

Characterization of electrostatic carrier substrates to be used as a support for thin semiconductor wafers

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Abstract

Mobile electrostatic carriers enable secure and reversible attachment of very thin semiconductor wafers by electrostatic forces which are induced by a permanent polarization state of a dielectric layer.

The paper reports on the electrical and thermal characterization of electrostatic carriers, also called “Smart Carriers”, prepared by thick film technology on alumina substrates and by thin film technology on silicon substrates. Development work revealed the strong impact of leakage currents when durable attractive forces at temperatures above 250 °C have to be attained. When using silicon as substrate material the electrostatic attraction was active for more than 1 hour at temperatures of 400 °C. The carrier system will be demonstrated at the poster stand

INTRODUCTION

Technical solutions for handling and processing of 20 – 100 µm thin semiconductor wafers represent a general requirement for the realization of miniaturized IC packages and electronic devices. In the case of gallium arsenide thinner wafers allow for increased heat dissipation and improved electrical performance if electrical contacts at the backside of GaAs devices are necessary. In the case of silicon based microelectronics very thin chips enable highly efficient power devices exhibiting the advantage of very small electrical resistance.

Until today handling and processing of thin semiconductor substrates is limited by high risk for wafer breakage if values of substrate thickness are of 100 µm or below. In the case of thin GaAs wafers thermoplastic materials, e. g. wax, is often used for reversible bonding of device wafer and a carrier substrate. However, due to poor temperature stability of thermoplastic polymers those carrier techniques don't offer the possibility for wafer processing steps at elevated temperatures. For instance sintering of evaporated metal layers at the backside of thin device wafers at temperatures around 400 °C could yet not be done by means of supporting plates.

Development of mobile electrostatic carrier substrates now offer a technical solution for processing of thin device wafers even at temperatures up to 400 °C.

PRINCIPLE OF ELECTROSTATIC CARRIERS

Semiconductor wafers like GaAs or silicon can be attached to a carrier substrate by electrostatic forces. The basic mechanism is used since many years within electrostatic wafer chucks. In order to derive a mobile wafer support system the electrostatic plate should have size and shape of a standard wafer and must maintain electrostatic attraction after disconnecting an external power supply over a longer period of time. Fig. 1 shows the technical principle of a mobile electrostatic carrier plate.

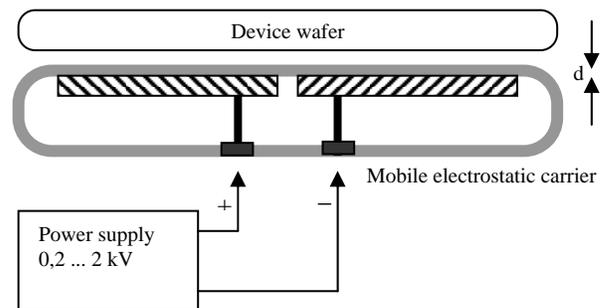


Fig. 1: Basic principle of electrostatic attraction between a mobile electrostatic carrier and a thin device wafer.

Device wafer and electrodes (hatched areas in fig. 1) of the electrostatic carrier represent the configuration of a plate capacitor. The thickness d of the insulating surface layer means the distance of the plates. The force F between two opposed electrode plates (area A), separated by a dielectric material (dielectric constant ϵ) and charged by an external power supply (voltage U) is given by the formula:

$$F = \epsilon A U^2 / 2 \cdot d^2 .$$

In the case of a bipolar configuration each electrode covers approximately one half of the wafer surface A . The capacity

can be calculated from a series connection of two capacitors having the thickness $2 \cdot d$ of the dielectric material. The attractive force of the bipolar electrostatic plate is then given by: $F = \epsilon A U^2 / 8 \cdot d^2$.

For reasonable technical parameters ($U = 250 \dots 1000 \text{ V}$, $d = 5 \dots 50 \mu\text{m}$) we derive values of attractive forces for wafers of 150 mm diameter in the range of 10 – 100 N for standard dielectric materials.

After disconnecting a power supply the electrical field of the capacitor configuration decays exponentially with time. The time constant τ is related to the insulation resistance R and the capacity C by $\tau = 1 / R C$.

