The development of a wafer prealigner based on the multi-sensor integration

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Abstract
Purpose – This paper sets out to propose a wafer prealigner based on multi-sensor integration and an effective prealignment method implemented on it.
Design/methodology/approach – The wafer and notch eccentricities, on which wafer prealignment is based, are calculated with the peripheral data of the wafer detected by a laser displacement sensor and a transmission laser sensor by means of barycenter acquiring algorithm in a one-particle system.
Findings – The center and notch prealignment precisions of the system are, respectively, $\pm 1.5\,\mu$m and $\pm 30\,\mu$rad. Experimentation has proved the validity and effectiveness of the system.
Practical implications – The wafer prealigner is a subsystem of the lithography in the semiconductor industry. The prealignment algorithm can be implemented in any object with random figures.
Originality/value – The periphery of the wafer is detected by a high-precision laser displacement sensor and a low-cost transmission laser sensor instead of a CCD linear sensor used by traditional wafer prealigners, which saves the space occupation of the structure and enhances the systematic prealignment precision. Using barycenter acquiring algorithm in a one-particle system to calculate the wafer and notch eccentricities is effective and valid.

Keywords Integrated circuits, Sensors

Paper type Research paper

1. Introduction

In the manufacture of integrated circuits, various processes are required to be performed on the silicon wafer that is the substrate of the chips in order for a circuit pattern to be imprinted thereon. The apparatus that finishes this job is called lithography, of which a prealigner is a crucial subsystem. A prealigner is a device that orients a wafer or a substrate so that its center is set at a predefined place and its flat or notch is set at a predefined angle. A silicon wafer needs to be prealigned, making sure when the deporting arm delivers it onto the work stage, it will be within the visual field of $7\,\mu$m of the work stage, so that the circuit pattern imprinting process can proceed successfully thereon (Lee *et al.*, 2001; Daniel and Jere, 1990).

In prior prealigners, the detection of the periphery of the wafer often utilizes a linear CCD array. After the wafer spun in one circle, the prealigner determines the center of the wafer by first fitting the sampled data curve of CCD to the standard curve without offset and then based on the amplitude and phase of the fitted curve. Next align the wafer center in coincidence with the turntable center via three vertical pins to separate them and the motion module for alignment. With the centers aligned, the wafer is spun again. The abrupt change in the curve caused by the notch can be observed. The curve apex is defined as the position of the notch. The method is simple and timesaving, but it can achieve relatively low precision, because the notch prealignment depends on one single sampled point – the curve apex, which means its precision is decided by the magnitude of the sampling frequency and influenced greatly by external disturbance. Even with the maximum sampling frequency of CCD selected, the disturbance of the signal decreased and the prealignment process executed consuming the maximum given time, the method can only arrive at the precision of about $100\,\mu$m. As the line size of wafer features becomes smaller and smaller, the prealignment precision cannot meet the demand of the lithography, besides a CCD array is a bulky component, it may not accommodate the narrow space due to the mechanical dimension limitation of the lithography (Kung, 2005; Blaine *et al.*, 2004; Randolph, 1998).

This paper has proposed a new wafer prealigner. The periphery of the wafer is detected by two sensors, one is the high-precision laser displacement sensor (the laser sensor for short infra), and the other is the low-cost transmission laser sensor (the transmission sensor for short infra). The data from the laser sensor can be used to determine the wafer eccentricity accurately, however in some cases, due to the specialties that when laser beaming radially at the bevel edges of the notch, it cannot reflect back to the receiver, the laser sensor fails in detecting the notch. Therefore, the transmission sensor is appended. Its emitter and receiver are set perpendicular to the plane of the wafer, which means it can detect the notch successfully under any condition. So actually the wafer

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prealignment is based on the integration of the two sensors. Both of the sensors are small enough to be embedded in the mechanical frame around, hardly occupying any space, thus having the advantage of space saving. In addition, high-sampling frequency is available for both sensors so that they can be sampled much more circumferential points on the periphery of the wafer than a CCD array can under the same circumstances, which enhances the prealignment precision of the system. The eccentricities of the wafer and notch are calculated by means of barycenter acquiring algorithm among one particle system. The algorithm is effective, valid, and applicable to any object with random figure other than the circular one.

