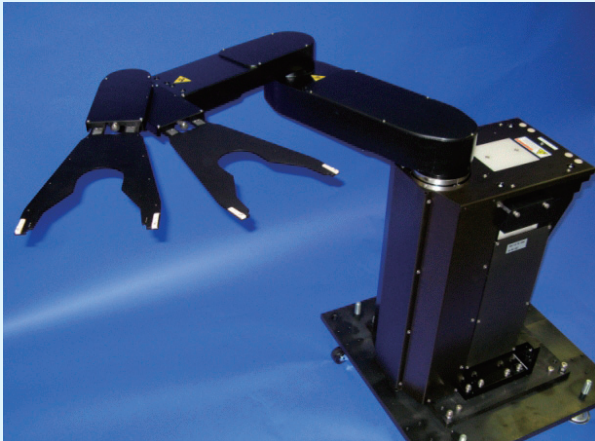# NT & NV series advanced semiconductor-transferring robot achieving both high speed and ease of use

Since the start of development in 1995, our semiconductor-transferring robot has met many customer needs, including high-speed transfer, high positioning accuracy, and automated teaching, and holds the top share in the industry at present. Moreover, our efforts have gone beyond standalone robots to offer integrated robot solutions at a higher level, and further expansion of our business can be expected. This paper introduces system models of the Kawasaki clean robots and auxiliary functions, focusing on the NT and NV Series.

Preface

In recent years, customers have been demanding improved throughput in semiconductor manufacturing equipment, necessitating an increase in the number of semiconductors transferred per unit of time. Customers have also been demanding the following:
① Improved maintainability via automation of robot position teaching
② Simplification of operations simulations performed before actual robot operation
③ Reduction of downtime (time during which the robot is shut down) for maintenance, etc.

Ever since developing the semiconductor-transferring robot in 1995, Kawasaki has provided clean robot solutions optimized for the customers' semiconductor manufacturing equipment. The culmination of our efforts has been the development and market introduction of the NT series, to wide acclaim. The NT series delivers high speed, high accuracy, and ease of use, and by combining the vacuum robot NV series, it can offer transfer capabilities in both atmospheric and vacuum environments.

1 NT Series

(1) Broad motion range and compact design
The NT series is a robot used in silicon wafer transfer mechanisms such as FOUP (Front Opening Unified Pod), a container that seals for transport silicon wafers to be used as semiconductor substrates, and EFEM (Equipment Front End Module), which transfers wafers between semiconductor manufacturing equipment processes. The NT series meets the Class 1 cleanliness requirements of the International Standards Organization (ISO). Furthermore, while in the past a traveling device was required for systems with four FOUPs lined up, we have now positioned the arm rotation center to be offset within the EFEM, enabling a longer arm length, and a broad motion range using upper and lower link arms (Table 1). This configuration frees up the space previously occupied by a travel device for use by a controller etc., enabling more effective use of space (Fig. 1).

Table 1 NT Series standard specifications

Model		NT420	NT520	NT620
Basic structure		Horizontal articulated type		
Motion range	θ 1 axis (rotation)　(°)	340	340	340
	Z axis (up-down)(mm)	400	470	600
	θ 2 axis (rotation)　(°)	340	340	340
	H1 axis (rotation)　(°)	340	380	380
	H2 axis (rotation)　(°)	340	380	380
Position repeatability (mm)		±0.1	±0.1	±0.1
Maximum reach (mm)		1,280	1,280	1,250.7

