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Precision assembly of a miniaturized wire deflector for electron-beam lithography

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ABSTRACT

The fast and precise deflection of electron-beams is mandatory for common electron beam tools and next generation multi-beam lithography systems. Electrostatic fields generated by an arrangement of electrodes with several electric potentials are used to control the electron beam. The miniaturization of such a beam-deflection system facilitates its integration at a favorable place within the electron-optical column. An efficient and accurate beam deflection with high sensitivity and low aberrations is consequently possible.

The novel wire-based electrostatic deflector for electron-beam Lithography Tools presented in this paper strictly pursues this approach. Design investigations as well as manufacturing and alignment procedures are reported. 24 wire electrodes are arranged in a circular FEA-optimized pattern and kinematically well-defined mounted to a supporting structure using the Solderjet Bumping technique [2,3]. This flux free solder technique ensures vacuum compatible joints free of hydrocarbons and with an excellent long-term stability.

A prototype of the wire deflector is measured by means of a high resolution X-ray computer tomography scanner (CT) [4]. The single wire elements of the wire deflector are symmetrically arranged to each other within an accuracy of a few microns.

1. Introduction

For a highly precise deflection of electron beams, electrostatic fields based on an arrangement of several electrodes with different voltage potentials can be used. The resulting electrostatic field deflects the electron beam, depending on the applied voltages U. If electrons having a velocity v enter a homogeneous electrostatic cross field of field strength E they will be deflected due to an electrostatic force $F = q * E$. The electrostatic field E can be generated by plates or wire shaped electrodes with length l and distance d. It can be derived that the deflection of the beam increases with length l and field strength E which is determined by $E = U/d$.

Frequently used electrostatic x–y deflection systems consist of 8 or 12 equal rod electrodes circularly arranged. It is very important to manufacture all parts with highest accuracy to keep deflection aberrations like deflection astigmatism or distortion low. Using short rods of largest possible diameter is therefore advantageous. Otherwise, replacing of rod electrodes by 2–3 wire electrodes each gives considerable room for performance improvement. A significantly reduced overall electrode surface can help to minimize contamination induced drift while keeping the deflector sensitivity nearly unchanged. To design long electrodes out of wires is also beneficial for accuracy reasons because of the wire straightness and springiness.

The state of the art of deflection devices for charged corpuscular beams is described in various patents. Vistec Electron Beam GmbH describes a circular electrode arrangement using wires [5]. Depending on the control sequence, different deflecting voltages can be applied to the electrodes. The electrode arrangement on different radii is beneficial for the reduction of certain higher order aberrations. Siemens Corp. presents a circular arrangement of cylindrical electrodes which are mounted parallel to the beam [6]. The position of the single electrodes is determined by holes within an insulating body. The cylindrical shape of the wires is assured by a mechanical preload using additional spring elements. To avoid an electrostatic charging of the insulating parts, an electric conductive shield is used. Both discussed compact arrangements allow the independent deflection of the e-beam simultaneously in x- and y-direction.

Wire deflectors are applicable to electron-optical columns of Scanning Electron Microscopes and Electron Beam Lithography Tools. A new generation Lithography Tool for Multi Shaped Beam Lithography was developed by Vistec Electron Beam GmbH using

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telecentric electron optics. The Multi Shaped Beam Lithography is a promising approach for high throughput mask and direct writing that addresses the shot count/writing time bottleneck [1] for the 22 nm node and beyond. A miniaturized wire deflector characterized by low third- and fifth order deflection aberrations will be integrated into the electron optical column.

2. Design and simulation of a wire deflector

The basic concept of the new deflector design is a kinematically well-defined arrangement of thin gold wires. The positions of the electrodes are calculated and optimized by the Finite Element Method.

As a result of basic design considerations, the x/y deflector should consist of twenty-four wire electrodes to which certain voltages can be applied to create the electrostatic field for deflecting the electron beam. This electrostatic field should be as homogeneous as possible, because any deviation from homogeneity causes aberrations of the underlying electron optics. This homogeneity can be achieved by means of an appropriate choice of the locations of the electrodes with respect to both angular position and distance from the electron optical axis. Deflection systems with these advantageous electron optical properties can be created by computerized optimization procedures.

