SINGLE-POSITION HALL EFFECT MEASUREMENTS

In semiconductor processing, it has become more and more important and also difficult to characterize material properties along with the continuous down-scaling of the critical dimensions. Sheet materials such as ultra-shallow junctions are widely used, and sheet resistance measurement has been developed for the study of these. In addition to the sheet resistance of film materials, the sheet carrier density and the mobility are also important properties for the performance of semiconductor device, e.g. in complementary metal-oxide-semiconductor (CMOS) transistors. However, most of the present measurement methods for determining the sheet resistance, the sheet carrier density, and the sheet carrier mobility require either special sample preparation or destructive machining of the sample. Some measurement methods also require several engagements between a probe and a test sample, which impairs the efficiency of the methods.

In order to characterize the sheet carrier density and the mobility of sheet materials, a fast, cheap, and non-destructive method is therefore desired. There are several methods employing microscopic multi-point probes produced by silicon-based micro-fabrication technology that can be used for the sheet resistance measurements. In WO2007045246A1 it has been shown that Hall effect measurement can be made with an in-line micro four-point probe to measure the sheet resistance, the sheet carrier density, and the Hall mobility. However, the method demands two measurement points, i.e. two different engagements between probe and test sample, which can cause large measurement errors when the electrical property is not ideally homogeneous across the sample under test.

Embodiments~~It is an object~~ of the present invention seek to improve the accuracy and reduce the time of determining an electrical property of a test sample. In particular, embodiments~~it is an object~~ of the present invention seek to improve the accuracy and reduce the time of determining an electrical property that depends on the distance to an electrical boundary of the test sample. According to embodiments of the present invention, only one measurement point, i.e. one engagement between probe and test sample, is necessary in a Hall effect

measurement. This maywill reduce the measuring time significantly and provide more accurate results for electrical transport properties of thin films.

According to a first aspect of the present invention, there is provided a method for determining a distance between a first position on an electrically conducting surface portion of a test sample and an electrical boundary of said electrically conducting surface portion by a multi-point probe comprising a first contact element, a second contact element, a third contact element, and a fourth contact element, each contact element defining a contact point for establishing an electrical contact with said test sample, said method comprising: (i.i) contacting said test sample with said first contact element, said second contact element, said third contact element, and said fourth contact element at said first position on said electrically conducting surface portion, (i.ii) applying a magnetic field having a major field component perpendicular to said electrically conducting surface portion at said first position, (i.iii) applying a first electrical potential across said first and third contact elements for generating a first current in said surface portion at said first position, (i.iv) measuring said first current through said first or said third contact element, (i.v) measuring a first voltage across said second and fourth contact elements, (i.vi) calculating a first resistance value (R_B) based on said first current and said first voltage, (i.vii) applying a second electrical potential across said second and fourth contact elements for generating a second current in said surface portion at said first position, (i.viii) measuring said second current through said second or said fourth contact element, (i.ix) measuring a second voltage across said first and third contact elements, (i.x) calculating a second resistance value ($R_{B'}$) based on said second current and said second voltage, (i.xi) calculating a first resistance difference ($\Delta R_{BB'}$) based on the difference between said first resistance value and said second resistance value, (i.xii) applying a third electrical potential across said first and second contact elements for generating a third current in said surface portion at said first position, (i.xiii) measuring said third current through said first or said second contact element, (i.xiv) measuring a third voltage across said third and fourth contact elements, (i.xv) calculating a third resistance value (R_C) based on said third current and said third voltage, (i.xvi) applying a fourth electrical potential across said third and fourth contact elements for generating a fourth current in said surface portion at said first

position, (i.xvii) measuring said fourth current through said third or said fourth contact element, (i.xviii) measuring a fourth voltage across said first and second contact elements, (i.xix) calculating a fourth resistance value ($R_{C'}$) based on said fourth current and said fourth voltage, and (i.xx) calculating a second resistance difference ($\Delta R_{CC'}$) based on the difference between said third resistance value and said fourth resistance value, and (i.xxi) defining a first relation (f) including a first, a second, and a third parameter representing said first resistance difference, said second resistance difference, and said distance between said first position and said electrical boundary, respectively, and (i.xxii) employing said first and second resistance differences ($\Delta R_{BB'}$, $\Delta R_{CC'}$, $\Delta R_{BB':2}$) as said first and second parameters, respectively, in said first relation for determining said third parameter representing said distance (y) between said first position and said electrical boundary.