FOUP ①　　　　　②　　　　　③　　　　　④

EFEM

Offset

Space required for traveling device　　　　Footprint of NT series robot
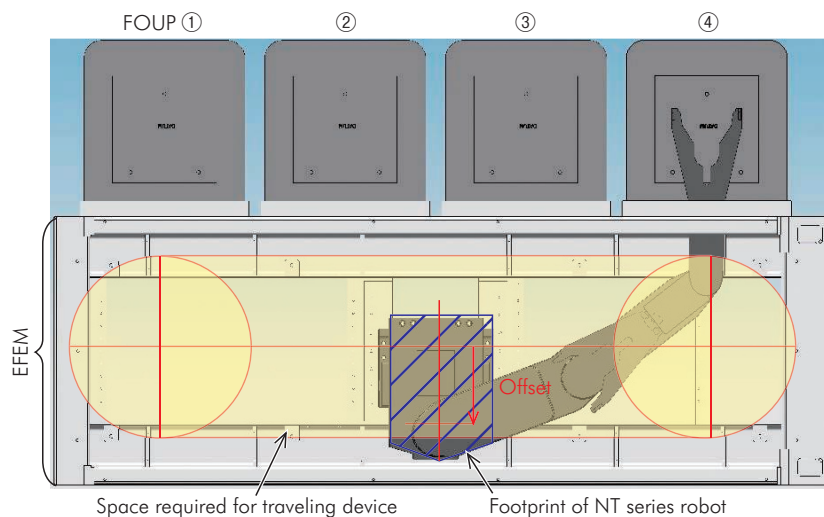
Fig. 1　Comparison with footprint of robot with traveling device
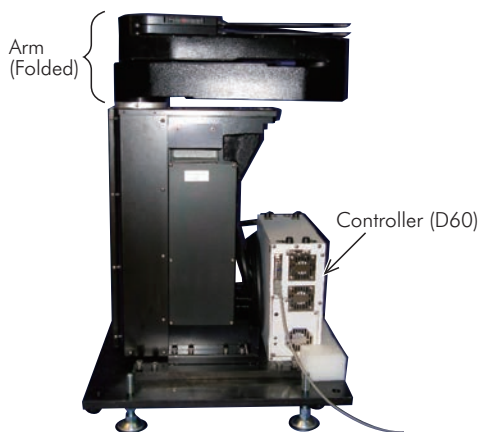

Arm
(Folded)

Controller (D60)

Fig. 2　Robot with arm folded and controller

In addition, we reduced the size of the robot when its arm is folded, enabling easy access from the front in case replacement is needed due to a breakdown. Furthermore, we made the controller itself smaller, so it fits easily in the space previously required for the traveling device (Fig. 2).

(2) High-speed, high-precision operation
The NT series has extended the arm length per robot unit to improve wafer transfer speed without boosting the relative angular speed between arms. While this configuration appears to result in smooth, stable operation, in reality it enables high-speed wafer transfer. For example, while it took robots with traveling device 1.2

seconds to move from FOUP ① to FOUP ④ (1,515 mm), the NT series can cover the same distance in 0.9 seconds. This high-speed operation was achieved through an arm drive based on our proprietary gear train configuration. The NS and NX series also uses a gear mechanism to transmit motive power from the AC servomotor to the arm.

For the NT series, however, we positioned a gearbox at each joint, for a configuration consisting of an AC servomotor and gears only. This arrangement boosted rigidity and simplified the configuration of the transmission mechanism, reducing the opportunities for error due to the transmission. It also contributed to improved positioning accuracy, achieving an accuracy of within ±0.1 mm.

In addition, we used a newly designed gearbox for the NT series. Gearboxes need to be free of backlash with a long operating life and high rigidity. Based on the latest component technology developed through years of experience, we have realized a wear-resistant design and high gear precision that achieve both compact size and reduced gear number while maintaining the reduction gear ratio. This gearbox is extremely smooth for a backlashless type, with little mechanical loss and characteristics close to those of a direct drive mechanism. However, unlike direct drive, it does not require a high-performance positioning detector or large-current amplifier, enabling more layout freedom and compact size. This design also contributes to improved precision of the automatic teaching function.
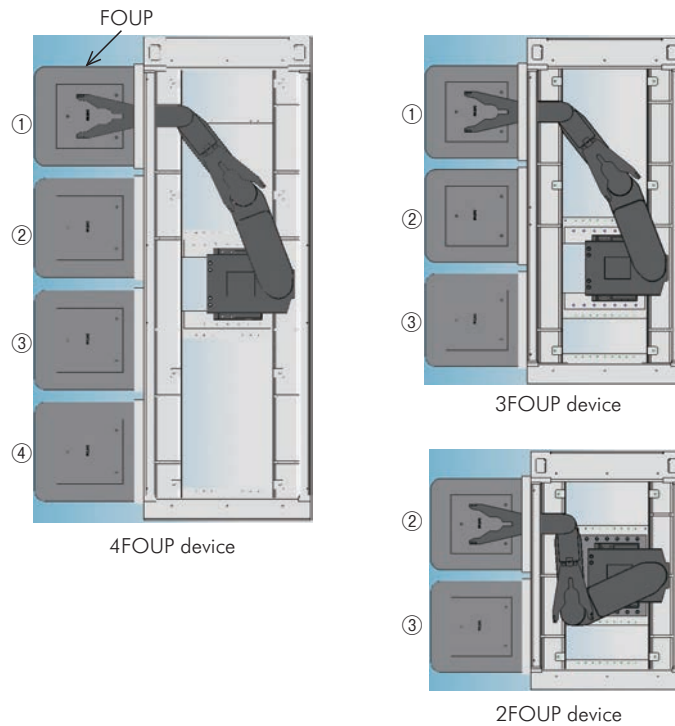
FOUP