To attain a long duration time for the electrostatic field any leakage currents have to be kept as small as possible. As the carriers are intended to be used at high temperatures and under high voltages also diffusion of ions might occur. Therefore the leakage current behavior has to be measured up to the temperatures of use.

High values of the capacity of the electrostatic carrier can be realized by choosing high- ϵ -materials for the dielectric cover layer. Especially ferroelectric materials having dielectric constants of several thousands could dramatically increase the duration time of electrostatic fields. However, the application of high- ϵ -materials must not deteriorate the electrical resistance between electrodes of electrostatic carrier and semiconductor wafer.

The electrical properties of Smart Carriers may further be influenced by carriers (electrons or holes) which are injected from the electrodes into the dielectric layer. This behavior is also known as Johnson Rahbek effect. According to this effect charges are located in direct vicinity of the interface between dielectric layer and the disposed device wafer. These charges remain resident for a longer period of time even after short circuiting of the electrode configuration. The time constant for the duration of this type of charging effect is distinctly larger than that one given in the equation above. The amount of charges generated by carrier injection depends on the duration time of the charging procedure. Therefore Coulomb type charging effect and Johnson Rahbek type charging effect can easily be distinguished.

MANUFACTURE OF ELECTROSTATIC CARRIERS

For experimental evaluation of “Smart Carriers” two different preparation techniques were applied: screen printing of thick film pastes on alumina substrates and thin film technique on silicon substrates.

For the thick film version silver-palladium (AgPd) metal paste was used for preparation of electrode areas. Various dielectric materials exhibiting different values of dielectric constant and prepared by multiple printing steps were applied as cover layer. Layer formation took place in a standard belt oven at 850 °C.

For the thin film version silicon wafers were thermally oxidized to achieve substrate insulation. Electrode areas

were sputtered with titanium tungsten (TiW) and patterned by lithography and adequate etching processes. Dielectric cover consists of silicon oxide and silicon nitride layers formed by CVD processes.

Fig. 2 and 3 show photographs of these two types of electrostatic carriers. In both cases large segment areas were chosen for electrode geometry.

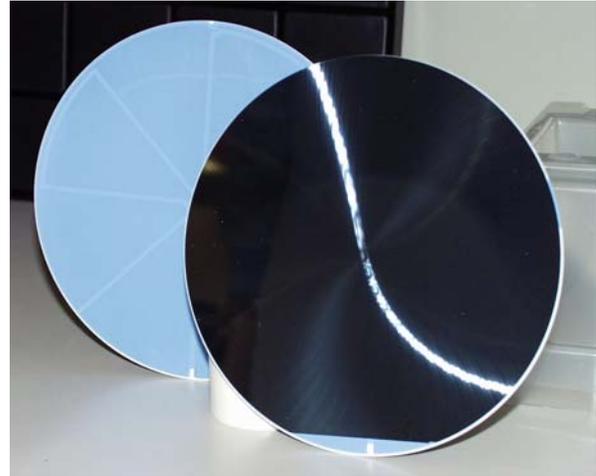


Fig. 2: Electrostatic carrier based on alumina plates with and without silicon wafer attached.



Fig. 3: Electrostatic carrier based on silicon wafer.

In a third variant TiW thin film electrodes were deposited on alumina substrates. It will be explained in the next section why this experiment was necessary to investigate possible causes for leakage currents which may occur at high temperatures.

ELECTRICAL CHARACTERIZATION

One important characterization of the electrostatic behavior of Smart Carriers is measurement of leakage currents for the targeted temperature range. This

measurement was done with a thin silicon wafer disposed upon the carrier. The stacked pair was placed on a controllable heating plate. The electrodes of the carrier were constantly connected to an external power supply generating a voltage of 250 V. Three different types of electrostatic carriers were investigated: AgPd thick film electrodes on alumina substrates, TiW thin film electrodes on alumina substrates and TiW thin film electrodes on oxidized silicon wafer substrates. Fig. 4 shows the measured leakage currents in dependence of applied temperature. Electrostatic carriers manufactured on alumina substrates reveal much higher values of leakage currents compared to silicon substrates. This behavior is independent of the type of electrode material used. It is therefore concluded that electrical insulation of alumina substrate was insufficient. The experiment also shows that thin and compact insulation layers prepared by thin film technology lead to satisfying values of electrical resistance even at temperatures up to 400 °C.