Fig. 1 shows on the left the electrostatic potential distribution of such an optimized deflection system consisting of wire electrodes. Because of the small cross sectional area of the wire electrodes there is enough free space between the electrodes to vary the positions of the electrodes in a wide range and excellent degrees of freedom for optimization. The electrodes are arranged in three different distances from the electron optical axis. The values of these distances and the angular positions of the electrodes are optimized such that the third and the fifth harmonic of the electrostatic potential created by the system are zero. Therefore, the homogeneity of the resulting electric field used to deflect the electron beam is very good and ensures a low-aberration electron optics which is necessary for lithography systems, e.g. the Multi Shaped Beam Lithography.

Based on the experiences during the development of a prior deflection system consisting of 12 electrodes, the demonstrator of a miniaturized wire deflector was designed as a cylindrical device with an outer diameter of 50 mm containing 24 deflecting wires arranged circularly on a radius of 6 mm. This design is compared to the optimized arrangement of Fig. 1 left much easier to manufacture, but the potential distribution of the electrostatic field is less homogenously. The electrodes have an effective length of 80 mm and a diameter of 0.1 mm. The deviation of each wire in terms of symmetry has to be less than 10 μm. After a tradeoff process, a monolithic tube design of the wire deflector was preferred. The chosen materials have to be vacuum compatible and without magnetic influence. Each wire will be electrically linked to a highly stabilized voltage up to 100 V. The generation of particles and molecules will be prevented by the design; all components are able to be cleaned by plasma activation. The electrodes are soldered to two solid connecting flanges by the Solderjet Bumping technique which will be explained in more detail later on. The angular distribution is kept uniformly in order to simplify the introduction of this solder technique. Fig. 1 shows on the right one of the two mounting flanges of the demonstrator attached to an assembly device with all 24 wires threaded through. Contacting the electrodes to a printed circuit board enables the intended interconnection and control.

The overall design of the device (see Fig. 4 left) is based on the functional separation between the interface for precise positioning and features for the necessary mechanical tension of the wires. The flux of force between the connecting flanges is realized via a hollow cylinder out of titanium. In addition, this cylinder shields the electrodes to the surrounding area. The flanges are designed to absorb the tensile stresses of the gold wires (150 MPa each) without influencing their position. The position of the wires is defined by two reference disks which determine the exact position using v-groove structures. No additional spring elements are used within this device to keep the tension since the preloaded wires act as springs themselves.

3. Assembly of the miniaturized wire deflector

The most important issue during the assembly of the wire deflector is to avoid any mechanical contact of the wires. The gold wires are very sensitive to mechanical stress, especially to crippling and scratches on sharp edges. Thus, an assembly device similar to an optical bench was designed, on which the mounting elements of all components of the wire deflector assembly are arranged.

To achieve an optimal shape and positioning of the single wires w.r.t. the wire deflector interface, the wires are strained. The strain force is induced by spring elements to apply an initial load to the wires. After applying the initial load, strain variations of the wires during the assembly process and over the life time period are minimized.