2. Framework of system

The wafer prealigner is shown in Figure 1. The robot arm takes one wafer out of a cassette and transfers it on the prealigner. The latter executes wafer prealignment, finding out the eccentricity and the notch orientation of the wafer, then positioning the center of the wafer in coincidence with the center of the turntable and orienting the notch to the desired angle. After the wafer prealigned, the deporting arm comes to take the wafer and delivers it onto the work stage. Thereby the whole process of prealignment is finished.

The system includes up-to-date hardware and software techniques. It consists of six modules as shown in Figure 2. The sensor module detects the periphery of the wafer. The signals of the sensors need to be handled by the signal handling module, whose jobs are mainly to filter the analog signals, get the digital signals from the open collector, magnify the code signal of the turntable and multiple its frequency. Signals handled, the data sampling module begins to sample data triggered by the clock signal provided by the handled code signal of the turntable. The sampled data are stored in the EMS memory of the industrial computer for the calculation module to process and calculate. The sampled data need further processing or transforming before calculation. For example, the controller of the laser sensor provides the 21-pin digital outputs which represent the binary complement code of the value of its screen display indicating the current measurement. In order to avoid the disturbance brought by the analog signal transferring, to the laser sensor, it is the 21-pin digital signals that are sampled instead of the analog signal, so that the calculation module needs to transform the obtained complement codes to the actual radial measurement values. After each of the radial distance of the sampled point, relative to the angle of the turntable, is determined, they can be used to calculate the eccentricity and notch orientation of the wafer. Then the calculated information can instruct the motion module to perform the actual wafer prealignment. The motion module positioning the wafer is controlled by a four-axis controlling card. If any axis of the motion module presses a limitation switch, the limitation module is able to make it recover from the limitative condition to the normal condition.

