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◆ 특집 ◆ 초음파 응용 제조공정 기술

평판디스플레이 세정 용 Quartz 메가소닉 시스템

Quartz Megasonic System for Cleaning Flat Panel Display

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In this article, the megasonic cleaning system for cleaning micro/nano particles from flat panel display (FPD) surfaces was developed. A piezoelectric actuator and a waveguide were designed by finite element method (FEM) analysis. The calculated peak frequency value of the quartz waveguide was 1002 kHz, which agreed well with the measured value of 1003 kHz. The average acoustic pressure of the megasonic cleaning system was 43.1 kPa, which is three times greater than that of the conventional type of 13.9 kPa. Particle removal efficiency (PRE) tests were performed, and the cleaning efficiency of the developed system was proven to be 99%. The power consumption of the developed system was 64% lower than that of the commercial system. These results show that the developed megasonic cleaning system can be an effective solution in particle removing from FPD substrate with higher energy efficiency and lower chemical and ultra pure water (UPW) consumption.

Key Words: Megasonic (메가소닉), Finite Element Method (FEM) (유한요소해석), Flat Panel Display (FPD) (평판디스플레이), Cleaning (세정), Particle Removal Efficiency (PRE) (파티클 제거 효율)

1. Introduction

Flat panel displays (FPDs) such as liquid crystal displays (LCDs), plasma display panels (PDPs) and light-emitting diodes (LEDs), are being widely used to display information.[1] The manufacturing processes of FPDs are similar to semiconductor fabrication processes, which include photolithography, chemical vapor deposition (CVD), etching, cleaning and so on. Among them, the cleaning process is considered to be a crucial step in preparing a clean surface for the next step.[1,2]

Until now, cleaning processes of FPDs have been usually wet processes that use chemicals such as acids and solvents. The most widely adopted cleaning recipes use standard cleaning 1 (SC-1) and standard cleaning 2 (SC-2), whose chemical compositions are NH_4OH with H_2O_2 and H_2O or HCL with H_2O_2 and H_2O, respectively.[2] With continual decrease of feature size, the particle sizes that need to be removed have become smaller, and as such, cleaning requirements have become much severer than ever before.[3] When the particle size becomes smaller, the van der Waals forces between the substrate and the contaminants increase in reverse.[4] In this case, the contaminants can hardly be removed using conventional wet cleaning methods. Furthermore, environmental concerns have limited the use of chemicals or large amounts of DI water.

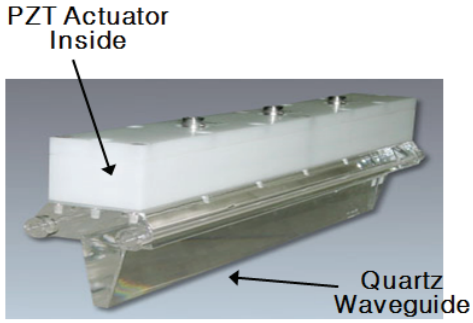
To solve these problems, ultrasonic cleaning systems were introduced in manufacturing semiconductors and FPDs.[5-16] In advance, there were researches about the mechanisms of ultrasonic cleaning.[17,18] In the cleaning process using megasonic system, there are researches about the effect of adding gases in cleaning liquids.[19,20] Studies about small bubbles or cavitation by megasonic system, were also reported.[21,22] In an ultrasonic cleaning system, physical forces from the vibrations of actuators promote the removal of particles from the substrate.[4] The spray-type megasonic cleaning system was developed and was applied to the cleaning process. But the drawback of this system was still large amount of chemical and ultra pure water (UPW) consumptions.[16]

In this work, a megasonic cleaning system for removal of micro/nano particles from FPD surfaces with lower power consumption and less use of chemicals and UPW is proposed. The design process of the lead zirconate titanate ($Pb(Zr{\bullet}Ti)O_3$ (PZT)) actuator and the quartz waveguide using the finite element method (FEM) software ANSYS is described. An acoustic analysis is also performed using the FEM software. The fabrication process of the system is explained. And the electrical characteristics of the system are measured and compared with the analysis results. To assess the performance of the proposed system, the acoustic pressures are measured and compared with that of the commercially available cleaning system.

