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INTERNATIONAL ELECTROTECHNICAL COMMISSION

# INTEGRATED CIRCUITS –
# THREE DIMENSIONAL INTEGRATED CIRCUITS –

## Part 2: Alignment of stacked dies having fine pitch interconnect

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International Standard IEC 63011-2 has been prepared by subcommittee 47A: Integrated circuits, of IEC technical committee 47: Semiconductor devices.

The text of this International Standard is based on the following documents:

| FDIS | Report on voting |
|---|---|
| 47A/1061/FDIS | 47A/1065/RVD |

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 63011 series, published under the general title *Integrated circuits – Three dimensional integrated circuits*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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# INTRODUCTION

Three-dimensional (3-D) integration of integrated circuits using through-silicon via (TSV) technology is an innovative solution to simultaneously achieve a greater performance, an improved versatility and a higher density of integrated circuits without miniaturization of feature sizes on a die. Die alignment during the die bonding is the key enabler of the fine pitch 3-D wiring between vertically stacked dies for proper physical contact. Maintenance of the alignment during the bonding process and afterward is as important as the precise overlap prior to die bonding. This standard describes a method of initial alignment and maintenance of alignment throughout the die bonding process that can be involved with mechanical shaking. The initial alignment is performed using the optical means. During the maintenance period, however, relative amount of the misalignment is converted to an electrical signal for on-the-fly alignment monitoring without the visual image.

# INTEGRATED CIRCUITS –
# THREE DIMENSIONAL INTEGRATED CIRCUITS –

## Part 2: Alignment of stacked dies having fine pitch interconnect

## 1 Scope

This part of IEC 63011 provides specifications of initial alignment and alignment maintenance between multiple stacked integrated circuits during the die bonding process. These specifications define the alignment keys and operating procedures of the keys. These specifications apply only if electrical coupling method of die-to-die alignment is used in the die stacking.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 63011-1, *Integrated circuits − Three dimensional Integrated Circuits – Part 1: Terminology*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 63011-1 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

**3.1**
**die bonding**
assembly step to adhere physically or chemically a die to another

**3.2**
**bonder**
apparatus performing die bonding

**3.3**
**signal generator**
apparatus generating electrical signals

**3.4**
**alignment key**
apparatus to monitor or adjust the alignment of the overlaid dies

**3.5**
**aligner**
apparatus to perform the alignment of the overlaid dies

# 4 Die alignment during three dimensional integration

## 4.1 Alignment during stacking

Once the upper die covers the bottom one, the patterns including align key on the bottom die are not seen any longer. Therefore, the image of the bottom die is stored in the memory. As the upper die is moved above the bottom die, the patterns on the upper die are compared with the stored patterns to be precisely aligned. The procedure is illustrated in Figure 1. The cross-patters indicate alignment keys, and they are placed at the same location on every die. The alignment keys are also used as a positioning reference for all other patterns on the die. The position of patters on the upper die is compared with memorized images of the lower die because the pattern on the lower die is covered by the upper one and no longer seen by general alignment tools.

