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Reeves's circular transmission line model and its scope of application to extract specific contact resistance

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Abstract

Reeves's CTLM was reviewed and its scope of application to extract specific contact resistance ρ_c was discussed theoretically. Using the same pattern provided by Reeves, the theoretical results with different ρ_c were calculated, which show that if the transfer length was small enough, the measurement of the contact end resistance R_E measurement was unreliable resulting in great error in the extraction of ρ_c or even no solution. The scope of application of this extraction method was also discussed. It is found that the scope of application was not strongly dependent on the measurement accuracy. It is also found that Reeves's CTLM could be used only if the sheet resistance beneath the contact metal was quite small or the specific contact resistance was quite large.

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Keywords: Reeves's CTLM; Contact end resistance; Transfer length

1. Introduction

Reeves's circular transmission line model (CTLM) [1] has been widely used to extract the specific contact resistance [2–7]. According to ISI Web of Knowledge, Ref. [1] had been cited 66 times. This method has some advantages over linear transmission line model (TLM), such as convenience (eliminating mesa etching process) and accuracy (no requirement for the assumption that the sheet resistance beneath the contact metal and the normal sheet resistance have the same value), as have been presented in Ref. [1]. However, some authors found that in some cases this method is not accurate and in some cases even not solvable [6,7]. According to Xue [7] and Cao [8], this is due to the inaccurate measurement of contact end resistance. However, few authors have discussed how accurate the measurement is needed in Reeves's CTLM and what is the method's scope of application.

In this paper, Reeves's CTLM is reviewed and its scope of application is analyzed theoretically. Our results show that Reeves's CTLM has its scope of application, which is not strongly dependent on the measurement accuracy. This model can be used only if the sheet resistance beneath the contact metal is quite small or the specific contact resistance is quite large. Beyond this application scope, the extraction by Reeves's CTLM may result in great error.

2. Theory

The mathematical description of this model is given in detail by Reeves [1] and some important results are reviewed in this paper. The test pattern for the extraction of specific contact resistance (ρ_c) is shown in Fig. 1. R_{sK}

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Nomenclature

ρ_c	specific contact resistance ($\Omega\,cm^2$)	R_E	contact end resistance (Ω)
R_{sK}	sheet resistance beneath the contact metal (Ω/sq)	$r_0, r'_1, r_1, r'_2, r_2$	different radiuses in Reeves's CTLM (μm)
R_{sH}	normal sheet resistance (Ω/sq)	ϕ	a function of αr_0
L_T	transfer length (μm)	Δ	another function of αr_0
α	reciprocal of transfer length (μm^{-1})	R'_E	measured contact end resistance (Ω)
R_1	resistance between the inner two contacts of Reeves's CTLM (Ω)	ΔR_E	difference between measured and theoretical R_E (Ω)
R_2	resistance between the outer two contacts of Reeves's CTLM (Ω)	ρ'_c	extracted specific contact resistance using Reeves's CTLM ($\Omega\,cm^2$)

is defined as the sheet resistance beneath the contact metal to distinguish it from R_{sH} the normal sheet resistance. The parameter α is defined as

$$\alpha = 1/L_T = \sqrt{R_{sK}/\rho_c}, \tag{1}$$

where L_T is the transfer length.

To extract ρ_c, three resistances should be measured, that is, R_1, R_2 and R_E. R_1 is the resistance between the inner two contacts, and R_2 the outer two contacts. They can be expressed as

$$R_1 = \frac{R_{sH}}{2\pi}\ln\left(\frac{r'_1}{r_0}\right) + \frac{R_{sK}}{2\pi\alpha r_0}\cdot E(r_0) + \frac{R_{sK}}{2\pi\alpha r'_1}\cdot\frac{B(r'_1, r_1)}{C(r_1, r'_1)} \tag{2}$$

and

$$R_2 = \frac{R_{sH}}{2\pi}\ln\left(\frac{r'_2}{r_1}\right) + \frac{R_{sK}}{2\pi\alpha r_1}\cdot\frac{B(r_1, r'_1)}{C(r_1, r'_1)} + \frac{R_{sK}}{2\pi\alpha r'_2}\cdot\frac{B(r'_2, r_2)}{C(r_2, r'_2)}, \tag{3}$$

where functions $B(r, x)$, etc. are defined in Appendix. The contact end resistance R_E is defined as the ratio of the output voltage of the middle ring contact to the input current when the output current is zero:

$$R_E = \left.\frac{V(r'_1)}{i(r_1)}\right|_{i(r'_1)=0} \quad \text{or} \quad \left.\frac{V(r_1)}{i(r'_1)}\right|_{i(r_1)=0}. \tag{4}$$