According to a second aspect of the present invention, there is provided a method for determining a distance between a first position on an electrically conducting surface portion of a test sample and an electrical boundary of said electrically conducting surface portion by a multi-point probe comprising a first contact element, a second contact element, a third contact element, and a fourth contact element, each contact element defining a contact point for establishing an electrical contact with said test sample, said method comprising: (i.i) contacting said test sample with said first contact element, said second contact element, said third contact element, and said fourth contact element at said first position on said electrically conducting surface portion, (i.ii) applying a magnetic field having a major field component perpendicular to said electrically conducting surface portion at said first position, (i.iii) applying a first electrical potential across said first and third contact elements for generating a first current in said surface portion at said first position, (i.iv) measuring said first current through said first or said third contact element, (i.v) measuring a first voltage across said second and fourth contact elements, (i.vi) calculating a first resistance value (R_B) based on said first current and said first voltage, (i.vii) applying a second electrical potential across said second and fourth contact elements for generating a second current in said surface portion at said first position, (i.viii) measuring said second current through said second or said fourth contact element, (i.ix) measuring a second voltage across said first and third contact

elements, (i.x) calculating a second resistance value ($R_{B'}$) based on said second current and said second voltage, (i.xi) calculating a first resistance difference ($\Delta R_{BB'}$) based on the difference between said first resistance value and said second resistance value, said multi-point probe comprising a plurality of contact elements, said plurality of contact elements comprising said first contact element, said second contact element, said third contact element, said fourth contact element and one or more additional contact elements, each of said one or more additional contact elements defining a contact point for establishing an electrical contact with said test sample, (ii.xii) defining a first configuration of contact elements of said plurality of contact elements, said first configuration of contact elements being composed of said first contact element, said second contact element, said third contact element, and said fourth contact element, (ii.xiii) defining a second configuration of contact elements of said plurality of contact elements, said second configuration of contact elements being composed of a fifth contact element, a sixth contact element, a seventh contact element, and an eighth contact element, at least one contact element of said second configuration of contact elements being a contact element of said one or more additional contact elements, (ii.xiv) contacting said test sample with said contact elements of said second configuration of contact elements at said first position on said electrically conducting surface portion at the same time as contacting said test sample with said contact elements of said first configuration of contact elements, (ii.xv) applying a third electrical potential across said fifth and seventh contact elements for generating a third current in said surface portion at said first position, (ii.xvi) measuring said third current through said fifth or said seventh contact element, (ii.xvii) measuring a third voltage across said sixth and eighth contact elements, (ii.xviii) calculating a third resistance value ($R_{B,2}$) based on said third current and said third voltage, (ii.xix) applying a fourth electrical potential across said sixth and eighth contact elements for generating a fourth current in said surface portion at said first position, (ii.xx) measuring said fourth current through said sixth or said eighth contact element, (ii.xxi) measuring a fourth voltage across said fifth and seventh contact elements, (ii.xxii) calculating a fourth resistance value ($R_{B',2}$) based on said fourth current and said fourth voltage, and (ii.xxiii) calculating a second resistance difference ($\Delta R_{BB',2}$) based on the difference between said third resistance value and said fourth resistance value, and (i.xxi) defining a first relation

(*f*) including a first, a second, and a third parameter representing said first resistance difference, said second resistance difference, and said distance between said first position and said electrical boundary, respectively, and (i.xxii) employing said first and second resistance differences ($\Delta R_{BB'}$, $\Delta R_{CC'}$, $\Delta R_{BB',2}$) as said first and second parameters, respectively, in said first relation for determining said third parameter representing said distance (y) between said first position and said electrical boundary.

According to a third aspect of the present invention, there is provided a method for determining a distance between a first position on an electrically conducting surface portion of a test sample and an electrical boundary of said electrically conducting surface portion by a multi-point probe comprising a plurality of contact elements, each contact element defining a contact point for establishing an electrical contact with said test sample, said plurality of contact elements comprising a first contact element, a second contact element, a third contact element, a fourth contact element and one or more additional contact elements, said method comprising: (v.i) defining a first configuration of contact elements of said plurality of contact elements, said first configuration of contact elements being composed of said first contact element, said second contact element, said third contact element, and said fourth contact element, (v.ii) defining a second configuration of contact elements of said plurality of contact elements, said second configuration of contact elements being composed of a fifth contact element, a sixth contact element, a seventh contact element, and an eighth contact element, at least one contact element of said second configuration of contact elements being a contact element of said one or more additional contact elements, (v.iii-iv) contacting said test sample with said contact elements of said first and second configurations of contact elements at said first position on said electrically conducting surface portion, (v.v) applying a magnetic field having a major field component perpendicular to said electrically conducting surface portion at said first position (v.vi) applying a first electrical potential across said first and third contact elements for generating a first current in said surface portion at said first position, (v.vii) measuring said first current through said first or said third contact element, (v.viii) measuring a first voltage across said second and fourth contact elements, (v.ix) calculating a first resistance value (R_B)