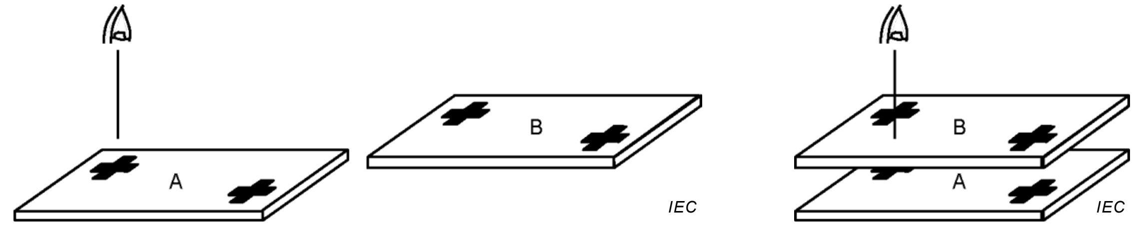


**Figure 1 – Procedure of alignment of dies during die stacking**

## 4.2 Alignment maintenance during die bonding

After the upper die is placed on top of the bottom one, the bonding process is proceeded to give the permanent physical contact on the bonder as shown in Figure 2. The bonding process is involved with thermal and mechanical agitation to provide the adhesive contact between the TSV and micro bump. Physical agitation destroys the alignment. The image of the bottom die is not observed by optical microscope using visible light. Although the infrared light penetrates the solid to the limited depth, the resolution deteriorates drastically as the thickness of the top die increases. In addition, the metallic piece of die holder blocks images in the infrared microscope. Another alignment sensor is desired to monitor the deviation from the perfect alignment using the electrical signal. The misalign information is, then, fed back to the aligner to compensate the misalignment. The aligner shall be capable of recovering the translational misalignment along the two principle axes parallel to the die surface, and rotational misalignment perpendicular to the die surface. The signal generator provides the source signal to be supplied to the die through the transmitter. The receiver collects the transmitted signal that is distorted by the amount of misalignment as depicted by a curve in Figure 2 below.

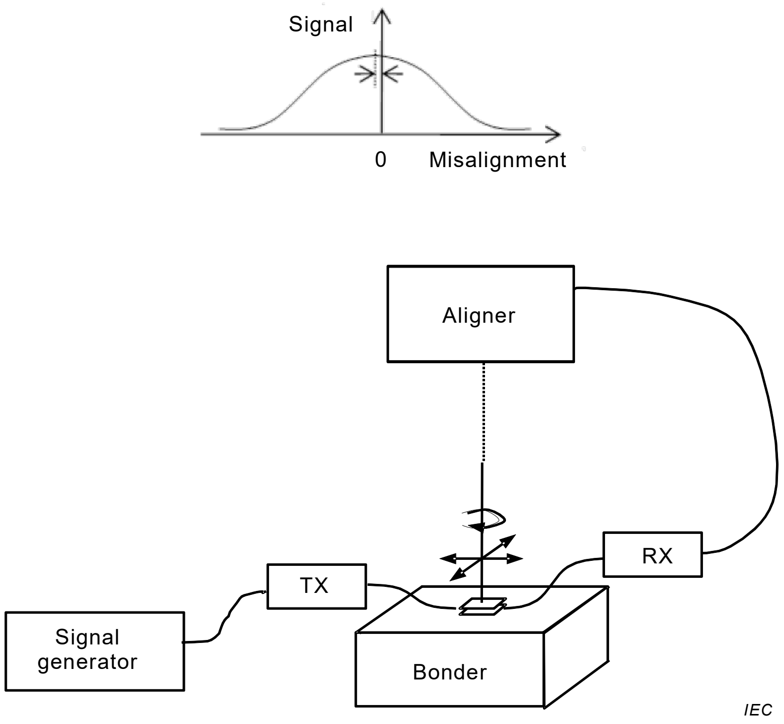


Figure 2 – Misalignment sensing and compensation by aligner

In order to convert the physical misalignment to the electrical signal during the die bonding step, the alignment keys shall sense the alignment when they are not in contact. The electrical or magnetic coupling is an efficient medium of alignment information. Figure 3 illustrates a possible example of alignment key deployment in the stacked two dies. The intensity of the received signal becomes strong when active alignment keys are placed on the facing surfaces of the two stacked dies, i.e. bottom of the upper die and top of the lower die. Both transmitter and receiver are located on the bottom die and the upper die does not have any active device so that the upper die does not need to have electricity. The power is provided through the fixed bottom die and the top floated upper die provides passive bridges. Then, the upper die is free to move for alignment recovery and bonding. The signal is emitted by the alignment key connected to the transmitter on bottom die, and it is coupled by left part of the bridge on bottom surface of the upper die. The signal travels to the right half of the bridge and couples back to the transponder that is connected to the receiver on the top surface of the bottom die. The attenuation of the received signal from the transmitted one is determined by the distance and misalignment of align keys. If the upper die shakes constantly, the amount of attenuation tells which direction is for the perfect alignment. The bridge on the upper die is exposed to the ambient, but the transponder on bottom die is covered with thin dielectric film to avoid direct contact between the alignment keys and to maximize the received signal as well. Clauses A.1 and A.2 show an example of the shape of a typical sensor element and the strength of coupling to misalignment.