① ② ③ ④

4FOUP device

① ② ③

3FOUP device

② ③

2FOUP device

Fig. 3 Layouts of 2/3/4-FOUP devices

(3) Layout freedom

We designed the NT series for use in EFEM. EFEM offers layout variations of two to four FOUP units, with a standard program available for each.

As shown in Fig. 3, even if the number of FOUP units varies, the same operation program can be used for access to each FOUP by positioning the robot at the 4FOUP position. This will enable accessing each FOUP only by specifying the FOUP numbers—FOUP ①, ②, ③ for a 3FOUP device, and FOUP②, ③ for a 2FOUP device, for example.

(4) Simple structure and easy maintenance

Of the two arms, the lower arm has two sets of built-in gear deceleration mechanisms and motors for the arm drive. In addition, the upper arm has built-in gear deceleration mechanisms and motors for the wrist drive, for up to a maximum of two axes. This positioning of a drive system at each joint results in a simple configuration (Fig. 4).

The cover to the arm joint can easily be removed to access gears inside the arm for adding grease, reducing the downtime required for periodic maintenance. In addition, we constructed the arm drive and wrist drive as modules (Fig. 5) so that maintenance locations can be identified with ease.
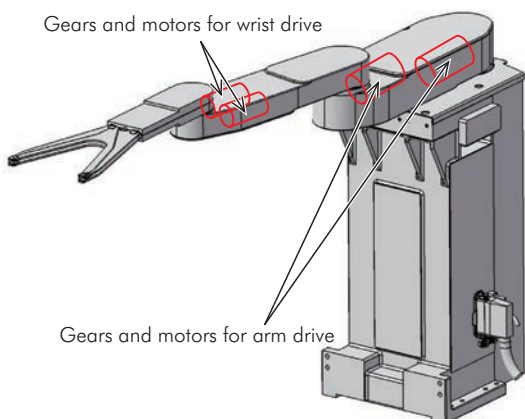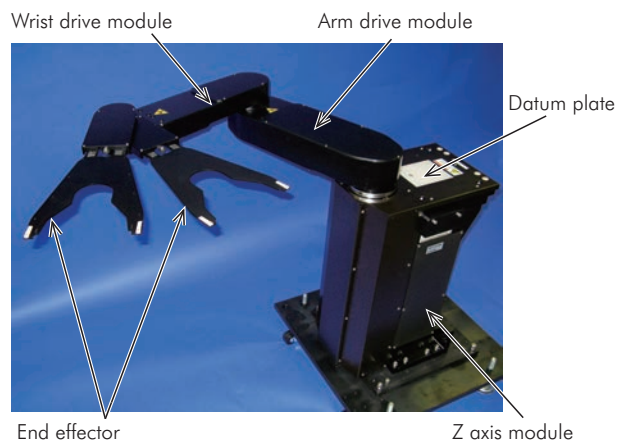

Gears and motors for wrist drive

Gears and motors for arm drive

Fig. 4 Locations of gears and motors

Wrist drive module

Arm drive module

Datum plate

End effector

Z axis module

Fig. 5 Drive system for modular configuration

Table 2 Controller specifications

Control type	D60 controller	D61 controller
Dimensions (mm)	W320×H300×D130	W445×H429×D130
Weight (kg)	12.5	18.5
Number of control axes	Max. 7 axes (2 robots, total 6 axes, aligner 1 axis)	Max. 12 axes (2 robots, total 11 axes, aligner 1 axis)
Drive system	Full digital servo	
Teaching method	AS language program	
Cooling method	External air intake and forced cooling	
Dedicated external signals	External emergency stop, external stop, safety fence	External emergency stop, external stop, safety fence, 2 systems each
Communication I/F	RS-232C×1	RS-232C×2
	Ethernet×1	Ethernet×1
General purpose input/output signals	Maximum input signals 16, output signals 8	Maximum input signals 32, output signals 16
Power requirements	Specifications: AC208V±10%, 50/60Hz, single phase	
	Voltage drop: Conforms to SEMI-F47	
	Grounding: dedicated grounding, 100Ω or less	
Exterior facing	SUS304	