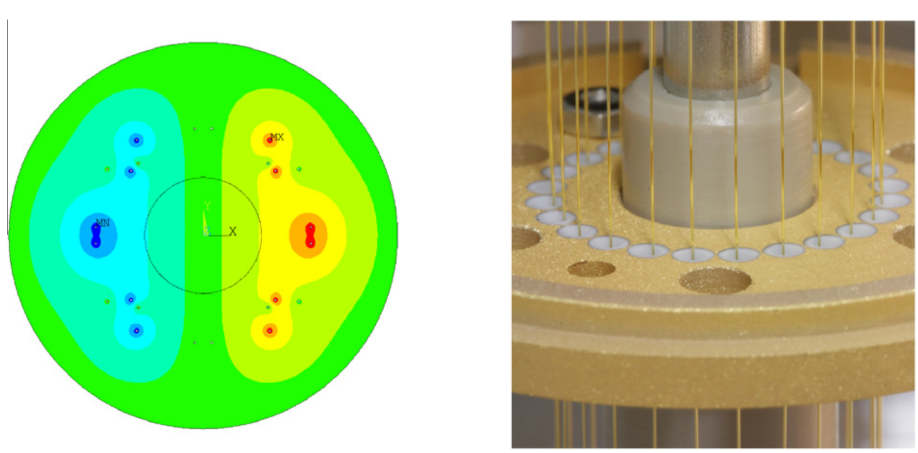
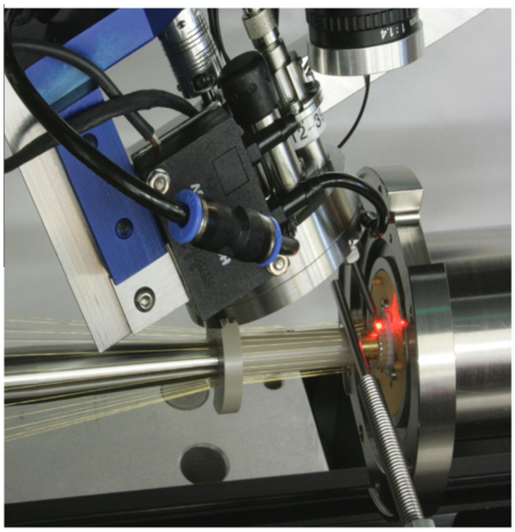


Fig. 1. Left: design concept of an x–y wire deflector with optimized positions of 24 wire electrodes on three different pitch circle diameters – potential field distribution for x activation. Right: realized arrangement of 24 wire electrodes on one circle diameter with same angular pitch.



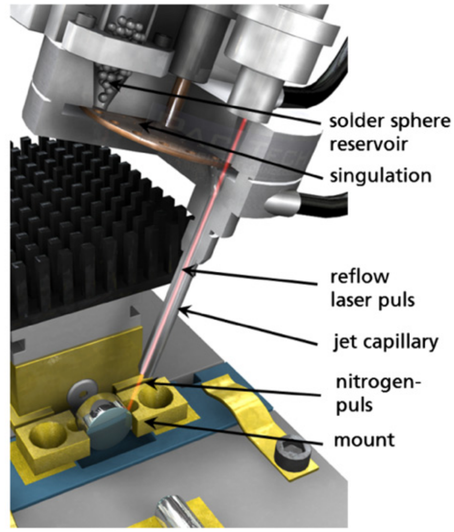


Fig. 2. Left: soldering of strained gold wire electrodes on connecting flange by Solderjet Bumping by means of the rotating assembly device. Right: operation principle of Solderjet Bumping at assembling of an optical system.

The final position accuracy is mainly defined by the manufacturing accuracy of the mounting flanges with precise pattern for the wire seats. These are made of a machinable glass ceramic. The achieved accuracy of the reference structures is 3–5 µm. The positioning of each wire is monitored during the assembly by an image processing which measures the position of wires w.r.t. the mounting structures.

A detail of the assembly device is shown in Fig. 2. Fig. 2 (left) illustrates the soldering process of a single wire element. On the right side is a part of the deflector with the reference flange, central is the bumping device and on the left side is the complex arrangement and feed of wires visible. The configuration respectively the operation principle of the solderjet bumping device is shown in Fig. 2 (right).

4. Solderjet bumping fixation technology

The Solderjet Bumping is a laser based soldering technique that allows placing discrete volumes of several solder alloys onto different substrates. It was originally developed for flip chip interconnections of semiconductor devices [2,3]. The bumping device so called "Bondhead" is capable to apply spherical solder preforms with diameters between 60 µm and 760 µm as well as a broad range of different solder alloys from low melting lead free indium or tin based alloys to high melting gold-tin or gold-germanium alloys.

During the Solderjet Bumping process, the spherical solder preforms are singularized and transferred from a reservoir to the placement capillary that has an inner tip diameter which is conical at the end and slightly smaller than the diameter of the solder spheres. Close to the joining area a laser pulse heats and melts the solder sphere and the nitrogen pushes the liquefied solder out of the capillary, accelerating it towards the components to be joined. The pulse energy ranges from a few milli-joules up to 5 J using pulse widths up to 30 ms depending on the solder alloy, the sphere diameter and the solder sphere volume, respectively.

