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# Sub-Pixel Resolution by Die to Database Reticle Inspection

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## Introduction

One of the main tasks, arising during the automatic reticle inspection is the task of providing low level of false and nuisance defects detection. In earlier publication [1] there were presented the causes of arising of false defects by die-to-database inspection. The main of these causes are misalignment of optical and reference images (1), as well as the high level of sensitivity of image acquisition sub-system (2).

The necessity of inspection fulfillment with high sensitivity level is stipulated by two causes. First, by the necessity of recognition of images with low contrast (semi-transparent defects), and second, by the necessity of taking into account the possibility of the worse chance of defects location alignment with digitization grid of the inspection system (Fig.1). This is stipulated by the probabilistic character of process of images digitization.

The first problem (1) is solved by means of the creation of multilevel alignment sub-system. This sub-system consists of the set of alignment procedures, which are performed both statically (before the scanning process), and dynamically (in scanning process). In order to get positive result VSA, which are being fulfilling also in the scanning process, must work in concord with dynamic auto alignment sub-system of images.

The second problem (2) leads to the necessity of solving of contradictory task. On the one hand, the necessity of semi-transparent defects detection with low contrast demands maximum sensitivity of image acquisition sub-system, and on the other hand, maximum sensitivity of this sub-system involves the increase of the false defects number.

## Description of the virtual scanning method

One of the ways of solving the above mentioned problem is the using of VSA, providing sub-pixel resolution by isolated defects of all types. The using of these algorithms allows to detect semi-transparent defects, not resort to use maximum sensitivity settings, and, thereby, not worsen detection probability of false and nuisance defects. In order to achieve necessary result these algorithms must be used concurrently with dynamic auto alignment sub-system, providing precise alignment of optical and reference images in the process of die-to-database inspection. For the providing of the effective building in of these algorithms to the inspection system, has being created the special two-level dynamic model of optical image. This model allows, on the one hand, to perform the precise alignment of optical image with a reference image, and on the other hand - to perform the analysis of optical image to get optimum mutual position of the digitization grid of the inspection system and detected defects position (Fig.1).

Both the VSA and the second level of dynamic model of optical image, are presented the VSS.

By the use of VSA sub-pixel resolution is achieved owing to the forming of dynamic two-level model of the process of automatic layout inspection. The first level of the model is formed by dynamic auto alignment sub-system, which provides the alignment of optical and reference images. The second level of the model is formed by VSA, which provide optimum alignment of digitization grid of inspection system with spatial defect location. VSS is designed like a sub-system of EM-6029B and EM-6329 die-to-database mask inspection systems.

Both the alignment of optical and reference images and also the alignment of digitization grid of inspection system with spatial location of mask pattern features are performed by means of two-levels model, which becomes actual on each scanning step.

The first level of the model appears to be a combination of two align halftone-model of optical and reference images, in which each pixel corresponds with appointed signal code. The most complicated problem during the building of this model level is the definition of current point of optical image, which corresponds with current point of reference image. This task is being solved in the scanning mask process owing to dynamic auto alignment sub-system of images. This sub-system (Fig. 4) has been built on the basis of multi canal comparator, which calculates on each step the number of differences of optical and reference images by sixteen possible variants of misalignment of these images. Further, according to the minimum of differences, the point of optimum alignment is defined.