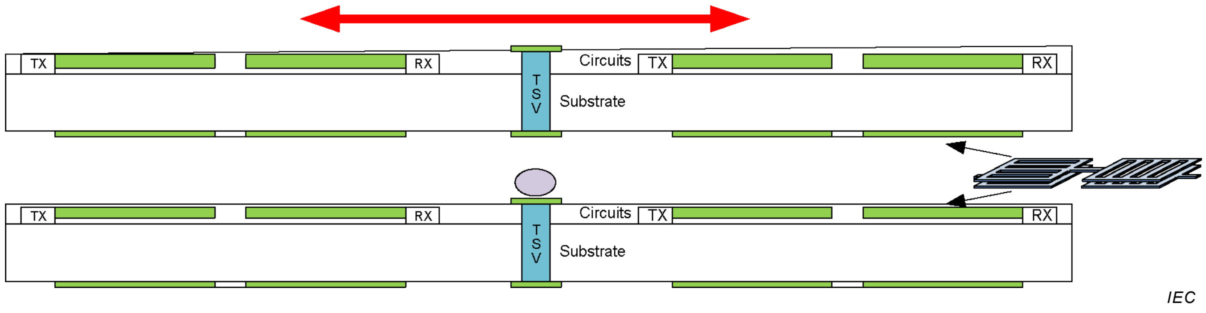


Figure 3 – Adjustment for translational misalignment

### 4.3 Alignment measurement after die stacking

The alignment of the two dies may be disrupted by the mechanical or thermal agitation during the die bonding process. The typical cross-section view of the stacked dies with misalignment in the vertical interconnects is shown in Figure 4. After the upper die is completely bonded onto the lower die mechanically and electrically, the alignment is once again measured by an appropriate instrument. The quality of the final alignment of the three dimensional integrated circuits is delivered in the form of amount of misalignment. An example of a structure for detecting misalignment after bonding is shown in Annex A.3.

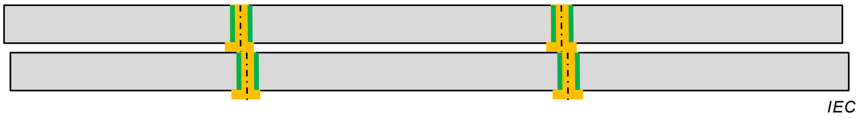


**Figure 4 – Final alignment of vertical interconnects between the adjacent layers of dies**

## 5 Alignment procedure

### 5.1 Initial die stacking

Place the bottom die and store the image of alignment key in the memory before the top die is brought above the bottom one. Then, compare the image of alignment key on the top die and that in the memory to make the initial alignment. The accuracy of the alignment shall be better than a half of spacing of alignment unit in the coupling alignment keys.

### 5.2 Final alignment

Turn on the electrical alignment key to track the alignment with electrical signal during the subsequent bonding process. Shake the upper die in X direction to get the best alignment along that direction using one of coupling alignment methods. And repeat the alignment check along Y direction. Rotate the upper die around the axis perpendicular to the die surface to compensate the rotational misalignment. Repeat translational and rotational alignment until the misalignment is small enough.

### 5.3 Assessment of alignment

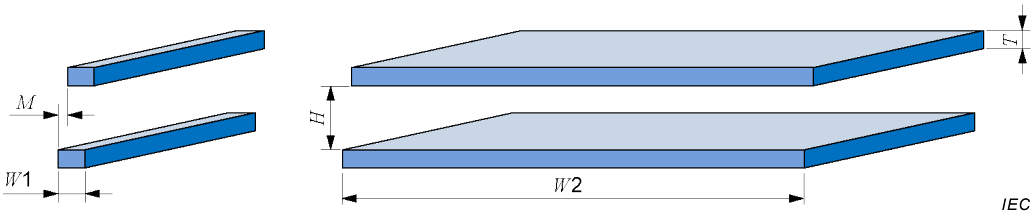
Whenever a layer of die is stacked, the quality of final alignment shall be measured using an appropriate method, e.g. resistance measurement as described in IEC 63011-3.