(5) Highly rigid body

The drive system for modular configurations is shown in Fig. 5. With a highly rigid structure for the arm and Z axis module, we perform shipping control so that errors in the Z axis direction (height direction) are held to within the standard value during movement (250 mm movement in the front-back direction for wafer placement in relation to 1 to 4 FOUP units) at the access port, including depression during arm operation, and vertical hand position adjustment error.

In addition, we perform shipping control so that the levelness can be recreated on the end effector placed at each access port position by using the datum plate for leveling (Fig. 5) when installing the robot. This has sharply cut the time required for level adjustment on access ports, reducing the robot installation time.
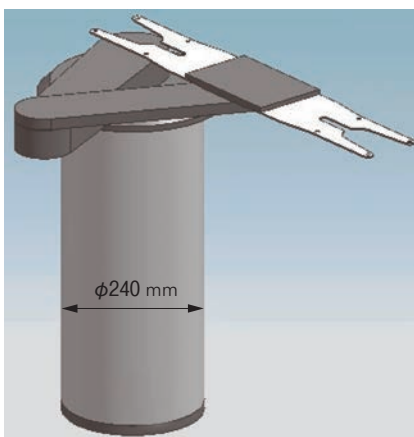
(6) Controller

Controllers driving the robot include the D60 controller and D61 controller. The D60 controller features a compact design, while the D61 controller is capable of driving two multi-axis robots by increasing the number of control axes. The controller specifications are shown in Table 2.

2 NV Series

(1) Compact body and stable operation

The NV series, developed as a vacuum robot for use in semiconductor manufacturing, uses a drive unit based on our NS series and features a compact design with a reduced body diameter and shortened body length (Fig. 6, Table 3).

ϕ240 mm

Fig. 6 External view of NV111

Table 3 NV111 standard specifications

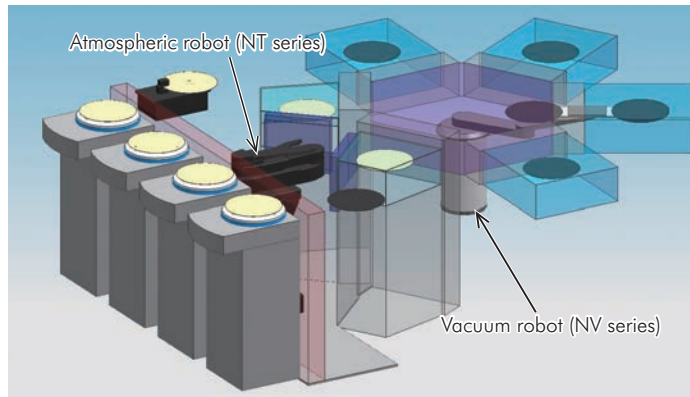| Model		NV111
Degree of freedom		3
Structure		Horizontal articulated type
Motion range	θ axis (rotation: JT2) (°)	−180 to +180
	Z axis (up-down: JT3) (mm)	0 to +30
	X axis (front to back: JT4) (mm)	−686 to +686
Repeatability (mm)		±0.1
Degree of vacuum (Pa)		$1.33×10^{-4}$

Fig. 7 Combination of atmospheric robot and vacuum robot

For the atmospheric side, we used cast aluminum parts that maintain rigidity while achieving compact size and light weight. Since the component parts are taken from drive systems with a long history of use, they are highly reliable and can maintain stable operations over long periods.

(2) Use of same AC servomotor and gear as NS410

For the drive mechanism, we used an AC servomotor and gear already used on the atmospheric robot NS410, to ensure a reliable drive configuration. As a result, we are able to use the same spare parts to ensure availability in case of a breakdown. Furthermore, with the drive system shared with the atmospheric robot, we use the same D61 controller for the NT series, NV series, and prealigner, enabling space savings and effective use of available space.