Either way R_E can be expressed as

$$R_E = R_{sK}F(r_1, r'_1)/2\pi. \tag{5}$$

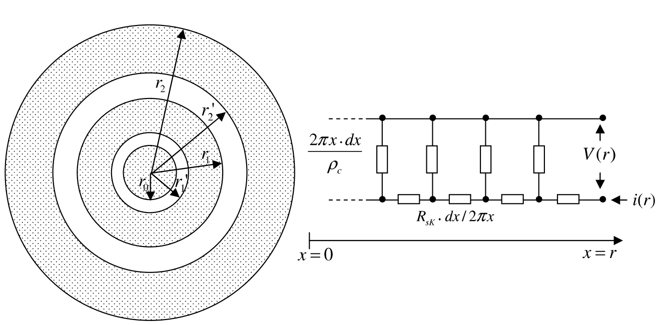

Fig. 1. Circular contact pattern and transmission line model parameters for circular contact.

From Eqs. (2), (3) and (5), one important equation can be derived:

$$\left[R_1\ln\left(\frac{r'_2}{r_1}\right) - R_2\ln\left(\frac{r'_1}{r_0}\right)\right]\Big/R_E = \left\{\ln\left(\frac{r'_2}{r_1}\right)\cdot\left[\frac{E(r_0)}{\alpha r_0} + \frac{1}{\alpha r'_1}\cdot\frac{A(r_1, r'_1)}{C(r_1, r'_1)}\right] - \ln\left(\frac{r'_1}{r_0}\right)\cdot\left[\frac{1}{\alpha r_1}\cdot\frac{B(r_1, r'_1)}{C(r_1, r'_1)} + \frac{1}{\alpha r'_2}\cdot\frac{A(r_2, r'_2)}{C(r_2, r'_2)}\right]\right\}\Big/F(r_1, r'_1). \tag{6}$$

(Two publication errors in this equation of Ref. [1] have been corrected. The corrected equation is also shown in Ref. [6].)

The RHS of this equation is defined as a function ϕ of (α r_0). Since R_1, R_2 and R_E can be measured, the LHS of Eq. (6) can be determined and hence α can be found. Thus, the specific contact resistance ρ_c, can be determined:

$$\rho_c = \left[R_1\ln\left(\frac{r'_2}{r_1}\right) - R_2\ln\left(\frac{r'_1}{r_0}\right)\right]\cdot r_0^2\cdot\Delta, \tag{7}$$

where

$$\Delta = 2\pi/\left[(\alpha r_0)^2\cdot\phi\cdot F(r_1, r'_1)\right]. \tag{8}$$

Reeves's CTLM is simple in process and accurate due to eliminating the assumption that $R_{sK} = R_{sH}$, but it is very complex in mathematics. Complexity in mathematics seems a rather small factor nowadays because many computer softwares can help us. However, it may result in some other problems that we will show below.

Just as have been mentioned by Cao [8], if ρ_c is quite small and R_{sK} is not quite small, the transfer length L_T is short and R_E is very small. In such case and using the asymptotic expression of modified Bessel functions [9], R_E can be expressed approximately as

$$R_E \approx R_{sK}/[2\pi\alpha\sqrt{r_1 r'_1}\sinh(\alpha r_1 - \alpha r'_1)] \approx R_{sK}L_T/[\pi\sqrt{r_1 r'_1}\exp[(r_1 - r'_1)/L_T]]. \tag{9}$$

Eq. (9) means that R_E is in exponential relationship with α. When $r_1 - r'_1$ is several times the transfer length L_T (ρ_c is small enough and R_{sK} is not so small), R_E measurement can become unreliable.