2. FPD Megasonic Cleaning System

2.1 The Structure of the Megasonic Cleaning System

The FPD megasonic cleaning system is mainly composed of two parts, the megasonic cleaning unit and the electric generator, which are shown in Figs. 1(a) and (b), respectively. The cleaning unit has a wedge shaped quartz waveguide with a PZT actuator attached on top.



(a)

(b)

Fig. 1 (a) Fabricated FPD cleaning megasonic system and (b) electric generator

When power is supplied to the PZT actuator, the actuator vibrates and the displacement is transferred through the waveguide.

For cleaning, the cleaning unit is placed on the top of the FPD substrates and its physical vibration is transferred through a water medium between the waveguide and the substrate with the SC-1 chemicals. Then it can help the removal of the micro particles from the substrate. The removed particles are washed away with fresh de-ionized (DI) water after cleaning.

2.2 FEM Analysis of the Megasonic Cleaning System

The cleaning system was designed by FEM analysis using the commercial FEM software. First, the PZT actuator was modeled with the analysis tool. The model was axis-symmetric and the nodes of the top and bottom electrodes were coupled to apply voltages. A series of calculations were performed from 800 kHz through 1200 kHz. The highest impedance value was 1004 kHz, which agreed well with experimentally measured value of 1005 kHz, as shown in Figs. 2(a) and (b), respectively.