based on said first current and said first voltage, (v.x) applying a second electrical potential across said second and fourth contact elements for generating a second current in said surface portion at said first position, (v.xi) measuring said second current through said second or said fourth contact element, (v.xii) measuring a second voltage across said first and third contact elements, (v.xiii) calculating a second resistance value ($R_{B'}$) based on said second current and said second voltage, (v.xiv) calculating a first resistance mean ($\overline{R_{BB',1}}$) of said first resistance value (R_B) and said second resistance value ($R_{B'}$), (v.xv) applying a third electrical potential across said fifth and seventh contact elements for generating a third current in said surface portion at said first position, (v.xvi) measuring said third current through said fifth or said seventh contact element, (v.xvii) measuring a third voltage across said sixth and eighth contact elements, (v.xviii) calculating a third resistance value ($R_{B,2}$) based on said third current and said third voltage, (v.xix) applying a fourth electrical potential across said sixth and eighth contact elements for generating a fourth current in said surface portion at said first position, (v.xx) measuring said fourth current through said sixth or said eighth contact element, (v.xxi) measuring a fourth voltage across said fifth and seventh contact elements, (v.xxii) calculating a fourth resistance value ($R_{B',2}$) based on said fourth current and said fourth voltage, (v.xxv) calculating a second resistance mean ($\overline{R_{BB',2}}$) of said third resistance value ($R_{B,2}$) and said fourth resistance value ($R_{B',2}$), and (v.xxvi) applying a fifth electrical potential across said first and fourth contact elements for generating a fifth current in said surface portion at said first position, (v.xxvii) measuring said fifth current through said first or said fourth contact element, (v.xxviii) measuring a fifth voltage across said second and third contact elements, (v.xxix) calculating a fifth resistance value ($R_{A,1}$) based on said fifth current and said fifth voltage, (v.xxx) applying a sixth electrical potential across said second and third contact elements for generating a sixth current in said surface portion at said first position, (v.xxxi) measuring said sixth current through said second or said third contact element, (v.xxxii) measuring a sixth voltage across said first and fourth contact elements, (v.xxxiii) calculating a sixth resistance value ($R_{A',1}$) based on said sixth current and said sixth voltage, (v.xxxiv) calculating a third resistance mean ($\overline{R_{AA',1}}$) of said fifth resistance value ($R_{A,1}$) and said sixth resistance value ($R_{A',1}$),

and (v.xxxv) applying a seventh electrical potential across said fifth and eighth contact elements for generating a seventh current in said surface portion at said first position, (v.xxxvi) measuring said seventh current through said fifth or said eighth contact element, (v.xxxvii) measuring a seventh voltage across said sixth and seventh contact elements, (v.xxxviii) calculating a seventh resistance value ($R_{A,2}$) based on said seventh current and said seventh voltage, (v.xxxix) applying an eighth electrical potential across said sixth and seventh contact elements for generating an eighth current in said surface portion at said first position, (v.xl) measuring said eighth current through said sixth or said seventh contact element, (v.xli) measuring an eighth voltage across said fifth and eighth contact elements, (v.xlii) calculating an eighth resistance value ($R_{A',2}$) based on said eighth current and said eighth voltage, (v.xliii) calculating a fourth resistance mean ($\overline{R_{AA'}}_{,2}$) of said seventh resistance value ($R_{A,2}$) and said eighth resistance value ($R_{A',2}$), (v.xliv) defining a first relation including a fourth, fifth, and sixth parameter representing said first resistance mean ($\overline{R_{BB'}}_{,1}$), said third resistance mean ($\overline{R_{AA'}}_{,1}$), and a first pseudo sheet resistance ($R_{P,1}$), respectively, (v.xlv) employing said first resistance mean ($\overline{R_{BB'}}_{,1}$) and said third resistance mean ($\overline{R_{AA'}}_{,1}$) as said fourth parameter and said fifth parameter, respectively, in said first relation for determining said sixth parameter representing said first pseudo sheet resistance ($R_{P,1}$), (v.xlvi) defining a second relation including a seventh, eighth, and ninth parameter representing said second resistance mean ($\overline{R_{BB'}}_{,2}$), said fourth resistance mean ($\overline{R_{AA'}}_{,2}$), and a second pseudo sheet resistance ($R_{P,2}$), respectively, (v.xlvii) employing said second resistance mean ($\overline{R_{BB'}}_{,2}$) and said fourth resistance mean ($\overline{R_{AA'}}_{,2}$) as said seventh parameter and said eighth parameter, respectively, in said second relation for determining said ninth parameter representing said second pseudo sheet resistance ($R_{P,2}$), (v.xlviii) defining a third relation (g_D) including a tenth, an eleventh, and a twelfth parameter representing said first pseudo sheet resistance ($R_{P,1}$), said second pseudo sheet resistance ($R_{P,2}$), and said distance between said first position and said electrical boundary, respectively, and (v.xlix) employing said first and said second pseudo sheet resistances ($R_{P,1}$, $R_{P,2}$) as said tenth and eleventh parameter, respectively, in said third relation (g_D) for determining said twelfth parameter