# Annex A
(informative)

# Alignment examples

## A.1 Alignment maintenance using capacitive coupling

Capacitive coupling between the two wires separated vertically by ‘$H$’, and misaligned horizontally by ‘$M$’ is modelled in Figure A.1. Two pairs of wires with different aspect ratio of the cross-section, $W/T$, are shown in Figure A.1 below.



**Key**

| | |
|---|---|
| $M$ | misalignment in horizontal |
| $H$ | wafer space in vertical |
| $W1$ | width of narrow wire |
| $W2$ | width of wide wire |
| $T$ | thickness of unit alignment key |

$W1$ and $W2$ to be discriminated.

**Figure A.1 – Capacitive coupling between two misaligned wires with different widths**

The relative attenuation of capacitance by the misalignment is significant when wires are narrow as shown on the left in Figure A.2. However, the absolute intensity of capacitive coupling becomes strong when the wires are wide. It is described on the right in Figure A.2 below.

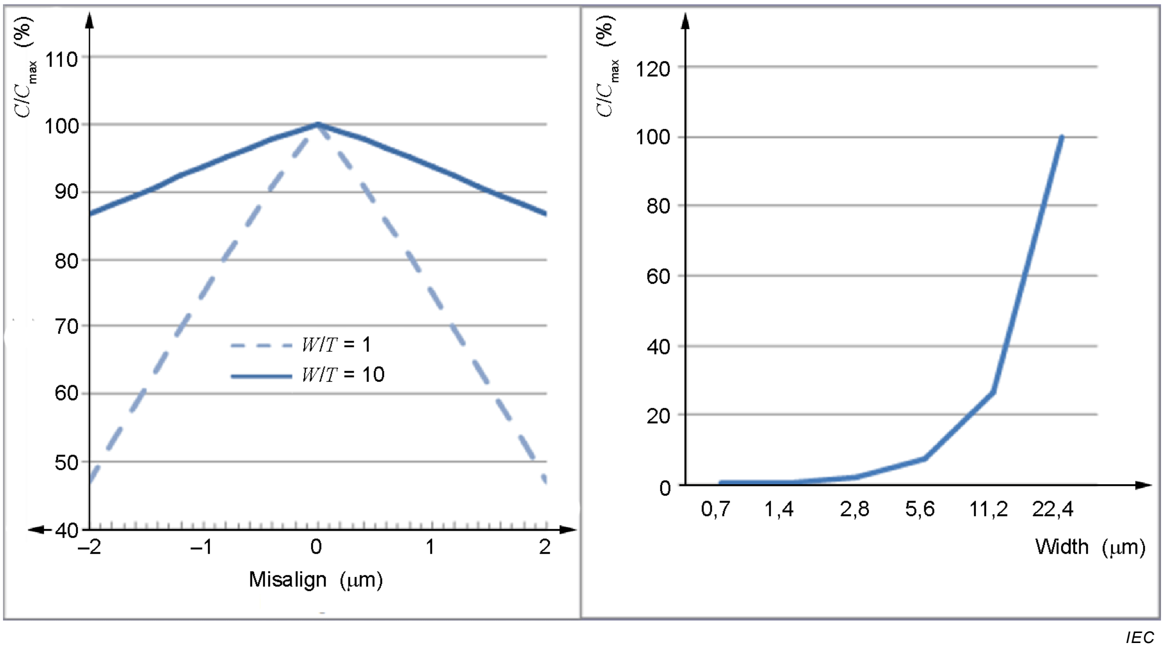
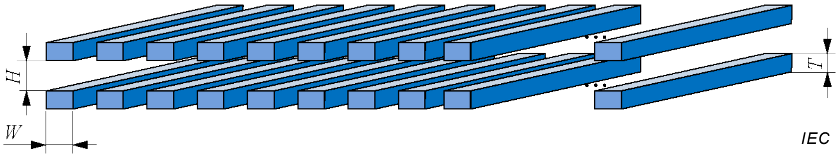


**Figure A.2 – Relative capacitance with misalign and metal width**

In order to have both coupling strength and alignment sensitivity, multiple narrow wires are necessary as illustrated in Figure A.3.