When the liquefied solder hits the wetting surfaces, it forms the solder joint by partially transferring its stored thermal energy and creating intermetallic phases during re-solidification. The joints provide mechanical fixation of the components as well as a good thermal and electrical connectivity between the gold wire electrodes, the mounting flanges and the electrical contacting carrier. Furthermore the solder joints provide a good long term, thermal and radiation stability and humidity resistance during usage in the electron optical column (EOC).

Because of the preferred vertical mounting position of the Solderjet Bondhead, the assembly device was realized as a rotating device in a horizontal orientation. By turning the assembly device, all mechanical fixations and electrical connections are made by this technology.

5. Computed tomography measurements of the miniaturized wire deflector

The performance of the wire deflector strongly depends on the wire positions in the assembled deflector system. Industrial X-ray computed tomography (CT) is a proper technique to control these positions [7]. With traditional 3D measurement techniques, like tactile probing or optical fringe projection, it is not possible to measure the wires within the assembled state.

When using industrial computed tomography, the measuring sample is positioned on a rotary table between an X-ray source and a detector (see Fig. 3 left). The CT-system v|tome|x used at the Fraunhofer IOF has two selectable X-ray sources (microfocus and nanofocus) and a 2048 x 2048 pixels detector [4]. With a plurality of 2D X-ray images from different rotation angles, it is possible to calculate the absorption coefficients of each point (voxel) within the wire deflector. The size of a voxel (smallest volume element) is an important characteristic of a CT measurement (see Fig. 3 right). The achievable voxel size is primarily given by the size of the object which has to fit completely into the conical X-ray beam.

To measure the position of the electrodes of the wire deflector, the voxel size has to be significantly smaller than the wire's diameter (100 µm). The size of the whole deflection system allows a minimum voxel size of about 45 µm. To achieve a higher resolution, the system is measured in three single zoomed in measurements of the bottom, middle and top part of the wire structure, respectively. By using this approach a voxel size of 7.6 µm can be realized.

After completing the reconstruction of the 3D voxel data out of 800 X-ray images, the results are analyzed using the software "Volume Graphic Max 2.0" and "Geomagic Qualify 12". Volume Graphic allows the user to inspect the voxel data for defects by "scrolling" through the object layers.

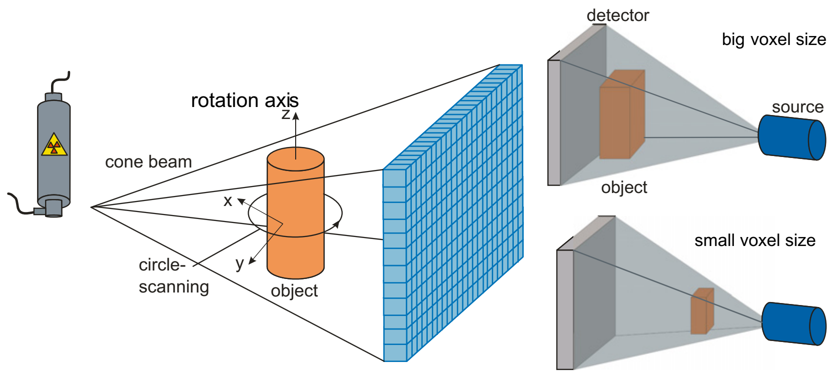


Fig. 3. Principle of industrial computed tomography.