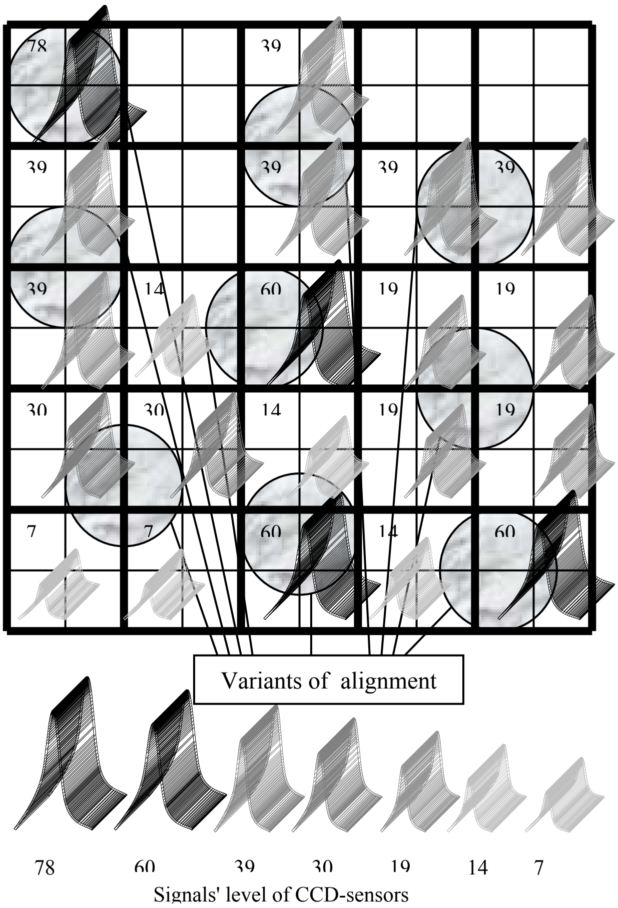


**Fig. 1.** Variants of defect placement, taking into account by virtual scanning

The second level of the model appears to be a halftone model; it has been got as a result of scanning of the first level model. The scanning is called virtual, because it is not connected with movement of real images and acquisition of optical images. It is performed by means of fulfilling of definite code transformation of the raster model of the first level, and as a result it is forming the second level model, which corresponds with some image, of which the real scanning haven’t been performed.

The building of the first level model is performed with outstripping relative to process of verification of optical and reference images, what makes the both model levels to be independent.

VSS allows to perform code transformation of halftone raster image model of the first level, and as a result it is formed models' set of the second level. Each of these models' set corresponds with certain variant of alignment of digitization grid of the inspection system with defect image (Fig.3). By means of analysis of amplitude contrast of each image model from the received models' set of the second level it is chosen that one, which corresponds with optimum alignment of digitization grid of inspection system to the current image feature (which can be , in particular, a defect).

VSA allow to introduce the correction of the determined defects location in pixel parts on the halftone image model, simultaneously changing halftone pixel codes, so as they would change, if equivalent misalignment would be during a real scanning. By all this in the image analysis sub-system storage is built halftone model having scanned pattern layout. After that it is performed elements’ group search, having signal amplitude higher than noise threshold, but lower than that allows to make the conclusion about the image presence.