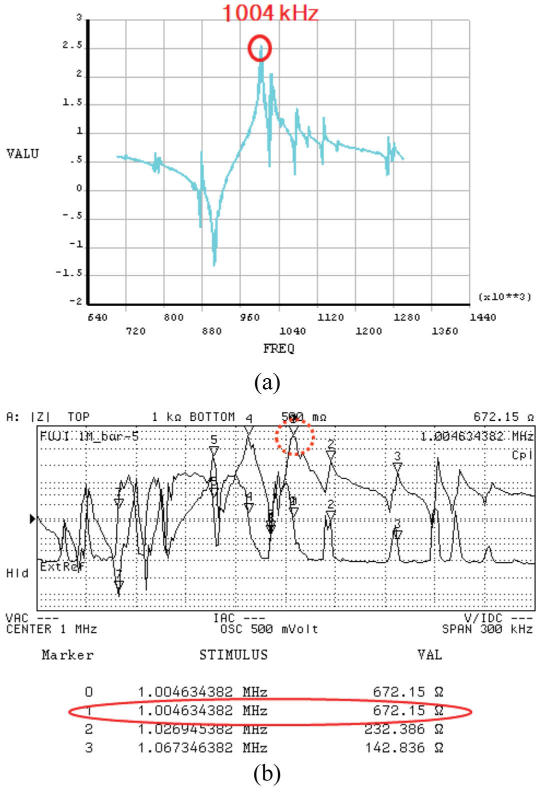


Fig. 2 (a) FEM result and (b) measured impedance graph of the PZT actuator

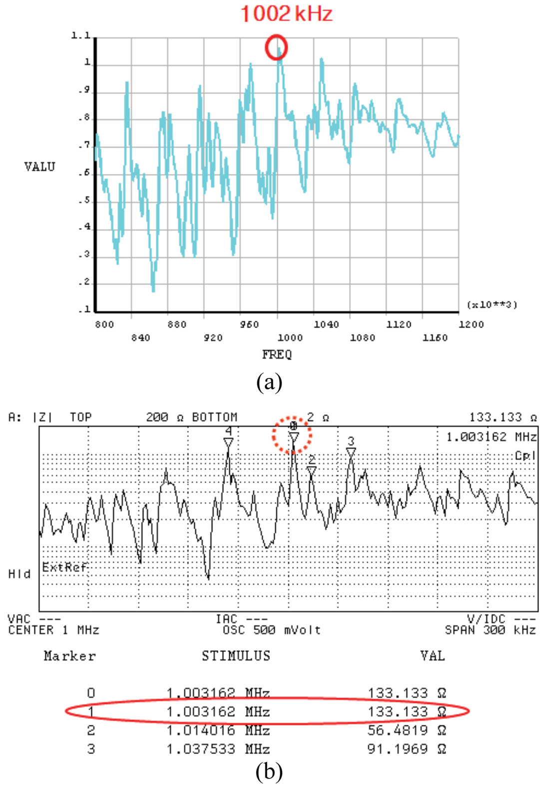


Fig. 3 (a) FEM result and (b) measured impedance graph of FPD cleaning system

To design the quartz transducer, a waveguide with the PZT actuator was modeled. The analysis model was also axis-symmetric. The PZT and the waveguide models were glued together for coupled analysis. A series of calculations between 800 kHz through 1200 kHz were done to predict the impedance characteristics of the system. The obtained peak frequency value was 1002 kHz, which agreed well with the measured value of 1003 kHz, as shown in Figs. 3(a) and (b).

2.3 Acoustic Analysis of the System

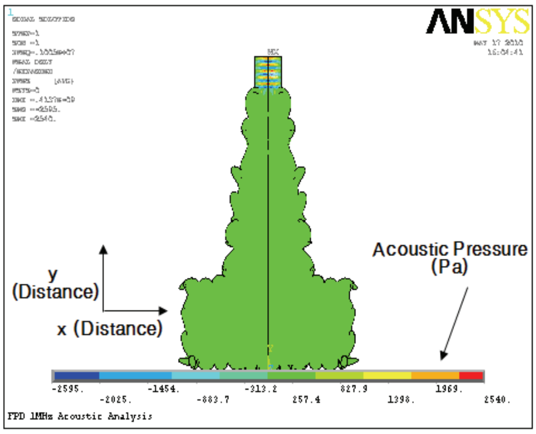
Acoustic analysis was performed using the FEM software. Firstly, the PZT actuator and the waveguide were modeled. And the water was modeled at the end of the waveguide to predict the acoustic pressure distributions. The density of the water was 1000 kg/m^3, and the velocity of sound in the water was 1500 m/s. Fluid-structure interaction (FSI) option was given at the interface of water because of the interaction between the waveguide and the liquid. Using this option, the acoustic pressure distribution due to the force from structural motion can be predicted.

The analysis results are shown in Figs. 4(a) and (b), respectively. The red color means the highest acoustic pressure and the blue means the lower acoustic pressure. This result supports the expectation that the developed waveguide will have good acoustic pressure distributions.

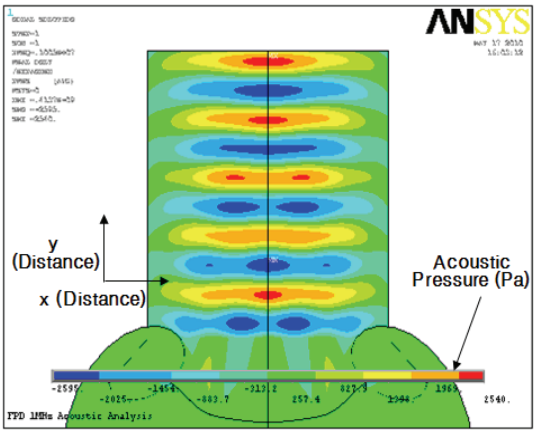
3. Experiments

3.1 Acoustic Pressure Measurement Setup

The acoustic pressure distributions were measured using the acoustic measurement setup shown in Fig. 5. The measurement setup has three-axis actuators so it can move in x, y, z direction for positioning. Therefore, it can scan all of the bottom part of the waveguide. For the measurement, an acoustic sensor is placed on the bottom of the waveguide and it scans all the area.