**Key**

*H* wafer space in vertical

*W* width of wire

*T* thickness of unit alignment key

**Figure A.3 – Multiple narrow wires**

Using the analysis of the capacitive coupling, the two types of alignment keys can be used as illustrated in Figure A.4.

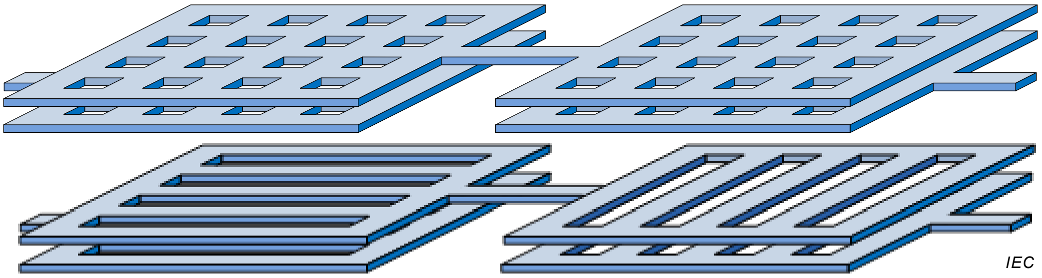


**Figure A.4 – 2-D alignment key in (top) mesh type and (bottom) conjugate X- and Y-direction detectors**

The attenuation of the received signal is function of the vertical separation of coupling pairs (*H*), *W*/*O* ratio, the number wires (*N*) and the dimension of the alignment keys. Figure A.5 shows the field simulation results of conjugate align keys with different dimensions.

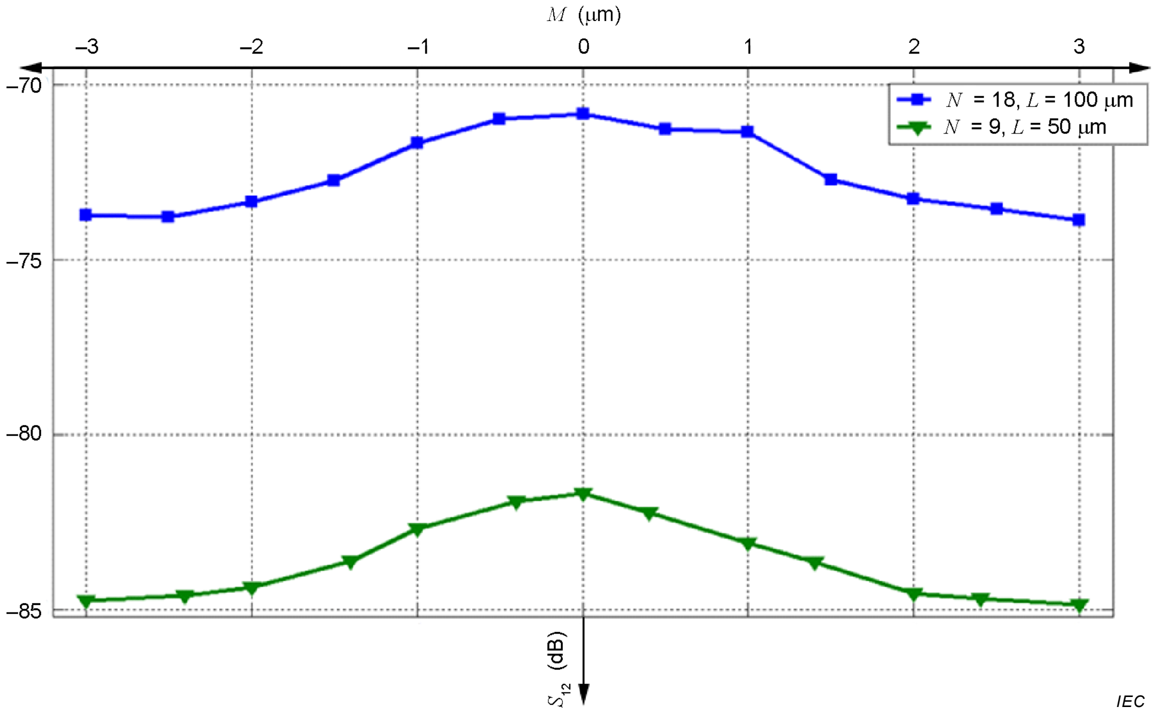


**Figure A.5 – $S_{12}$ roll-off with misalignment (*M*) for at *H* = 10 µm, ratio = 0,1, *f* = 0,01 GHz, and *T* = 0,5 µm**

For proper functionality of the alignment sensor in different technologies the following parameters that are listed in the Table A.1 are desired to be specified. In some cases, different classes of dimensions of alignment keys may be specified.