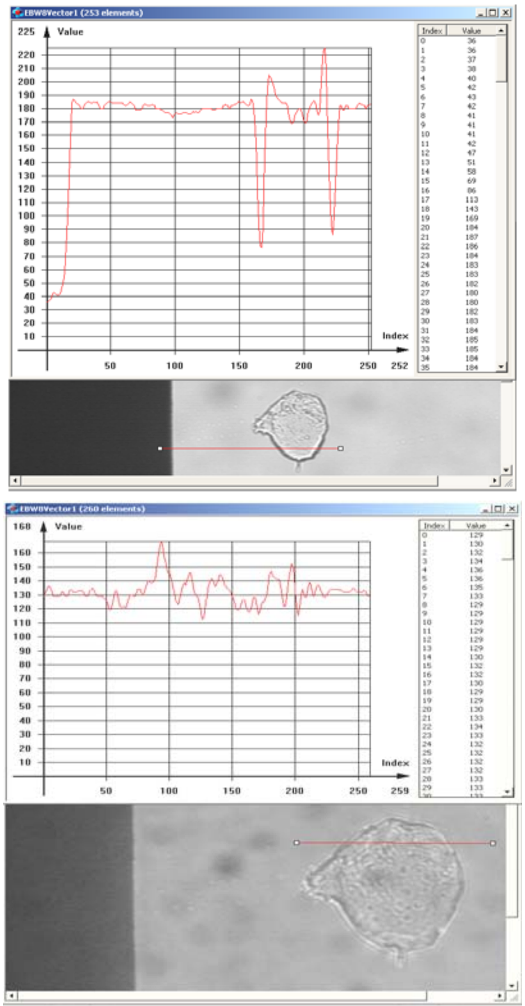


**Fig. 2.** Semitransparent defect examples and proper signals’ diagrams of CCD-sensor (amplitude contrast of defect)

Further, it is performed gradient analysis of spatial signal distribution, received during the process of pattern photometric measurement, which allows to reveal compact areas of signals’ anomalies. This analysis is performed in the nearest environment of current alignment point of real and reference images in the range of the work of dynamic auto alignment sub-system.

In the case of detection a cluster of signals with monotony levels changing, it is performed signals group integration, after that formed integral value is given to pixel, corresponded with current point. This value is being analysed and, in the case of the exceeding of signal amplitude threshold value, it is registered as a defect.

Such approach allows to perform optimum alignment between digitization grid of the automatic reticle inspection system and mask pattern in one pixel range by the both co-ordinates. In its turn, it allows to get always maximum possible amplitude contrast of signals in the digital image model of small elements on the output of used photoreceivers. Accordingly, such approach allows to tune the image acquisition sub-system without taking into account the possibility of near-pixel sizes defects' passing through adjacent photoreceivers (Fig. 1). VSS is used during comparing both contrast and halftone images.

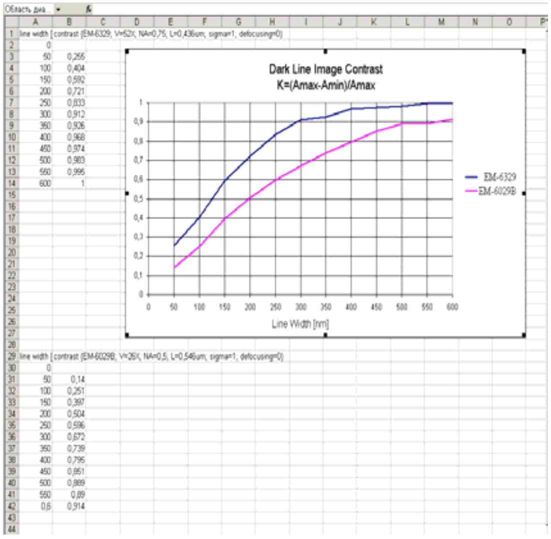


**Fig. 3.** The influence of feature sizes on its contrast for the lenses with different apertures

VSS goes well with dynamic auto alignment sub-system of images, which performs the alignment of optical and reference images in whole or fractional pixel parts, but work with outstripping. VSA perform the signal code modification on the model only, without changing of real mutual position of optical and reference images from the point of view their global alignment.

VSS don't change (neither improve no worsen) mutual alignment of optical and reference images, but only align the digitization grid of the inspection system with real defect position.

These two sub-systems form two-levels image model, which allows, on the one hand**,** to perform precise alignment of optical and reference images on each scanning step, and on the other hand – to perform optimum digitization of pattern.

For example, in image acquisition sub-system, which has amplitude resolution on the level of four signal units, a defect with size of one pixel, having 40% optical contrast, after scanning can be presented by four pixels with amplitude electric contrast on 10% level. Virtual scanning algorithm, performing the integration of adjacent elements, in this case transforming it into one pixel element with 40% amplitude contrast. Fig.2 shows a semi-transparent defect example. Performing of such transformation would allow, in its turn, to detect such defect with high probability.