Moreover, use of a common AC servomotor and gear ensures that many functions previously developed for the atmospheric robot, including various software and collision detection and other functions, are available for general use. An example of D61 controller usage is shown in Fig. 7.

(3) Vacuum seal and in-vacuum drive transmission mechanism

Since we used the same drive system as the atmospheric robot, drive transmission from the atmospheric side to the vacuum side is necessary. In the NV series, we used a magnetic flow seal on the area where the rotation drive force is transmitted to the vacuum side, and a bellows on the vertical Z axis. These serve to maintain a stable seal and enable a vacuum of 1.33×10^{-4} Pa as a usable vacuum environment.

We used such materials as aluminum and stainless steel for the arm and other parts used in vacuum, to reduce the amount of gas emitted from the parts surfaces. Moreover, for the drive inside the arm, we used a timing belt or stainless steel belt. The belt material varies depending on the semiconductor manufacturing device process, and the selection depends on the gas emission performance demanded for the transfer system.

(4) Wafer detection

With the NV111, a fiber sensor for wafer detection can be attached to the tip of the hand, and the sensor amplifier used is shared with the atmospheric robot. We used a Teflon material to cover the fiber sensor, in order to reduce emitted gases. The AC servomotor and sensor amplifier are shared with the atmospheric robot, enabling wafer sniffing (wafer detection at each stage) just as with the atmospheric robot. Going forward, we will also look at using this sensor for automatic teaching.

3 Contact type (touch sensing type) automatic teaching function

(1) Summary

In robot position teaching, which must be performed accurately and in a short time inside the limited space available within the increasingly complex semiconductor manufacturing devices, operators must have highly advanced skills. To address this situation, we have developed a contact-type automatic teaching function that can easily perform teaching without relying on the skills of the operator.

The contact-type automatic teaching function features the following characteristics, which are attracting attention from customers.

① Teaching can be performed in a short time in cramped spaces.

② Since teaching is not dependent on operator skills, there is little variance in teaching accuracy.

③ Expensive sensors or special sensor tools are not required.
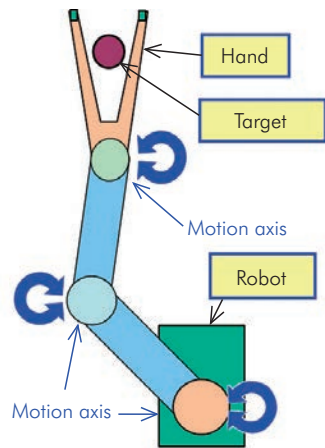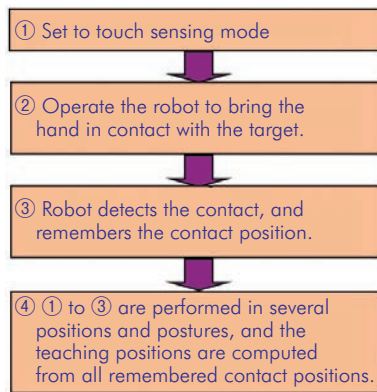
④ Sensing is not dependent on environmental factors

① Set to touch sensing mode

② Operate the robot to bring the hand in contact with the target.

③ Robot detects the contact, and remembers the contact position.

④ ① to ③ are performed in several positions and postures, and the teaching positions are computed from all remembered contact positions.

Hand

Target

Motion axis

Robot

Motion axis

Fig. 8 Touch sensing operation

(water droplets, corrosive gases, high temperatures, etc.).

(2) The position detection method

The teaching operation requires registration of the X, Y, Z coordinates for performing the wafer capture/placement operation. The basic position detection operation using touch sensing is shown in Fig. 8. In touch sensing, since the position detector (encoder) normally required for robot operations is used for touch position judgment, there is no need to add a new external sensor. The NT robot uses our proprietary highly rigid gear train configuration, enabling operation with virtually no hysteresis or backlash on the motor/encoder side even when driven from the load side. As a result, unlike the belt drive or the differential gear reduction drive, detection on the motor axis is possible even with the slightest deviation due to touch from the load side. Moreover, with the force limited to 1 to 2N, it does not cause any damage to the target.
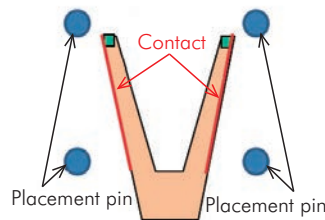
(3) Example of position detection method

An example of a target (tool positioned in place of a wafer for teaching) being used is shown in Fig. 9(a). The teaching position is found by computation based on multiple positions detected by sensing, the target dimension and mounting position, and the hand dimension. The target may be pre-mounted on the device side, or it can be mounted when the teaching operation is performed.