**Table A.1 – Alignment key dimensions**

| Parameter Name | Class-1 | Class-2 |
|---|---|---|
| Side length of unit alignment key(*L*) | | |
| Thickness of unit alignment key(*T*) | | |
| Wafer space (*H*) | | |
| Ratio of *W*/*O* (ratio) | | |
| Number of holes (*N*) | | |
| Frequency (*f*) | | |

## A.2 Alignment maintenance using inductive coupling

Similarly, the strength of the inductive coupling can be also used as an indicator of misalignment of dies that are not in contact. The deployment of the inductors and transmitter and receiver can be either one of the configurations described in Figure A.6 depending on the availability of electricity in the upper die.

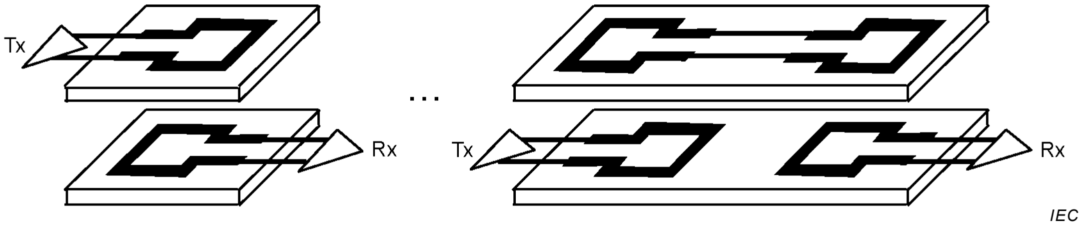


**Figure A.6 – Alignment keys for inductive coupling alignment detector when the electricity in the upper die is (left) available and (right) unavailable**

## A.3 Alignment measurement after stacking is completed

Since the relative position of the upper die is fixed and immobile when the die bonding is completed, alignment measurement using capacitive or inductive coupling cannot be used. In order to measure the quality of the alignment of the stacked die, another stationary method of measurement is required. Figure A.7 describes an example of final measurement method. Multiple TSVs are prepared where some pitches of them are different in each layer. If TSVs in the middle align perfectly, misalignment increases in TSV pairs away from the centre. Eventually disconnected TSV pairs appear at the same distance from the centre. On the other hand, if the upper die is displaced to the right, the locations of open TSV connections appear deviated from the centre. The amount of deviation represents the amount of misalignment.

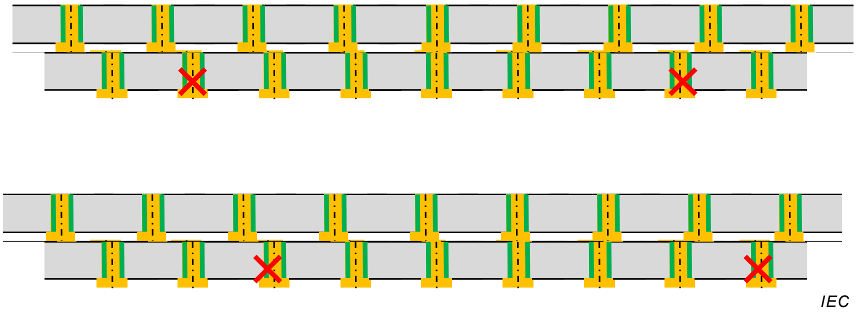


**Figure A.7 – Alignment measurement keys of (top) aligned and (below) misaligned stacking**

# Bibliography

IEC 63011-3, *Integrated circuits – Three dimensional integrated circuits – Part 3: Model and measurement conditions of through-silicon via*