(a) Overall view



(b) Magnified view

Fig. 4 Acoustic analysis results

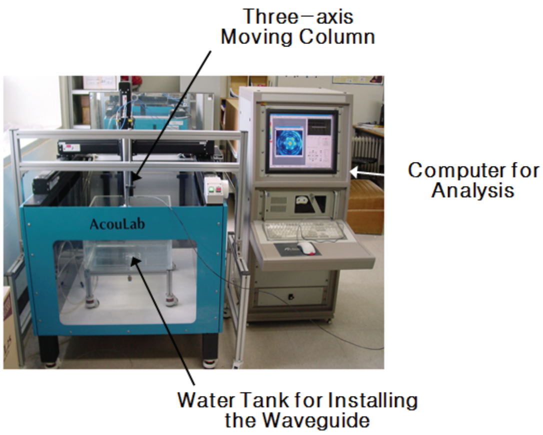
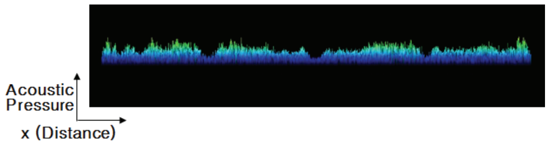
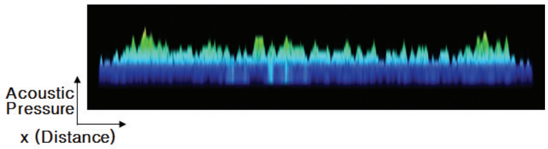


Fig. 5 Acoustic pressure measurement setup of the FPD cleaning megasonic system

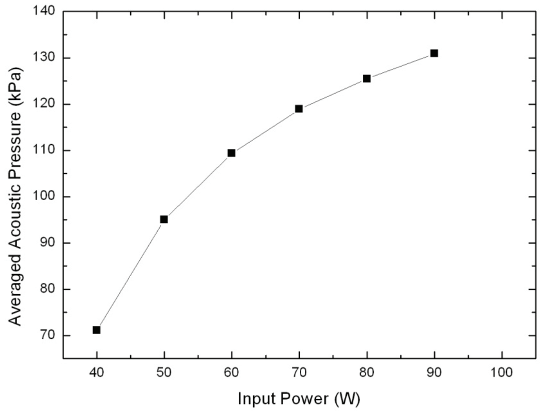


(a) The conventional megasonic system (Spray-type)

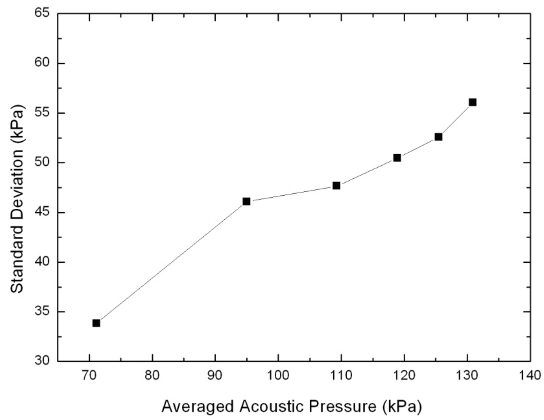


(b) The developed one

Fig. 6 Acoustic pressures



(a) Average acoustic pressure vs. input powers



(b) Standard deviations vs. average values

Fig. 7 Acoustic pressure distribution

The measurements were performed at different input powers, and the obtained data was transferred to the computer for analysis. The measured acoustic pressure distributions of the conventional megasonic system

(Spray-type) is shown in Fig. 6(a) and those of the developed system in Fig. 6(b), respectively. The average acoustic pressure of our developed product was 43.1 kPa, which is three times greater than that of the conventional type of 13.9 kPa. Consequently, higher system output power is expected compared to the commercial product. The distribution of our product is also seen to be better, which can be interpreted into a well distributed output power level.

After measuring acoustic pressures, averages and standard deviations were obtained through calculations of raw data. Average values of acoustic pressure of the developed megasonic system for different input powers are shown in Fig. 7(a) and the standard deviations for different average values in Fig. 7(b), respectively.