In Fig. 9(a), position detection is performed by bringing the inside of the hand into contact with the target, but the location or object to be contacted is not necessarily determined beforehand. Fig. 9(b) shows an example of position detection when the outside of the hand is brought into contact with the placement pin for placing the wafer. In addition, Fig. 9(c) shows a FOUP example, with position detection performed by bringing the wafer held in the hand into contact with the side walls.

Target

Contact

(a) Example using target

Contact
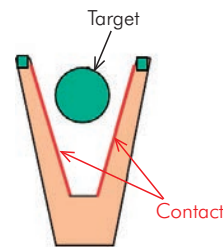
Placement pin   Placement pin

(b) Example of placement pin

Wafer   FOUP

Contact   Contact
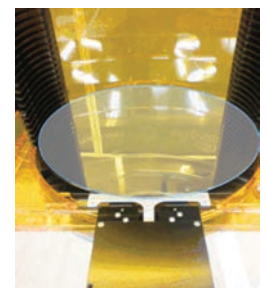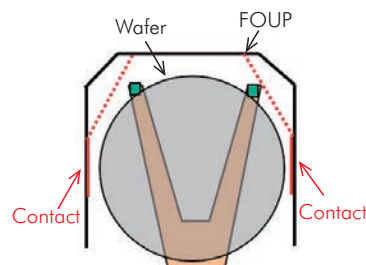
(c) Example using wafer

Fig. 9 Example of position detection method

With the semiconductor-transferring robot, the hand shape or wafer holding method (edge grip, vacuum chuck, etc.) can vary depending on the customer or device, and the wafer capture/placement position structure can also vary. If the contact-type automatic teaching function is used, and if pre-determined points for position, shape, and dimensions, etc., exist near the teaching position, these can be used to perform teaching. Since most variations in contact points (location, number) or direction can be addressed with a change in software, installation is easy even when adding as an additional function to existing equipment.

(4) Application technology
With the high rigidity of its motion transmission system, and its ability to transmit position changes in the detection axis during touch sensing to the motor or encoder with minimal loss, the NT series enables high-precision sensing. In addition, use of this touch sensing technology can be applied as follows to the robot self-diagnosis function. By periodically sensing specified points within the equipment to confirm their position, changes to the robot status can be monitored over time, with warnings sent to the equipment side whenever threshold values are exceeded to prevent the occurrence of troubles.

Table 4 Main functions of simulator

· Interference check	· Operation trajectory display
· Cycle time verification	· TP simulation
· I/O simulation	· External communication connection
· Operation waveform display	

4 Semiconductor-transferring robot simulator

(1) Summary
We also actively pursue development of a simulator specially designed for the semiconductor-transferring robot, which can be broadly utilized all the way from the order placement stage to robot installation and after the equipment begins operation. This is a simulator that runs on a computer, with functions as shown in Table 4. The simulator consists of an I/O screen, a teach pendant screen, an operations screen for inputting AS language (robot language), a graph display screen for waveform display of speed and position, etc., and a 3D drawing screen for the robot. The screen configurations are shown in Fig. 10.

(2) Simple robot application examination
The simulator uses special tools to simplify such operations as setting the robot motion range or drawing target parts at access positions, etc. based on the equipment layout drawing. In addition, it sets the operations parameters (robot posture, and various offset values for operations) and operations sequence to automatically generate data read with standard operations software, and it performs interference checks, operations trajectory examination, operations sequence checks, and cycle time measurements (Fig. 11). Since these operations do not require special software technology and can be performed in a short time, this is a tool that can be widely utilized to give new customers a clear idea of what to expect.

