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Analysis of Surface Microdefects Localization Possibilities

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Introduction

Adsorption phenomenon as well as surface structure variation of samples, especially semiconductors, calls significant electron work function variation. Well-known methods of electron work function measurement, such as photoelectric and thermoelectronic, yield to of Kelvin–Zisman vibrating probe method by properties. The latter method is the best approbated and is characterized by the highest sensitivity in surface physics [1, 2]. This method is realized by various measuring instruments which spatial resolution mainly is determined by the diameter of vibrating probe and reaches about hundred nanometers. Subsequent reduction of vibrating probe tip's diameter can change converter working conditions from quasielectrostatic to tunnel therefore we will not analyze it. Else, all measurement systems are inert, i.e. their frequency pass band is limited, so even analysis of small surface area requires some time [3], for instance analysis of 1 mm^2 area with 1 µm spatial resolution runs around ($10^4 \ldots 10^6$) *s*, i. e. from 0.11 to 11 days.

Usually surface microdefects cover small part of real structure surface under investigation therefore vibrating probe with tip's diameter considerably higher than the area of possible microdefect can be used for rapid control. However by which indication it is possible to localize such microdefect. The aim of this work was to investigate the possibilities localization of microdefect or microdefect's group when the diameter of vibrating probe tip's is noticeable higher the dimension of microdefect.

Scanning speed of samples surface

Simplified model of Kelvin–Zisman converter and sample under investigation is shown in Fig. 1. Vibrating electrode 1 and surface of investigating sample form periodically alternating, i. e. parametric, capacity $C(t) = C_0\left[1+(\Delta C/C_0)\cos\omega t\right]^{-1}$. Electric charge of the capacity is proportional to difference of electron work functions, i. e. $Q(t) = C(t)(A_1 - A_2)q^{-1}$, here q – electron charge. If we choose high nominal resistor R to warranty $RC_0\omega >> 1$, we will have voltage signal of the frequency ω, the amplitude of which is proportional to difference of electron work functions. This is informative signal, which is gained and detected later.

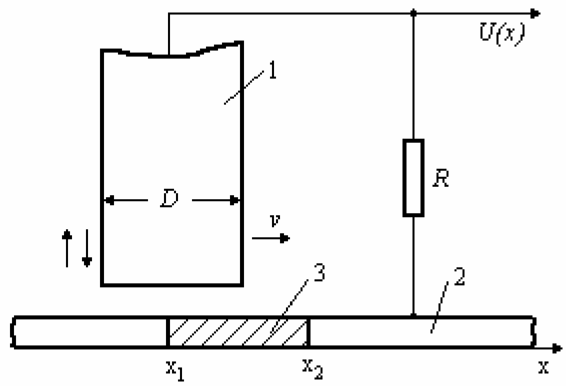

Fig. 1. Model of vibrating electrode (1) and surface of sample under investigation (2). 3 – defective area which diameter is x_2-x_1=*D*, *v* – speed of electrode shift (scanning)

According to theoretical analysis and experimental study the threshold linear resolution of this method is determined by dimension of vibrating electrode tip, when distance between the tip and sample surface is significantly less the dimension of the tip and also if electronic equipment has infinitive frequency pass band. It is necessary accept appropriate transfer characteristic of equipment (Fig. 2) for more precise estimation of scanning speed. The nature of characteristic depends on vibrating electrode tip area and geometry of informative surface area: quadrate–strip (1), circle–strip (2), circle–circle (3). There are few papers [4, 5] analyzing vibrating probe scanning speed and results are close to our but authors didn't present analysis of optimal scanning speed, its dependence on dimension of vibrating probe and frequency pass band of electronic system.

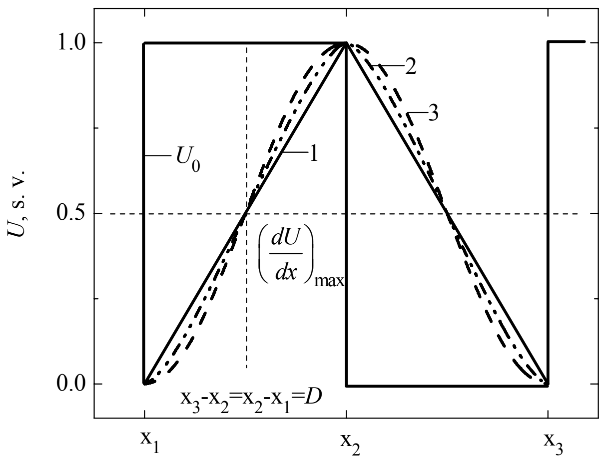

Fig. 2. Accepted character of surface potential U_0, which characterizes informative area and measured the potential, when electrode's tip and informative area are such: quadrate–strip (1), circle–strip (2), circle–circle (3).