Thus, the inspection system, which has a detection capability P without using VSA, must be designed taking into account the possibility of defect (with near-pixel sizes) dividing into parts during photometric scanning. Usage of VSA allows not to take into account this opportunity and, accordingly, to provide the better detection capability P-ΔP. In response to this fact it is certainly necessary to take into account real resolution capability of tool's optical sub-system. Features contrast for lenses of EM-6029B and EM-6329 inspection systems is shown in Fig. 3.

As the Fig. 6 indicates, real tool's lens resolute the pattern features, essentially lesser than pixel size, with satisfactory contrast. So, for example, for the elements with the sizes of 0.12 µm is getting optical contrast on the level 0.5 and 0.3 for lenses with aperture 0.75 and 0.5 accordingly.

**Results of the use of VSA**

During the inspection using die-to-die or die-to-database comparison methods on each step of image scanning it is possible to know exactly what pattern must appear. Especially it is possible to determine exactly in the case of die-to-database method, because in this case the reference image has an ideal form, that essentially decrease the analysis complication and increase considerably its trustworthiness. This circumstance allows on each scanning step due to quite easy hardware logic to have the sign, which determines the type of inspected pattern. That allows to choose the proper virtual scanning alghorithm for each defect type separately, and to spread forming principles of the two-levels model of layout digitizing to all defects types.

Sub-pixel resolution by such approach allows to get the detection capability of inspection system for image with high contrast at the minimum 20% more. Accordingly, the image capture factor $K_d$ [2] {$K_d$ =Defect size/ (λ / NA)} decrease approximately on 20%. The value of sub-pixel detection capability by such approach is 0,20µm by pixel size 0,25µm, 0,40µm by pixel size 0,5µm. By lesser pixel sizes these values can be different, depending on specific realizations of image acquisition sub-system and using algorithms. The calculation value of sub-pixel detection capability by the pixel size of 0,15µm is 0,12µm.

The value of element's contrast, beginning with that they can be printable defects is difficult to determine because of the multiformity of mask classes, differed by this sign. These values depend on many factors, such as, for example, wavelength of wafer stepper, the type of layout, on the transmission value of substrate material and photomask coating and so on. In some cases the critical value of transmission errors can be on the 6% level [3]. The necessity of transmission error inspection on such level can appear, for example, during the work with weak-contrasted images [4,5].

**Conclusions**

Thus, the usage of the two-levels model of image with VSA**,** working concurrently with dynamic auto alignment sub-system, allows to improve the detection capability of die-to-database reticle inspection system, namely:

- to increase the detection capability of the inspection system (to decrease the detection threshold) without a pixel size changing;
- to decrease the probability of false defect detection owing to the inspection system can inspect at lower

sensitivity settings and provide the possibility of weak-contrasted (semi-transparent) images detection.

This improvement of detection capability take place without changing of optic-mechanical sub-system parameters. By the next developing steps of the presented VSS is supposed:

- to modernize the algorithms and the developing of new VLSI, realizing these algorithms, that will allow, presumably, to increase the range of sub-pixel resolution from 20% till 30% relatively to pixel size;
- the usage of VSA for improving the characteristics of the inspection process of phase shift masks.

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The description of the new Virtual Scanning Algorithms (VSA), providing sub-pixel resolution, is presented. VSA are developed specially for EM-6029B and EM-6329 die-to-database reticle and photomask inspection systems of UE"KBTEM-OMO" Minsk, Belarus. For the effective building of these algorithms into the inspection system the special two-level dynamic model of optical image was created. This model allows to perform the precise alignment of optical image (collected from the reticle) with a reference image (generated from the design data), and to perform the analysis of optical image to get optimum mutual position of the digitization grid of the inspection system and detected defects position. VSA calculate the second level of this model. Both the VSA and the second level of dynamic model of optical image are presented the Virtual Scanning sub-System (VSS). VSS allows to increase the detection capability of automatic reticle inspection system by means of achievement sub-pixel resolution. During detection of semi-transparent defects, VSA allow to get maximum available amplitude contrast of the CCD-signals on the image model. VSA allow also the inspection system to work without using maximum sensitivity settings with the same detection capability. Result is the reduction of the risk of false or nuisance defects detection while keeping maximum sensitivity to printable defects. The VSS design and test results are discussed. Ill. 3, bibl. 5 (in English; summaries in English, Russian and Lithuanian).