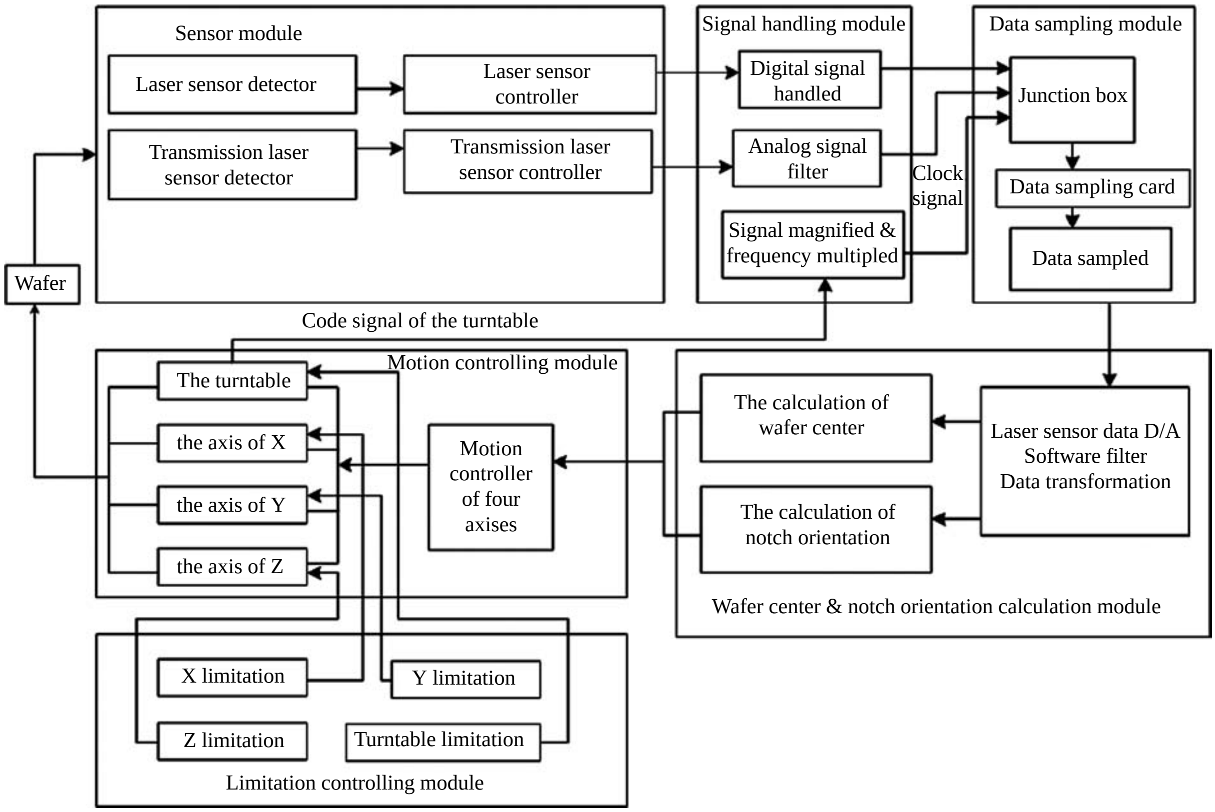
3. Method of wafer prealignment

3.1 Flow of wafer prealignment

Wafer prealignment includes center and notch prealignments. The process of the wafer prealignment includes four steps. The first step, as the wafer being spun in one circle, the data sampling card is sampling the wafer peripheral data from the laser and transmission sensors, triggered by the external clock signal provided by the code signal of the turntable. Therefore, each of the sampled point is relative to a certain angle of the rotation, namely the polar coordinates of each point are determined. The second step, the peripheral data from the laser sensor is used to calculate the wafer eccentricity by means of barycenter acquiring algorithm among one particle system, at the same time based on the shape of the notch, the data of one of the sensors is selected to calculate the coarse orientation of the notch. The third step, based on the determined eccentricity of the wafer, x and y stages in motion module align the wafer so that its center is set in coincidence with the turntable center. The forth step, the turntable spins the notch under the transmission sensor based on the

Figure 1 The proposed wafer prealigner

Figure 2 The framework of the modules of the system



determined coarse orientation of the notch, and then begins to re-sample the data of the notch section triggered by the signal which is created by multiplying four times of the code signal of the turntable. The re-sampled data of the notch is used to calculate its eccentricity accurately by means of the barycenter acquiring algorithm as well. The connecting direction from the eccentricity of the notch to the center of the turntable is defined as the notch direction. After it is determined, the turntable spins with the relative angle so that the notch direction is set to the desired angle. Thus, wafer prealignment is finished.

3.2 Center prealignment of the wafer

The wafer center needs to be set to the position of the turntable center. In the proposed prealigner, the required center prealignment precision is $\pm 1.5\,\mu$m. The key is to find the wafer eccentricity. Nowadays the shape of the notch on the edge of wafers is either semicircular or V-shape, so technically the wafer is not a standard circle. Therefore, in this paper the calculation of the wafer eccentricity is not by the traditional method of data fitting by least-square, but by means of barycenter acquiring algorithm among one particle system which can be adapted to any object with random figure.

The equations (1) and (2) of the barycenter of the object are:

$$\bar{x} = \frac{M_y}{M} = \frac{\sum_{i=1}^{n} m_i x_i}{\sum_{i-1}^{n} m_i} \tag{1}$$

$$\bar{y} = \frac{M_x}{M} = \frac{\sum_{i=1}^{n} m_i y_i}{\sum_{i-1}^{n} m_i} \tag{2}$$

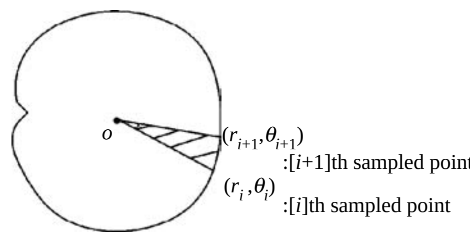
hereinto, $M = \sum_{i=1}^{n} m_i$is the total quality of the object:

$$M_y = \sum_{i=1}^{n} m_i x_i, \quad M_x = \sum_{i=1}^{n} m_i y_i$$

are the static moments of the y and x-axes, respectively.

N is the number of the effective sampled points on the wafer periphery. Each point is relative to the code value of the rotation, so that the polar coordinates are (r_i, θ_i). The wafer is divided into n sectors based on the effective sampled points, as shown in Figure 3, and each sector area is defined as d. The density of the wafer is defined as ρ, which is assumed as

Figure 3 Data sampling for wafer eccentricity calculation with the barycenter acquiring algorithm



even on the plane of the wafer. The turntable center is defined as the origin of the reference frame.