In practice the last, i. e. third, case (or close to that) commonly takes place. We prefer this case because output signal may be precisely and simply described as follow $U(x) = U_0 \sin^2 ax$. Even in ideal case the output voltage is shifted towards vibrating electrode movement. In this case coordinate of the center of defective area may be determined by maximal value of derivative i. e. $\left(\frac{dU}{dt}\right)_{max} \sim \left(\frac{dU}{dx}\right)_{max} \sim (\sin 2ax)_{max}$ in assumption fixed speed of electrode shift. Vibration frequency of real size electrode is adjusted in the range of some kHz because at higher frequency the combinative modes can easy form and reduce operating conditions of converter. Thus, estimating low frequency filter's time constant we state that frequency pass band of such converter will not exceed some hundred Hz. If we will ignore narrow frequency pass band and will select scanning speed free, we can obtain inadmissible uncertainties of surface potential and its coordinate. Figure 3 shows the theoretic dependencies relative error of voltage determination and defective area center's coordinate determination on scanning speed. The scanning speed is expressed as a part of maximal speed defined by ratio of vibrating probe diameter D to measuring device's time constant τ [3]. According to Fig. 3 uncertainty of determination defective area center's coordinate grows faster than uncertainty of this area surface electric potential's when scanning speed increases. Therefore, the main attention must be kept to accuracy of coordinate determination when we select the value of scanning speed. In practice acceptable scanning speed may be $(0.01...0.03)v_m$. In this case maximum error of defect center coordinate determination will not exceed 3 % and surface potential – 0.5 %. These dependencies qualitatively were validated in experiment. It is important to select appropriate (not high) scanning speed in study microdefective areas, which dimensions are considerably less than diameter of vibrating probe.

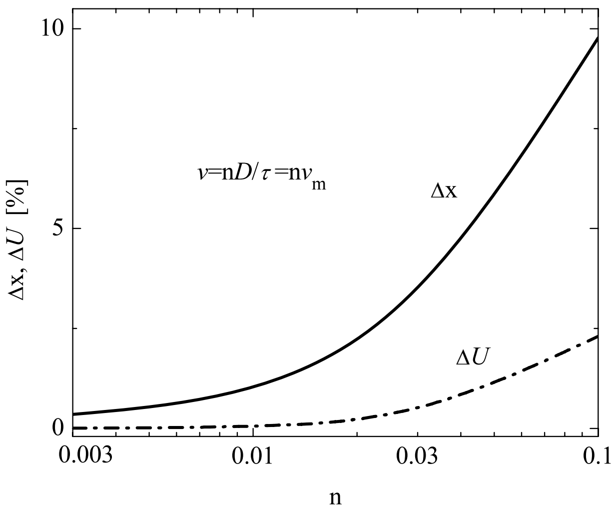

Fig. 3. The theoretic dependencies relative error of voltage determination and defective area center's coordinate determination. Scanning speed expressed as a part of maximal speed $v_m = D/\tau$ (τ–time constant of measuring device).

Method localization of surface microdefects

Analyzing possibilities localization of surface microdefects, we will have in mind the model presented in Fig. 1 in which defective area width (or diameter) is far less the diameter of vibrating probe, i. e. $x_2 - x_1 << D$. It seems as simply quasi–electrostatic system, but its correct analysis is very complex as follows by investigation of V. P. Pronin [7]. We preferred experimental investigation.

We had used 7.5 mm diameter vibrating probe to warrant sufficient measurement accuracy. The diameter of constructed defective area $(x_2 - x_1)$ was 1 mm and distance between electrode tip and sample with defective area was 1 mm. Time constant of measuring device was 0.1 s. Scanning speed equal to $0.01D/\tau$ =0.75 mm/s was fixed in experiment. Such scanning speed warranted low measurement uncertainty according to Fig. 3. Experimental results of investigation surface electric potential are presented in Fig. 4. It is possible in unambiguous way to establish coordinate of defective area whereas center of defective area's by derivative maximum of signal leading edge according these results. The derivative maximum often coincides with middle of leading edge. Time constant of leading edge cannot be shorter than $(3\ldots5)\tau$ after experimental results even if defective area is characterized by δ-function, i. e. $(x_2 - x_1) \to 0$. If we ignore this fact we will have large errors in establishment of defective area coordinate. So we must noticeably reduce scanning speed when we record signal with time constant of leading edge close or shorter to 5 τ. In general we state that with