representing a value of said distance (y) between said first position and said electrical boundary.

According to a fourth aspect of the present invention, there is provided a method for determining an electrical property at a first position on an electrically conducting surface portion of a test sample, said electrically conducting surface portion having an electrical boundary and said method comprising: (a) determining a distance (y) between said first position on said electrically conducting surface portion of said test sample and said electrical boundary of said electrically conducting surface portion as defined in the first aspect, (b) defining a first resultant relation including said electrical property and a fifteenth parameter representing said distance (y), and (c) employing said distance (y) as said fifteenth parameter in said first resultant relation for determining said electrical property.

According to a fifth aspect of the present invention, there is provided a method for determining an electrical property at a first position on an electrically conducting surface portion of a test sample, said electrically conducting surface portion having an electrical boundary and said method comprising: (a) determining an additional distance (y_2) between said first position on said electrically conducting surface portion of said test sample and said electrical boundary of said electrically conducting surface portion as defined in the second aspect, (b) defining a first resultant relation including said electrical property and a fifteenth parameter representing said additional distance (y_2), and (c) employing said additional distance (y_2) as said fifteenth parameter in said first resultant relation for determining said electrical property.

According to a sixth aspect of the present invention, there is provided an apparatus for determining a distance between a first position on an electrically conducting surface portion of a test sample and an electrical boundary of said electrically conducting surface portion, said apparatus comprising: a multi-point probe comprising a first contact element, a second contact element, a third contact element, and a fourth contact element, each contact element defining a contact point for establishing an electrical contact with said test sample, and a control unit

adapted for performing the method for determining a distance or additional distance as defined in the first aspect.

According to a seventh aspect of the present invention, there is provided an apparatus for determining an electrical property at a first position on an electrically conducting surface portion of a test sample comprising: a multi-point probe comprising a first contact element, a second contact element, a third contact element, and a fourth contact element, each contact element defining a contact point for establishing an electrical contact with said test sample, and a control unit adapted for performing the method for determining an electrical property at a first position on an electrically conducting surface portion of a test sample as defined in the fourth aspect.

There is also disclosed~~The object of the invention is achieved according to a first aspect of the invention by~~ a first position on an electrically conducting surface portion of a test sample and an electrical boundary of the electrically conducting surface portion by a multi-point probe comprising a first contact element, a second contact element, a third contact element, and a fourth contact element, each contact element defining a contact point for establishing an electrical contact with the test sample, the method comprising: (i.i) contacting the test sample with the first contact element, the second contact element, the third contact element, and the fourth contact element at the first position on the electrically conducting surface portion, (i.ii) applying a magnetic field having a major field component perpendicular to the electrically conducting surface portion at the first position, (i.iii) applying a first electrical potential across the first and third contact elements for generating a first current in the surface portion at the first position, (i.iv) measuring the first current through the first or the third contact element, (i.v) measuring a first voltage across the second and fourth contact elements, (i.vi) calculating a first resistance value (R_B) based on the first current and the first voltage, (i.vii) applying a second electrical potential across the second and fourth contact elements for generating a second current in the surface portion at the first position, (i.viii) measuring the second current through the second or the fourth contact element, (i.ix) measuring a second voltage across the first and third contact elements, (i.x) calculating a second