Total quality of the wafer is calculated by equation (3):

$$\sum_{i=1}^{n} \iint_{d} \rho \cdot r\mathrm{d}r\mathrm{d}\theta \tag{3}$$

Static moment of y-axis of the wafer is calculate by equation (4):

$$\sum_{i=1}^{n} \iint_{d} \rho \cdot r^2 \cos\theta \mathrm{d}r\mathrm{d}\theta \tag{4}$$

Static moment of x-axis of the wafer is calculated by equation (5):

$$\sum_{i=1}^{n} \iint_{d} \rho \cdot r^2 \sin\theta \mathrm{d}r\mathrm{d}\theta \tag{5}$$

According to equations (1) and (2), the coordinates of the wafer eccentricity are calculated as in equations (6) and (7):

$$\bar{x} = \frac{\sum_{i=1}^{n} \iint_{d} \rho \cdot r^2 \cos\theta \mathrm{d}r\mathrm{d}\theta}{\sum_{i=1}^{n} \iint_{d} \rho \cdot r\mathrm{d}r\mathrm{d}\theta} = \frac{\frac{1}{3}\sum_{i=1}^{n} r_i^3 [\sin\theta_{i+1} - \sin\theta_i]}{\frac{1}{2}\sum_{i=1}^{n} r_i^2 [\theta_{i+1} - \theta_i]} \tag{6}$$

$$\bar{y} = \frac{\sum_{i=1}^{n} \iint_{d} \rho \cdot r^2 \sin\theta \mathrm{d}r\mathrm{d}\theta}{\sum_{i=1}^{n} \iint_{d} \rho \cdot r\mathrm{d}r\mathrm{d}\theta} = \frac{\frac{1}{3}\sum_{i=1}^{n} r_i^3 [\cos\theta_{i+1} - \cos\theta_i]}{\frac{1}{2}\sum_{i=1}^{n} r_i^2 [\theta_{i+1} - \theta_i]}. \tag{7}$$

After the wafer eccentricity determined, x and y stages in motion module move relative distances, able to position the wafer center to the origin, namely the turntable center, thus the center prealignment of the wafer is finished.

3.3 Notch prealignment of the wafer

Notch prealignment is more complicated than center prealignment of the wafer. From the prealignment flow in Section 3.1, it is known that notch prealignment involves two orientations – one is called coarse orientation which only needs to find the coarse start and end points of the notch, the other is called precise orientation which needs to calculate the eccentricity of the notch.

3.3.1 The coarse orientation of the notch

In the process of the data sampling for center prealignment of the wafer, the data from both sensors are sampled synchronously as the turntable is spinning in one circle. The data sampled this time can be used to calculate not only the wafer eccentricity, but also the start and end points of the notch (the connecting direction from the start or end point of the notch to the wafer center is defined as the coarse orientation of the notch). For calculation of the wafer eccentricity, it is the data from the laser sensor being used. For calculation of the start and end points of the notch, the data from which sensor being used depends on the shape of the notch.

The notch is a little slot with almost 1 mm in depth and 1.15° of splaying angle in the periphery of the wafer. Most of them are V-shape, few of them are semicircular. Different sensor displays different specialties when detecting the notch section. For the laser sensor, when it detecting the notch with V-shape, at two bevel edges of the notch its reflecting light cannot return to the receiver, which results to this part of points being out of range, however it does not happen when it detecting the notch with semicircular shape. For the transmission sensor, because its emitter and receiver are set perpendicular to the plane of the wafer, no matter what shape the notch belongs to, it can manage to measure all notch points. The method is integrating two sensors and choosing the data from one of them based on the shape of the notch to find the coarse orientation as quickly and accurately as possible.

For the notch with V-shape, the feature of the laser sensor being out of range at the notch bevel edges can be utilized to position the notch coarse orientation very quickly. Specifically, speaking, the start and end points of the data segment being out of range are, respectively, the start and end points of the notch.

For the notch with semicircular shape, both of the sensors can manage to detect the notch. Considering the data of the laser sensor includes much more disturbance than the transmission sensor does, for the sake of precision it is the data of the transmission sensor that is utilized to find the coarse orientation of the notch. The method is calculating the differential coefficients of its sampled peripheral data circularly in one circle. The points of the minimum and the maximum are, respectively, the start and end points of the notch.