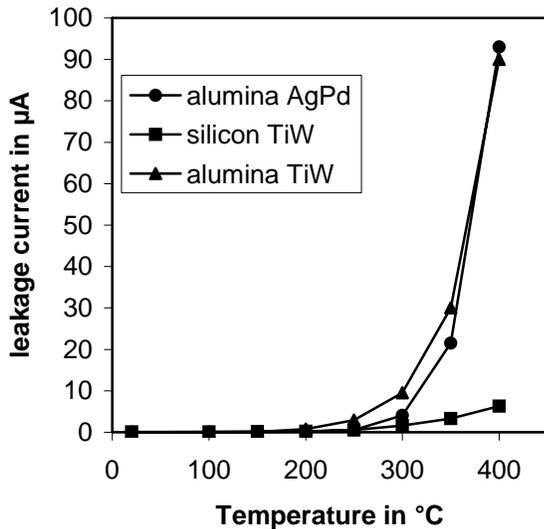


Fig. 4: Comparison of leakage currents of different types of electrostatic carrier plates at temperatures up to 400 °C .

In a further experiment it was investigated whether the ceramic surface can be further passivated in order to increase its electrical resistance. An additional insulating layer was deposited on the alumina surface. Afterwards TiW electrode areas were prepared and the electrical tests were repeated. As shown in fig. 5 the value of leakage current was reduced by a factor of 100 in the case of the modified ceramic surface.

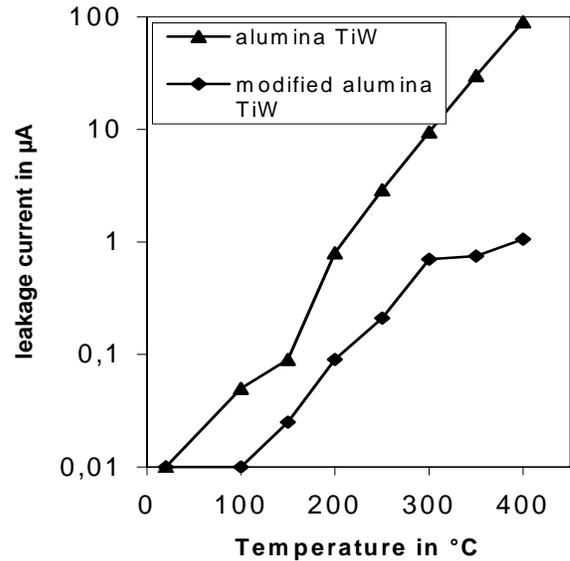


Fig. 5: Comparison of leakage currents of electrostatic carrier plates made of alumina and modified alumina substrates.

In order to verify the holding effect of the electrostatic configuration it was tried to shift the thin silicon wafer which was disposed and electrostatically bonded onto a Smart Carrier. The experiment showed that in the case of initial alumina substrates the silicon wafer could be removed at temperatures above 300 °C. For Smart Carriers based on silicon substrates a disposed wafer could be securely fixed at temperatures up to 400 °C. This result is in accordance with leakage current behavior of the two types of electrostatic carriers (see fig. 4). To achieve long duration time of electrostatic forces at temperatures above 300 °C minimization of leakage currents is an important requirement.

In a second electrical test series the time and temperature dependent decay of the electrical field was measured by means of an electrostatic field sensor. For this purpose Smart Carriers were placed on a heating plate without wafer on top and charged for a certain time. Then the electrostatic field above an electrode area was measured by the sensor in a contactless manner and at constant temperature.