resistance value ($R_{B'}$) based on the second current and the second voltage, (i.xi) calculating a first resistance difference ($\Delta R_{BB'}$) based on the difference between the first resistance value and the second resistance value, (i.xii) applying a third electrical potential across the first and second contact elements for generating a third current in the surface portion at the first position, (i.xiii) measuring the third current through the first or the second contact element, (i.xiv) measuring a third voltage across the third and fourth contact elements, (i.xv) calculating a third resistance value (R_C) based on the third current and the third voltage, (i.xvi) applying a fourth electrical potential across the third and fourth contact elements for generating a fourth current in the surface portion at the first position, (i.xvii) measuring the fourth current through the third or the fourth

value and the fourth resistance value, and both the alternative including the steps (i.xii) to (i.xx) and the alternative including the steps (ii.xii) to (ii.xxiii) further comprising: (i.xxi) defining a first relation (*f*) including a first, a second, and a third parameter representing the first resistance difference, the second resistance difference, and the distance between the first position and the electrical boundary, respectively, and (i.xxii) employing the first and second resistance differences ($\Delta R_{BB'}$, $\Delta R_{CC'}$, $\Delta R_{BB';2}$) as the first and second parameters, respectively, in the first relation for determining the third parameter representing the distance (y) between the first position and the electrical boundary.

The method ~~according to the first aspect of the present invention and the alternative replacing steps (i.xii) to (i.xx)~~ may further comprise: (iii.xxiv) calculating a first resistance mean ($\overline{R_{BB'},1}$) of the first resistance value (R_B) and the second resistance value ($R_{B'}$), (iii.xxv) calculating a second resistance mean ($\overline{R_{BB'},2}$) of the third resistance value ($R_{B,2}$) and the fourth resistance value ($R_{B';2}$), and (iii.xxvi) applying a fifth electrical potential across the first and fourth contact elements for generating a fifth current in the surface portion at the first position, (iii.xxvii) measuring the fifth current through the first or the fourth contact element, (iii.xxviii) measuring a fifth voltage across the second and third contact elements, (iii.xxix) calculating a fifth resistance value ($R_{A,1}$) based on the fifth current and the fifth voltage, (iii.xxx) applying a sixth electrical potential across the second and third contact elements for generating a sixth current in the surface portion at the first position, (iii.xxxi) measuring the sixth current through the second or the third contact element, *(iii.xxxii) measuring a sixth voltage across the first and fourth contact elements*, (iii.xxxiii) calculating a sixth resistance value ($R_{A',1}$) based on the sixth current and the sixth voltage, (iii.xxxiv) calculating a third resistance mean ($\overline{R_{AA'},1}$) of the fifth resistance value ($R_{A,1}$) and the sixth resistance value ($R_{A';1}$), and (iii.xxxv) applying a seventh electrical potential across the fifth and eighth contact elements for generating a seventh current in the surface portion at the first position, (iii.xxxvi) measuring the seventh current through the fifth or the eighth contact element, (iii.xxxvii) measuring a seventh voltage across the sixth and seventh contact elements, (iii.xxxviii) calculating a seventh resistance value ($R_{A,2}$) based on the

additional distance between the first position and the electrical boundary, the fourth relation (g_D) further including a fourteenth parameter representing the additional distance between the first position and the electrical boundary, and the method further comprising: (iv.xlix) employing the first and the second pseudo sheet resistances ($R_{P,1}$, $R_{P,2}$) as the tenth and eleventh parameter, respectively, in the fourth relation (g_D) for simultaneously determining the thirteenth parameter and the fourteenth parameter representing the distance (y) and the additional distance (y_2) between the first position and the electrical boundary, respectively.

In the alternative including step (iii.xlix) the fourth relation may be equivalent to $R_{P,1}/R_{P,2} = g_D(y)$, where $R_{P,1}$ represents the first pseudo sheet resistance, $R_{P,2}$ represents the second pseudo sheet resistance, and g_D represents a function including the distance y as a parameter, the function g_D defining a peak value at a specific distance, and the function g_D increasing as a function of the distance below the specific distance and decreasing as a function of the distance above the specific distance, the method may further comprise: (iii.xlx) comparing the distance and the specific distance to determine if the additional distance (y_2) is below or above the specific distance in the fourth relation. The additional distance (y_2) determined this way is typically more accurate than the distance (y), since it is derived from resistance means instead of resistance differences.

