New electret charging technique for energy harvesting

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A low-cost technique offers a way to charge electrets by effectively generating ions using a negative ion air purifier.

During the last decade, the power requirements of portable electronic devices have steadily increased, and are predicted to exceed the capacity of conventional secondary batteries in future. As a result, micro power generation systems that could replace these batteries have begun to receive significant attention.\(^1\)

While electromagnetic induction is not suitable for very small power generators, electrostatic induction offers numerous advantages, such as a simple structure and high output voltage at relatively slow speeds. A promising area is the use of electrostatic induction with an electret, which is a dielectric material with a semi-permanent charge.\(^2\) Here, we present a method of using low-cost equipment to charge electrets. We have been able to generate large potentials with very good long-term stability. The highest charge density achieved was 32.99\(\text{mC/m}^2\) for silicon dioxide (\(\text{SiO}_2\)) and 2.61\(\text{mC/m}^2\) for Cytop, an amorphous fluoropolymer.\(^3\)

Electrets have been used as key components in microphones, power generators, and so on in an effort to save on the operating power supply of such devices.\(^2\) Our method uses a new charging technique for \(\text{SiO}_2\)\(^4\) and Cytop\(^5\) electrets using a negative ion air purifier, which can generate ions very effectively up to 2.1 trillion ions/cm\(^3\). The air purifier apparatus, which produces both positive and negative air ions, can be used to reduce electrostatic charges on various objects, such as semiconductor wafers and dies during the fabrication process.\(^6\) This unit operates directly from a standard 120V AC power source. After connecting to any AC line, the negative ions are emitted by the four-needle emitter assembly with an ion output of 20 trillion ions/s and particle effectiveness as small as 0.1\(\mu\)m at 2.9cm from the emitter.\(^7\)

The setup consists of multiple parallel needles located a few millimeters above the sample surface, approximately 2±1mm. Three negative ion generators means that each one has four needles for charging the wafer (4 inch), as well as a DC spinner. The motor is fixed on a base so that it can be used for wafer rotation.

Figure 1. Schematic of the multiple ionizer. As samples are charged, the needles of the negative ion generator are perpendicular to the wafer. GND: Ground. Alu-Plate: Aluminum plate.

Figure 2. Charging an electret using a negative ion generator. Top: The entire setup. Bottom: The needles are perpendicular to the wafer with an equal distance between them for enhanced homogeneity.

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during charging. The SiO$_2$ wafer should be fixed to the plate by a steel clip during rotation to avoid cracking and to ensure a good connection between the plate and the wafer. The plate is made from aluminum (because of its near-perfect conductivity) and is fixed to the shaft of the motor. The wafer is connected to the ground to avoid double polarities (e.g., negative polarity only). The housing is made from plexiglass for isolation and safety, including holes to allow in fresh air during charging (ionization) (see Figures 1 and 2).

Samples were either oxidized with a thickness between 0.5 and 1.5 µm or spin-coated with 7.1–11.0 µm Cytop. A maximum charge density of 32.99 mC/m$^2$ was achieved for SiO$_2$ and 2.61 mC/m$^2$ for Cytop, approximately twice that obtained by corona charging. In addition, corona charging can only charge a small chip once (size 10 × 20 mm$^2$)\(^8\). Homogeneity depends on different parameters, such as charging time, wafer rotation during charge, and the thickness of the electrets. Consequently, SiO$_2$ (standard deviation: $\sigma_{st} = 17.12V$, maximum potential: $-274V$, mean: $-247.33V$) is more homogeneous than Cytop (standard deviation: $\sigma_{st} = 121.09V$, maximum potential: $-1000V$)

mean: $-850.9V$). The main parameter that determines homogeneity is wafer rotation during charging. In the case of an oxidized, 0.5 µm-thick SiO$_2$ layer, the standard deviation is $\sigma_{st} = 17.12V$. By increasing the charging time under the same conditions, the standard deviation increases. For example, after 120 minutes of charging, the standard deviation becomes $\sigma_{st} = 94.67V$ for the same thickness (see Figure 3). In contrast, using three 120° wafer rotations during charging, without using a spinner, the standard deviation becomes $\sigma_{st} = 235.5V$, with a SiO$_2$ thickness of 1.5 µm (see Figure 4).

The long-term stability of the provided charge is essential when using a charging technique for energy harvesters. For SiO$_2$, about 67% of the charge still remains after 150 days (thickness: 0.5 µm). With a thickness of 1.5 µm, the charge decreases more quickly, falling to 59% within 150 days. In the case of Cytop, 80% of the charge remains after 162 days (thickness: 11.0 µm) (see Figure 5).

In summary, the technique presented here uses a negative ion generator to charge electrets and provides excellent charging results. Compared to corona charging, the equipment used in our technique is both cheaper and safer. Our multiple ionizer can charge a 4 inch wafer without scanning, and with good uniformity of surface potential. The maximum charge density for SiO$_2$ (32.99 mC/m$^2$) is found to be about twice that of corona charging and Cytop (2.61 mC/m$^2$). A disadvantage of the presented design is a mechanical sensitivity that results in low yield in the fabrication process. To improve the yield, we plan to decrease this sensitivity.

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References