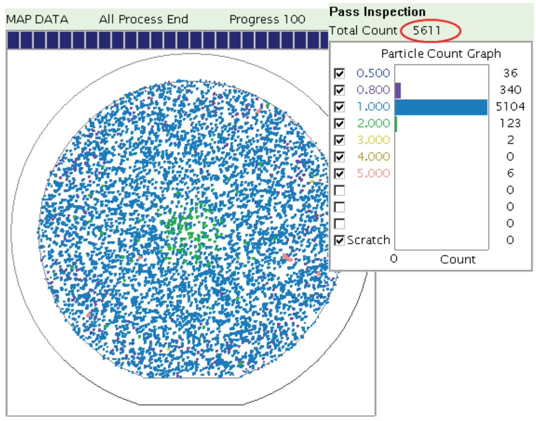
3.2 PRE Test

Another index that can explain the megasonic cleaning system performance is the particle removal efficiency (PRE) test. This experiment is being processed by deposition of micro-sized particles and cleaning them with the proposed cleaning system. When the particle deposition is completed, the number of particles is being counted using a particle counting machine. And after cleaning process, the number of remained particles is counted again for comparison. 6-inch silicon (Si) wafers were used as substrates for this experiment.

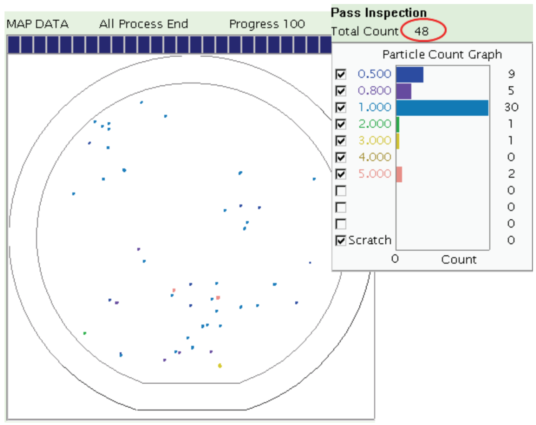
Firstly, a bare wafer was cleaned and 1 μm-sized particles were deposited on the wafer. And then, it was loaded on the developed cleaning apparatus. To clean the particles, the waveguide moves slowly over the wafer at the supplied electric power of 130 W. The particles that were separated from the surface were removed by spreading DI water at a flow rate of 7 l/min.

After cleaning, the wafer was transferred to the particle counter again and the number of particles was counted again. The experimental results of before and after cleaning, are shown in Figs. 8(a) and (b), respectively. The deposited particle number before cleaning was 5,563, but the number of particles remaining after cleaning was 48. The cleaning efficiency of the developed cleaning system was calculated as 99% using the experiment result.

With respect to power consumption, the developed product used only 64% of power, that is, 430 W/m^2, compared to the commercial system of 1,200 W/m^2. In addition, chemical consumption was reduced from 100 l/min to 20 l/min, which is 80% saving.



(a) Before particle cleaning



(b) After particle cleaning

Fig. 8 Cleaning experiment results

4. Conclusions

In this work, the megasonic cleaning system for cleaning micro/nano particles from FPD surfaces was developed, aiming for power consumption reduction and chemical and UPW savings. FEM analysis using Ansys was performed to design the PZT actuator and waveguide. The highest impedance value of the PZT actuator was 1004 kHz, which agreed well with experimentally measured value of 1005 kHz. In addition, the obtained peak frequency value of the quartz waveguide with the PZT actuator, was 1002 kHz, which agreed well with the measured value of 1003 kHz.

The acoustic pressure distributions were measured and compared with those of the conventional spray-type megasonic system. The average acoustic pressure of our developed product was 43.1 kPa, which is three times greater than that of the conventional type of 13.9 kPa. Based on the result of the PRE test, the cleaning efficiency of the developed cleaning system was 99%. With respect to power consumption, the developed product needed only 64% of power, which is 430 W/m^2, but the commercial system needed 1200 W/m^2. Additionally, chemical consumption was reduced from 100 l/min to 20 l/min, which is 80% saving.

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