The coarse orientation of the notch is calculated almost as synchronously as the wafer eccentricity is, with no need to re-sample any data. However, the search for it is inevitable because it is the premise to the precise orientation of the notch afterwards.

3.3.2 The precise orientation of the notch

The precision of the coarse orientation of the notch above is out of the required range which is $\pm 30\,\mu$rad for the proposed prealigner. The reason for that is because the sampled data used to calculate the coarse orientation involves the random wafer eccentricity. In order to arrive at the required notch prealignment precision, the notch needs further precise orientation, which is to re-sample the data of the notch section and calculate the notch eccentricity with the new sampled data after the center prealignment of the wafer is finished as the influence of the random wafer eccentricity gone. Owing to the laser sensor's incapability when detecting the V-shape notch, the transmission sensor is chosen as the measuring tool for the precise orientation of the notch. However, the measuring precision of the transmission sensor is lower than the laser sensor, in order to compensate the deficiency, the frequency of the clock signal of re-sampling the notch data is multiplied four times as before, which means the resolution of rotation angle is improved four times, and the computer can obtain four times more points than to use the previous frequency, therefore the notch eccentricity calculated meets the precision requirement.

To re-sample the notch data, the notch needs to be spun to the position of the transmission sensor. The turntable will spin quickly until the start point of the notch arrives at the transmission sensor, beginning the process of data re-sampling, then will continue to spin slowly until the end point of the notch gets through the sensor, ending the process of data re-sampling. Therefore, the start and end points of the data segment re-sampled are actually decided by the start and end points of the notch determined in the aforementioned coarse orientation, which is not accurate enough as mentioned. In order to eliminate the influence brought by the coarse orientation, the start and end points of the actual calculated data segment are going to be re-determined based on the newly sampled data, so as a matter of fact not all the re-sampled data are going to be used to calculate the precise orientation of the notch.

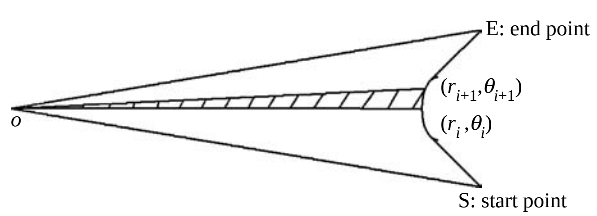
The method of re-determining the start and end points of the notch is as follows. With the wafer center aligned, the data from the transmission sensor changes abruptly when the notch section passing through the sensor. The controller of the sensor provides a digital signal whose output is relative to a limitative value which needs to be set in the controller beforehand. If the measured data are greater than the set limitation, the digital output will be 1, otherwise it will be 0. With the splaying angle of the notch being about 1.15° and the sampling frequency being fixed, regardless of the distinction of notch shape, the number of data sampling in notch section is relatively invariable, which is 850. The limitative value is set based on the principle that there will be about 850 of the points in notch section being re-sampled. The analog signal of the transmission sensor represents the peripheral data of the notch and the digital signal of it includes the information which the re-determination of the start and end points of the notch needs. Two signals need to be sampled synchronously. Analyze the digital signal, selecting the point where it changes from 1 to 0 as the renewed start point of the notch, and the point where it changes from 0 to 1 as the renewed end point of the notch. The data segment between the start point and the end point is the effective one for calculating the notch eccentricity.

In this paper, the notch eccentricity is regarded as the eccentricity of the sector with the notch figure as the contour line, as shown in Figure 4. The eccentricity is also calculated by means of the barycenter acquiring algorithm as the wafer eccentricity is, which proves the barycenter acquiring algorithm can be adapted to any object with random figure. Equations of the coordinates of the notch eccentricity are similar with equations (6) and (7). The only difference is the range of the integral angle. As for the wafer eccentricity, the range is $0 \sim 360°$ as for the notch eccentricity, the range is within two certain angles represented, respectively, by the re-determined start and end points of the notch. With the notch eccentricity determined, the connecting direction from it to the turntable center is the precise orientation of the notch. The turntable spins the wafer accordingly so that the notch is set to the desired angle.

4. Experiment

The following experiment is to prove whether the proposed prealigner has met the required prealignment precision.