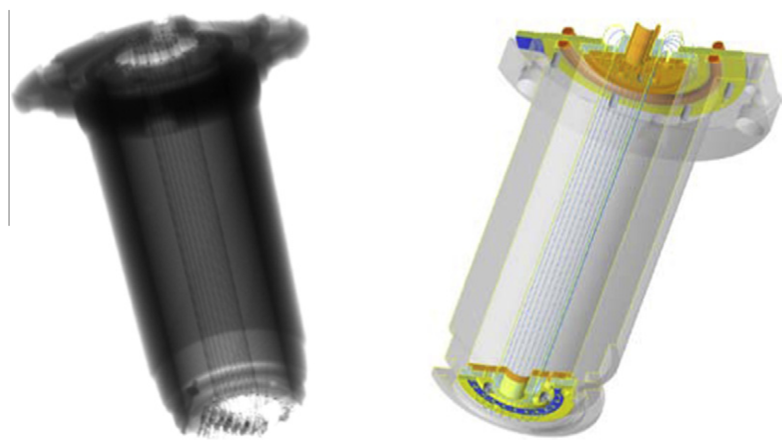


Fig. 4. Left: CT image of assembled device. Right: CAD model of the deflector.

The geometrical analysis of the wire positions requires an intermediate step. It is necessary to extract the wire surfaces out of the voxel model. In Volume Graphic this can be done by using a threshold gray value between material and background. The surface can be extracted and converted into a polygonal model (STL). In the next step Geomagic Qualify is used for analyzing the wire positions.

The wire positions were analyzed by calculating the distances from each wire to the center axis of the wire deflector, within the 24 wires and the angles between the wires-center connections. Those measurements were accomplished in three sections of the polygonal model (see Fig. 5), at the lower, middle and upper part of wire deflector (see Fig. 4). The nominal angle between adjacent wires is 15° ± 0.036° (approx. ±0.004 mm deviation) with a maximum deviation of 0.085°. The standard deviation of the distances to the deflector's center axis is ±0.005 mm w.r.t. to the average value of 6.005 mm.

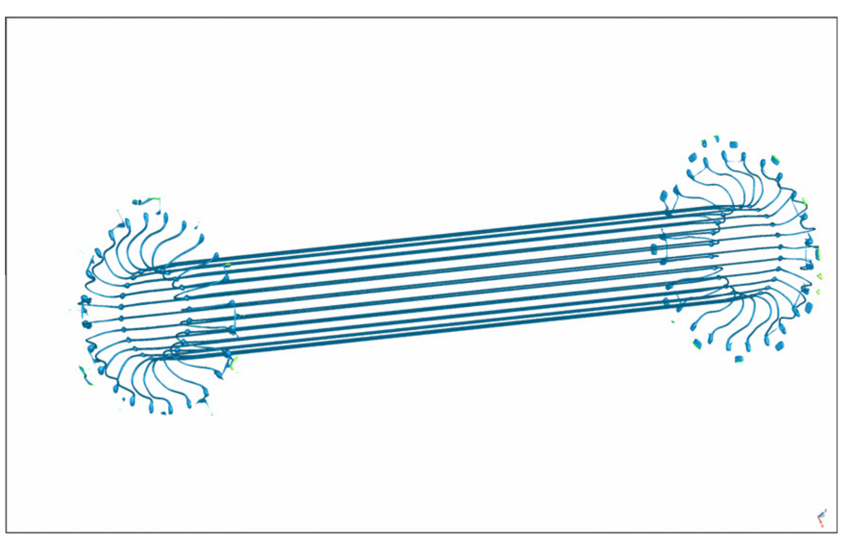


Fig. 5. Reconstructed wire-model based on CT measurements.

6. Summary

Based on the conceptual investigations and FEM simulations a prototype of a miniaturized electrostatic x–y deflector for e-beams with 24 wire electrodes arranged on a 12 mm pitch circle diameter was designed, assembled and metrologically characterized. For assembly of the prototype, a special device which allows positioning, alignment and fixation of the wires in the monolithic deflector housing was developed and successfully used, strictly avoiding damaging the very sensitive electrodes.

The Solderjet Bumping was used as flux and polymer-free joining technology for a long term stable fixation of the wires at the supporting structure.

The position of all electrode wires was measured by means of a computed X-ray tomography. Most of the electrodes are located within the acceptable position error budget of 10 μm; only one electrode is positioned with a failure of 22 μm.

Prove of concept of the wire deflector in the electron optical column is planned and will be performed by Vistec Electron Beam GmbH in early 2012.

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