**С. М. Аваков. Субпиксельное разрешение при контроле фотошаблонов методом сравнения с проектными данными // Электроника и электротехника. – Каунас: Технология, 2007. – № 7(79). – С. 45–48.**

Представлены новые алгоритмы виртуального сканирования (АВС), обеспечивающие субпиксельное разрешение. АВС разработано специально для установок контроля фотошаблонов методом сравнения с проектными данными ЭМ-6029Б и ЭМ-6329, разработанных УП «КБТЭМ-ОМО» (Минск, Беларусь). Для обеспечения эффективного встраивания этих алгоритмов в систему контроля, создана специальная двухуровневая динамическая модель оптического изображения. Модель позволяет выполнять точное совмещение оптического изображения (получаемого с фотошаблона) с эталонным изображением (генерируемым из проектных данных) и выполнять анализ оптического изображения для получения оптимального взаимного расположения сетки дискретизации установки контроля и обнаруживаемых дефектов. АВС формируют второй уровень этой модели. АВС и второй уровень динамической модели представляют систему виртуального сканирования (СВС). СВС позволяет улучшить обнаружительную способность установки автоматического контроля фотошаблонов за счёт достижения субпиксельного разрешения. При обнаружении полупрозрачных дефектов эти алгоритмы позволяют, в частности, получать максимально возможный амплитудный контраст сигнала ПЗС на модели изображения. АВС позволяют установке контроля работать не используя предельные возможности по чувствительности с сохранением той же самой обнаружительной способности. Результат – уменьшение риска обнаружения ложных или некритичных дефектов при сохранении максимальной чувствительности к критичным дефектам. Обсуждаются результаты проектирования и предварительных испытаний СВС. Ил. 3, библ. 5 (на английском языке; рефераты на английском, русском и литовском яз.).



**S. M. Avakaw. Subpikselio skiriamoji geba atliekant fotošablonų kontrolę lyginimo su projektiniais duomenimis metodu // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007. – Nr. 7(79). – P. 45–48.**

Pateiktas virtualių skenuojančiųjų algoritmų (VSA), leidžiančių pasiekti subpikselio skiriamąją gebą, apibūdinimas. VSA sukurti specialiai EM-6029B ir EM-6329 fotošablonų kontrolės sistemose įmonėje KBTEM-OMO (Minskas, Baltarusija). Siekiant šiuos algoritmus efektyviai įterpti į kontrolės sistemą, sukurtas specialus dviejų lygių dinaminis optinio vaizdo modelis. Modelis leidžia tiksliai išlygiuoti gautą optinį vaizdą su atraminiu vaizdu, sugeneruotu pagal projektinius duomenis, taip pat atlikti vaizdo analizę siekiant gauti optimalų kontrolės sistemos diskretizavimo tinklelio ir aptiktų defektų tarpusavio išdėstymą. VSA apskaičiuoja antrąjį šio modelio lygmenį. VSA ir antrasis dinaminio modelio lygmuo sudaro virtualų skenavimo posistemį (VSP). VSP leidžia padidinti sistemos gebą aptikti defektus pritaikant subpikselio skiriamąją gebą. Aptinkant pusiau permatomus defektus VSA leidžia gauti maksimalų vaizdo modelio CCD signalų amplitudės kontrastą. Pritaikius VSA, kontrolės sistemos jautris padidėjo. Dėl to sumažėjo klaidingų aptikimų skaičius. Aptariami VSS projektavimo ir pirminių bandymų rezultatai. Il. 3, bibl. 5 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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