Figure 4 Data sampling for notch eccentricity calculation with the barycenter acquiring algorithm



The apparatuses which the experiment needs are the wafer prealigner as shown in Figure 1, a 12 in. wafer with markers on it, a CCD camera and a photo sampling card. The set direction of the CCD camera is above the wafer, perpendicular to the plane of the wafer. The CCD camera takes photos of the magnified markers on the wafer as shown in Figure 5. The measurement method of the experiment is as follows. Prealign the same wafer repeatedly for 25 times, and each time the original position of the wafer on the prealigner is different. When one prealignment procedure finished, the CCD camera will take a photo of the markers on the wafer, so there will be 25 different photos which will be analyzed as a group by the photo analytical software. Specifically, speaking, one of those photos is selected as the standard pattern, and then the rest are matched with it, by which 25 groups of the coordinates of pixel are acquired, then the values of 3σ in x and y coordinates are calculated, respectively. Table I displays a group of experimental results, where it is shown that the values of 3σ in x and y coordinates have already met the required prealignment precision of micron rank. The experiment has been implemented repeatedly and the same ideal results can be achieved. It has proved that the proposed wafer prealigner has achieved the required prealignment precision.

5. Conclusion

In this paper, a new wafer prealigner has been established. It integrates the laser sensor and the transmission sensor to detect the periphery of the wafer instead of a CCD linear sensor. Both of the sensors are relatively small in dimension, able to be embedded in the mechanical frame around it, thus having the advantage of space saving. And high-sampling frequency is available for both sensors so that they can sample much more points on the periphery of the wafer than a CCD array can under the same circumstances,

Figure 5 The CCD photo of the magnified markers on the wafer

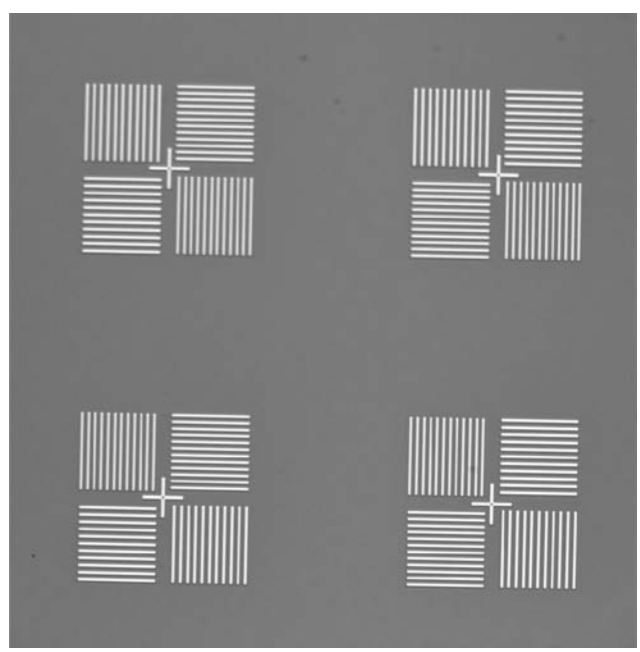


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Table I The results of the prealigner for the experiment of prealignment precision

Photo No.	The value of *x* pixel	The value of *y* pixel
1	522.07	514.72
2	522.07	514.5
3	522.1	514.51
4	522.48	514.63
5	522.66	514.39
6	522.51	515.41
7	522.68	515.14
8	522.61	514.56
9	522.68	514.21
10	522.99	514.89
11	523.21	514.57
12	523.07	514.63
13	523.08	514.01
14	523.29	514.43
15	523.49	513.7
16	523.47	514.65
17	523.4	514.13
18	523.6	514.43
19	523.37	513.95
20	523.66	514.18
21	523.63	513.91
22	523.93	514.45
23	524.06	514.62
24	524.05	515.16
25	524.17	514.63
	$3\sigma\ (x) = 2.83\ \mu m$	$3\sigma\ (y) = 1.80\ \mu m$

Note: 1.5 μm/CCD pixel

which enhances the systematic prealingment precision. The prealigner manages to position the wafer achieving the required prealignment precision of micron rank, based on the wafer and notch eccentricities calculated by using the information extracted from the two sensors with the byracenter acquiring algorithm which is applicable to any object with random figure. Experimentation has proved the validity and effectiveness of the method presented in this paper.

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