I/O screen

Teach pendant screen

Operations screen

Graph display screen
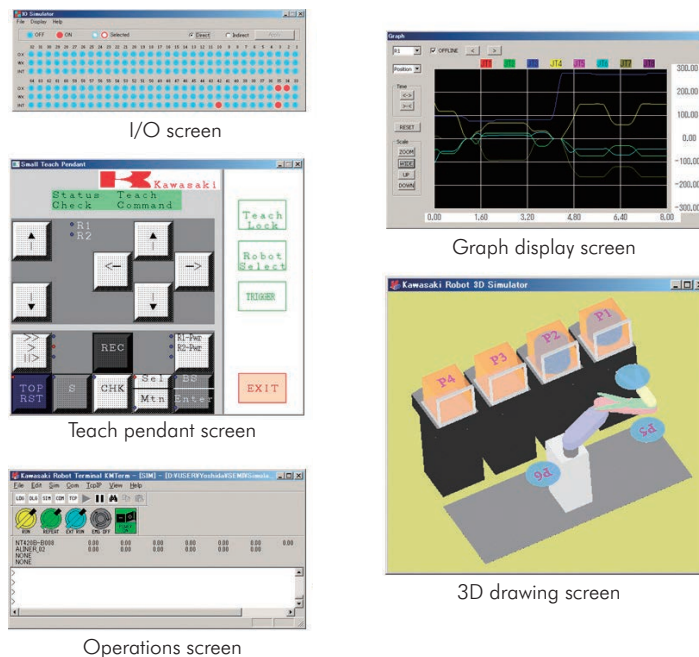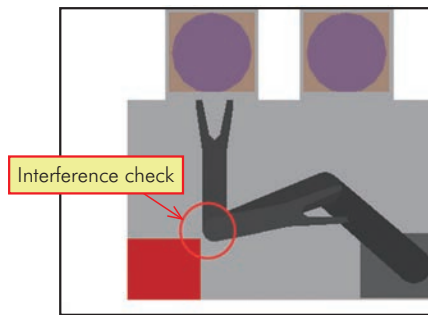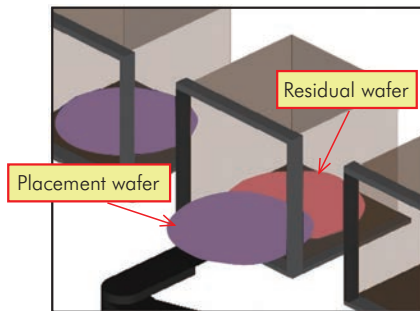
3D drawing screen

Fig. 10 Simulator screen configuration

(a) Interference check

(b) Operations sequence check

Fig. 11 Simulator functions

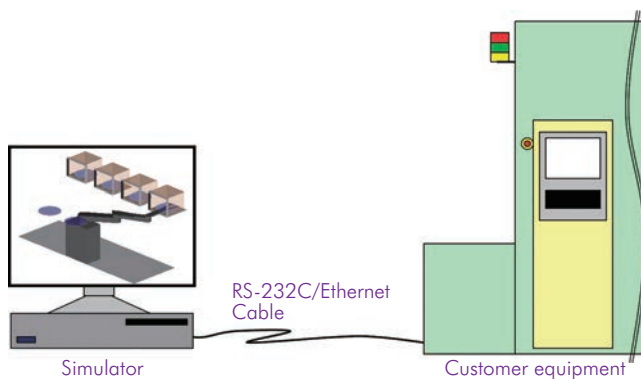Fig. 12 Connections with equipment

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(3) External communication connections

This simulator can be connected to external equipments through a computer's Ethernet port or RS232C port. As a result, the simulator can be connected with equipments (Fig. 12) before the robots are delivered to the customer, and the communication interface and robot operations can be checked. In the past, linkage checks with software on the equipment side could not be performed until after the robot has been delivered and connected with the equipment, including wiring and piping for electrical power and air. By contrast, since the robot software used in our simulation can be directly installed and used on the robot controller, the linkage checks can be performed offline, reducing the evaluation time required on the actual robot.

Furthermore, we use highly reliable software that has already undergone a rigorous debugging process, reducing the risk of interference accidents during evaluation on the actual robot.

(4) Troubleshooting

If trouble occurs at the delivery site, data saved at that time is read into the simulator where the trouble can be recreated, enabling quick investigation of the cause and early resolution of the trouble.

Concluding remarks

Semiconductor-transferring robots with faster operating speeds will continue to be developed, and silicon wafers will continue to grow in size as well. We will continue efforts to refine our technology so that we can continue to provide products that earn the satisfaction of our customers.