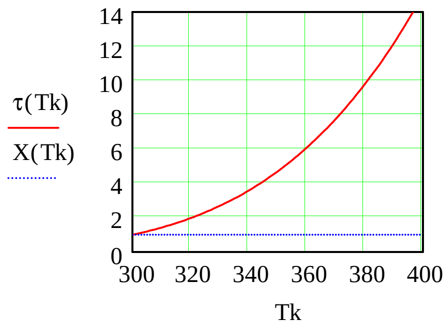
$$tbd_{Mz}(V, T) := \tau(T) \cdot \tau_{o} \cdot \exp\left(\frac{G(T) \cdot thick_{SiO2}}{V \cdot volt}\right)$$

$$tbd_{McP}(V, T) := Ao \cdot e^{\frac{Q(V) \cdot ev}{k \cdot T}} \cdot 0.02$$





$$X(T) := \frac{\exp\left[\frac{-E_b}{k}\cdot\left(\frac{1}{T}-\frac{1}{300}\right)\right]}{\left[\frac{1}{\exp\left[\frac{E_b}{k}\cdot\left(\frac{1}{T}-\frac{1}{300}\right)\right]}\right]}$$



$A \equiv 10^{-8}\cdot cm \quad MV \equiv 10^{6}\cdot volt \qquad mil \equiv 10^{-3}\cdot in$