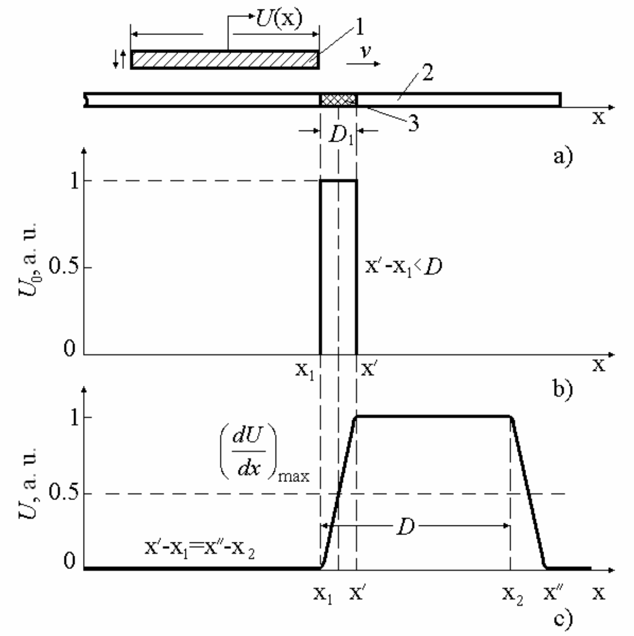

Fig. 4. Accepted model of defective area (a), constructed surface electric potential (b) and measured electric potential (c). Defective area's size is less the diameter of vibrating probe and . $U_0 \gg U$.

scanning speed $v=0.01D/\tau$ we will easy measure surface potential and will straight establish coordinate of defective area if width or diameter of this area will be larger than $0.1D$, i. e. $x_2-x_1 \geq 0.1D$.

Still we had analyzed defective area linear dimension and transition process of signals registered by measuring device assuming signal amplitudes noticeably higher noise voltage. In experiments it was always satisfied. Our surface electric potential measuring device has 100 % negative feedback, which enlarged measurement accuracy and measured voltage value coincided to sample's voltage. It is true if size of informative area is greater the size of vibrating probe. Now we are analyzing case when informative area is noticeably les the area of the tip vibrating electrode and the value of registered voltage will be much less the potential of informative area. It was experimentally established that measured voltage value U is related to defective area potential by relation:

$$U \approx U_0 \, D^2 / d^2 \, , \qquad (1)$$

where $d=x_2-x_1$ (assuming profile of defective area as circle), so measured voltage is low, therefore it is necessary to give attention to the noise voltage.

We would like demonstrate experimental results (Fig. 5) dealing with the same vibrating electrode (D=7.5 mm) and defective area was simulated by three circular shape areas with diameter 1 mm and distance between areas 2 mm. According to experimental results it is possible to detect defective areas with area noticeably less the area of vibrating probe tip. Analogous measurements were carried out with vibrating electrode which tip diameter was 10 μm. Due to insufficient accuracy of scanning device it is possible to compare only qualitatively these results.