The additional distance may replace the distance for any purpose, e.g. for determining an electrical property of a test sample.

There is also disclosed~~The objects are according to a second aspect of the present invention obtained by~~ a method for determining a distance between a first position on an electrically conducting surface portion of a test sample and an electrical boundary of the electrically conducting surface portion by a multi-point probe comprising a plurality of contact elements, each contact element defining a contact point for establishing an electrical contact with the test sample, the plurality of contact elements comprising a first contact element, a second contact element, a third contact element, a fourth contact element and one or more additional contact elements, the method comprising: (v.i) defining a first configuration of contact elements of the

respectively, in the second relation for determining the sixth parameter representing the first pseudo sheet resistance ($R_{P,1}$), (v.xlvi) defining a third relation including a seventh, eighth, and ninth parameter representing the second resistance mean ($\overline{R_{BB',2}}$), the fourth resistance mean ($\overline{R_{AA',2}}$), and a second pseudo sheet resistance ($R_{P,2}$), respectively, (v.xlvii) employing the second resistance mean ($\overline{R_{BB',2}}$) and the fourth resistance mean ($\overline{R_{AA',2}}$) as the seventh parameter and the eighth parameter, respectively, in the third relation for determining the ninth parameter representing the second pseudo sheet resistance ($R_{P,2}$), (v.xlviii) defining a fourth relation (g_D) including a tenth, an eleventh, and a twelfth parameter representing the first pseudo sheet resistance ($R_{P,1}$), the second pseudo sheet resistance ($R_{P,2}$), and the distance between the first position and the electrical boundary, respectively, and (v.xlix) employing the first and the second pseudo sheet resistances ($R_{P,1}$, $R_{P,2}$) as the tenth and eleventh parameter, respectively, in the fourth relation (g_D) for determining the twelfth parameter representing a value of the distance (y) between the first position and the electrical boundary.

The fourth relation may be equivalent to $R_{P,1}/ R_{P,2} = g_D(y)$, where $R_{P,1}$ represents the first pseudo sheet resistance, $R_{P,2}$ represents the second pseudo sheet resistance, and g_D represents a function including the distance y as a parameter, the function g_D defining a peak value at a specific distance, and the function g_D increasing as a function of the distance below the specific distance and decreasing as a function of the distance above the specific distance, and the method may further comprise: (v.xlx) determining a distance by the method according to the first aspect of the present invention for representing an auxiliary distance, and (v.xlxi) comparing the auxiliary distance and the specific distance to determine if the distance is below or above the specific distance in the fourth relation.

The methods ~~according to the first and second aspects of the present invention~~ require only a single engagement between the probe and the test sample for accurately determining the distance.

~~The features described below may be employed for both the first and second aspects of the present invention.~~

The contact points may define a first line intersecting each of the contact points. The contact points of the first contact element, the second contact element, the third contact element, the fourth contact element, and the one or more additional contact elements may define a first line intersecting each of the contact points prior to the contact points contacting the test sample. The contact points of the first contact element, the second contact element, the third contact element, and the fourth contact element, may be located in the given order along the first line. The contact points of the fifth contact element, the sixth contact element, the seventh contact element, and the eighth contact element, may be located on and/or in the given order along the first line.

The spacing between the contact points of the first and second contact elements, the second and third contact elements, and the third and fourth contact elements may be approximately equal to a first spacing value (s_1). The spacing between the contact points of the fifth and sixth contact elements, the sixth and seventh contact elements, and the seventh and eighth contact elements may be approximately equal to a second spacing value (s_2).

In the alternative replacing steps (i.xii) to (i.xx) the first relation may be equivalent to $\Delta R_{BB'}/\Delta R_{BB';2} = f_D(y,s_1,s_2)$, where $\Delta R_{BB'}$ represents the first resistance difference, $\Delta R_{BB';2}$ represents the second resistance difference, and f_D is a function including the distance y between the first position and the electrical boundary, the first spacing value s_1, and the second spacing value s_2.

The function $f_D(y,s_1,s_2)$ in said first relation $\Delta R_{BB'}/\Delta R_{BB';2} = f_D(y,s_1,s_2)$ may be be equivalent to $(3*\arctan(s_1/2y) - \arctan(3s_1/2y)) / (3*\arctan(s_2/2y) - \arctan(3s_2/2y))$.