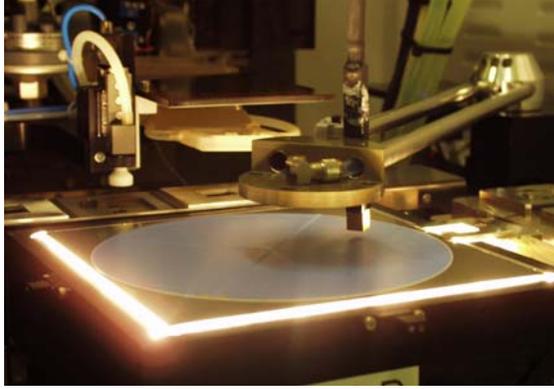


Fig. 6: Photograph illustrating the non-contact measurement of the electrostatic field above an electrode area of an electrostatic carrier. Measurement is done at temperatures up to 300 °C.

An example of this type of measurement is shown in fig. 6. The electrostatic carrier was charged at a voltage of 250 V near room temperature. Then the power supply was disconnected and the hotplate was heated to 300 °C. The field sensor was moved over the electrodes in certain time intervals and the remaining field was measured.

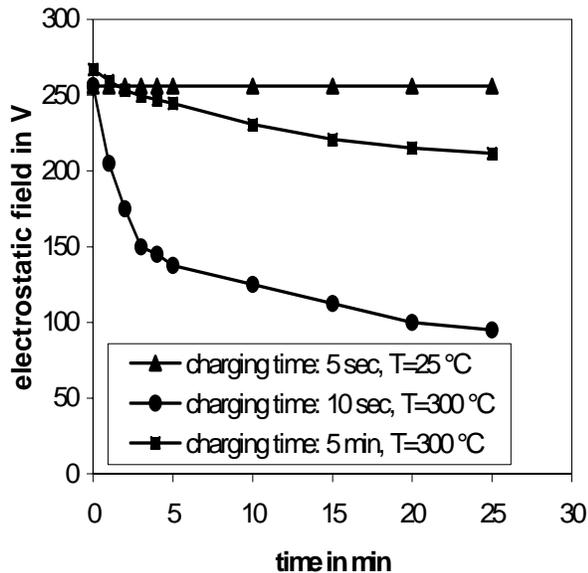


Fig. 7: Measurement of the decay of the electrostatic field in dependence of the duration time of the charging process and the applied temperature.

Fig. 7 shows the result of the measurement of the decay of the electrical field for a Smart carrier based on silicon wafer substrate.

First data series in fig. 7 shows the room temperature behavior of the Smart Carrier (plot symbol: rectangle). Practically no decay of the electrical field is detected within 30 minutes after disconnecting the power supply. For a charging time of 10 seconds and measured at a constant temperature of 300 °C the electrical field is reduced to 50 % within 5 minutes. A distinct difference appears in the case of a charging time of 5 minutes: less than 20 % of the initial field strength got lost within 25 minutes. This behavior is explained by the Johnson Rahbek effect: electrical charges are injected into the dielectric cover layer and thereby lead to a durable charging effect and strong electrostatic fields because the charges are located close to the surface. In order to verify the high temperature capability of Smart Carriers based on silicon substrates a thin silicon test wafer was electrostatically attached to it and then put into an oven which ran under nitrogen atmosphere. Temperature profiles having dwell times of 1 hour at 400 °C were applied. When unloading the wafer pair the thin test wafer was still securely fixed onto the surface of the electrostatic carrier.

CONCLUSIONS

Mobile electrostatic carriers allow easy attaching and removing of thin device wafers. As there are no polymeric adhesives involved, no costly subsequent cleaning processes are required. The carrier is reusable for several times and is also fully compatible with standard handling systems. Smart Carriers were prepared on alumina substrates and on silicon wafer substrates by thick film and thin film technology. Silicon based electrostatic carriers reveal more reliable high temperature capabilities. This is due to lower leakage currents within the thin film layer built-up, high flatness of wafer substrates as well as high thermal conductivity of silicon plates. Alumina substrates may be used when high chemical resistance of the carrier is of interest. An additional electrical passivation of the alumina ceramic material is recommended if electrostatic attraction has to withstand processes above 200 °C for longer time. Next step of development work are adaptation of the design of electrostatic carriers for specific process environments.

ACKNOWLEDGEMENT

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