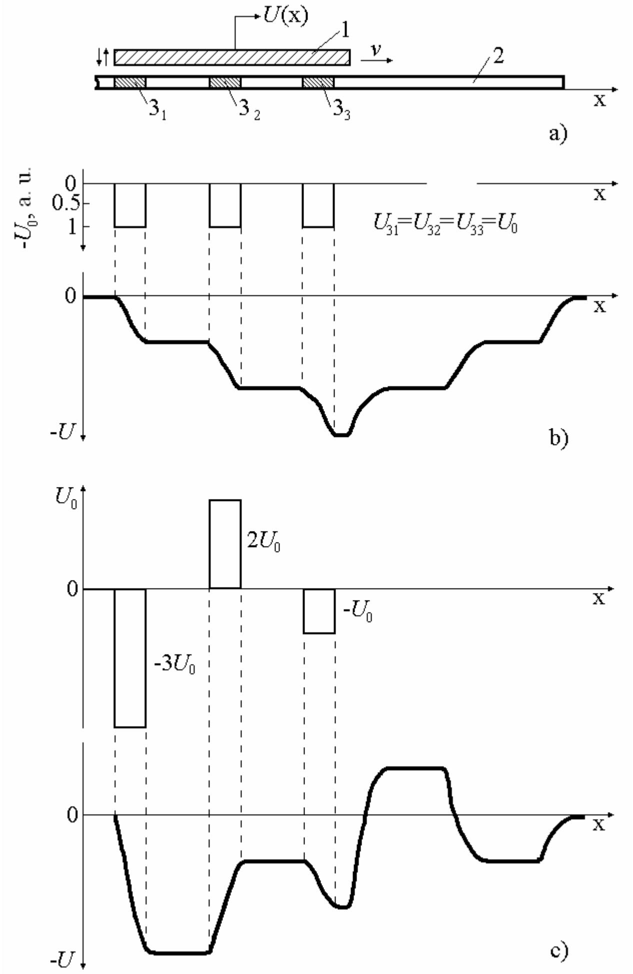

Fig. 5. Constructed experimental model of some defective areas (a) and measured surface electric potential when potential of defective areas are equal and same sign (b) or different values and signs (c). Potential of defective area is far greater than measured.

Conclusions

Analysis of theoretical results and carried out experiments on real samples and its models allows us state that contactless capacitic electric potential measuring devices operating on principle vibrating Kelvin Zisman probe allows:

– to localize single microdefects its groups when their dimensions are less the diameter of vibrating probe;

– approximately measure surface electric potential and jointly electron work function of these microdefective area;

– full-automatic of measuring process with computer analysis and processing of results.

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V. Bulbenkienė, R. Pūras, S. Sakalauskas. Analysis of Surface Microdefects Lokalization Possibilities // Electronics and Electrical Engineering. – Kaunas: Technologija, 2006. –No. 6(70).– P. 87–90.

Analysis of linear spatial resolution of vibrating Kelvin–Zisman electrode is carried out in case when the size of defective area is substantially less than diameter of vibrating probe. Dependence of relative error of voltage determination and defective area center's coordinate determination on scanning speed was examined and influence of measuring device pass band was estimated also. Analysis of theoretical results and carried out experiments on real samples and its models allows us to state that contactless capacitic electric potential measuring devices operating on principle of vibrating Kelvin Zisman probe allows to localize single microdefects and its groups when their dimensions are less the diameter of vibrating probe, approximately measure surface electric potential and electron work function of these microdefective areas. Ill. 5, bibl. 7 (in English; summaries in English, Russian and Lithuanian).

В. Булбенкене, Р. Пурас, С. Сакалаускас. Анализ возможностей локализации поверхностных микродефектов //Электроника и электротехника. – Каунас: Технология, 2006. – № 6(70). – С. 87–90.

Проведен анализ линейной разрешающей способности метода вибрирующего зонда Кельвина–Зисмана, когда размер исследуемой дефектной поверхности намного превышает диаметр вибрирующего зонда. Исследовано влияние скорости сканирования на неопределенность измерения поверхностного электрического потенциала дефектной области и координаты дефектной области, оценено влияние полосы пропускаемых частот измерителя. Анализ теоретических результатов и проведенные эксперименты позволяют делать вывод, что емкостным измерителем поверхностного электрического потенциала можно локализировать отдельные микродефекты и области их групп, когда геометрические размеры таких групп намного меньше диаметра вершины вибрирующего зонда, приблизительно установить поверхностный электрический потенциал этих областей и работу выхода электронов Ил. 5, библ. 7 (на английском языке; рефераты на английском, русском и литовском яз.).

V. Bulbenkienė, R. Pūras, S. Sakalauskas. Paviršinių mikrodefektų lokalizavimo galimybių tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2006. – Nr. 6(70).– P. 87–90.

Išanalizuota virpančiojo Kelvino ir Zismano elektrodo metodo linijinė skiriamoji geba, kai tiriamos defektinės srities matmenys yra gerokai mažesni už elektrodo skersmenį. Išnagrinėta defektinės srities paviršinio potencialo ir jos koordinatės matavimo neapibrėžties priklausomybė nuo žvalgos greičio, įvertinta keitiklio praleidžiamų dažnių juostos įtaka. Teorinių rezultatų analizė, atlikti eksperimentiniai tyrimai su realiais bandiniais įgalina tvirtinti, kad talpiniai paviršinio potencialo matuokliai leidžia lokalizuoti pavienių mikrodefektų ir jų grupių sritis, kai tų sričių geometriniai matmenys kur kas mažesni už virpančiojo elektrodo viršūnėlės skersmenį, apytiksliai nustatyti šių mikrodefektinių sričių paviršinį elektrinį potencialą ir išlaisvinimo darbo vertę. Il. 5, bibl. 7 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).