Shielding effectiveness of meltblown non-woven thin fiber noise suppression sheet

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Abstract—**A new noise suppressor made by meltblown technique has been developed and studied by measurements and electromagnetic simulation. The shielding effectiveness from plane wave can be calculated using the sheet resistance by regarding the non-woven fabrics as a continuous metal sheet. The model of the only thin fibers have been constructed in order to clarify the noise suppression mechanism of high noise suppression performance of thin fibers. The direction of input electric field has been changed to discuss the conductive condition between fibers. As a result, the shielding effectiveness increases with the fiber layer increase and the conductivity of surface element of fibers increase, respectively.**

Keywords-NSS; Non-Woven Fabric; conductive noise; shielding effectiveness; sheet resistance

I. Introduction

As tremendous usage of electric and electronic appliances which generating electromagnetic noise around us, such unwanted noise give a potential influence to the wireless telecommunication performance. Electromagnetic noise suppression sheet is widely used in many electronic components for electromagnetic noise countermeasure in RF range [1]. Besides popular ferromagnetic NSS, a non-woven fabric noise suppression sheet (NSS) made of synthetic fibers coated with non-magnetic metal (PULSHUT^{TM}, Asahi Kasei, Corp.) has been applied as lighter and thinner noise suppressors recently [2]-[4]. The proposed NSS will not disturb electromagnetic compass placed nearby as non-magnetic nature, which is not possible by a ferro magnetic noise suppressors.

This non-woven fabric noise suppressor consists of three layers; the center layer consists of thin fibers with a diameter of nominally 1 μm. The outer layers sandwich the thin fiber layers and are made of thick fibers with a diameter of nearly 10 μm. The thin layer is made of meltblown fibers [5] and the thick layers consist of spunbond fibers [6].

Previous study experimentally demonstrated that the conductive noise suppression with a microstrip line(MSL) using the non-woven fabric type noise suppressor is larger than that when using a continuous conductor in the 0.4 to 1.5Ghz range [4]. In order to clarify the mechanism of shielding effectiveness [3], simple periodic structure model is analyzed and predicted that the thin fiber layer could be most beneficial for the better electromagnetic noise suppression [4], which has been briefly verified recently [7]. It is also reported that non-woven fabric noise suppressors based only thin fibers exhibited a good noise suppression as well as continuous film [8][9]. It is commonly claimed in these papers that sheet resistance is a major design parameter to define the degree of noise suppression.

However, it remains as open question to clarify the relationship between the large noise suppression, the micro structure and the microstructure design guideline.

Therefore this paper systematically discuss the shielding effectiveness(SE) of a metal-coated non-woven fabric made with only thin fibers as an NSS by means of experiments and electromagnetic simulation. We firstly developed a set of new non-woven fabric NSS consisting only of thin fibers, and applied them to experiments. Then a simulation model of the non-woven fabric made from synthetic thin fibers is developed, and the volume current with input electric field of different angles is discussed. Furthermore, the model of the only thin fibers with different layers have been constructed in order to clarify relationship between the shielding effectiveness and the number of layer. The conductivity of surface element around fibers is changed to discuss the shielding effectiveness.

II. Meltblown Non-Woven Fabric

The non-woven fabric NSS is composed of the nonmagnetic metal-coated non-woven fabric of 9.2 μm in diameter. The fiber is made by meltblow technology as shown in Fig. 1.

Meltblown method is a method to produce nonwovens consisted of fine fibers with diameter range of 1~20 μm. By changing the fiber diameter, porosity of the fabric could be adjusted to meet the needs of electronics application. In this method, polymer is first melted in the extruder, and then molten polymer is blown out from the spin head by high-speed hot gas. As an example of spinning condition, in case of polyethylene terephthalate (PET) nonwoven, the temperature at the extruder is being set at 300 °C, the extruding rate is set at 20kg/hr per 1 meter, and the temperature of spinning gas is set at 360 °C for stable manufacture.

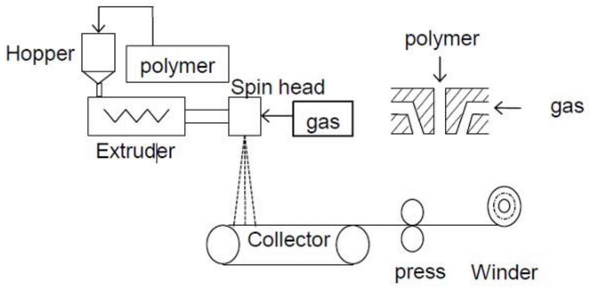
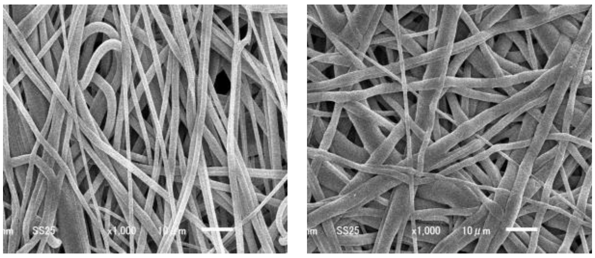
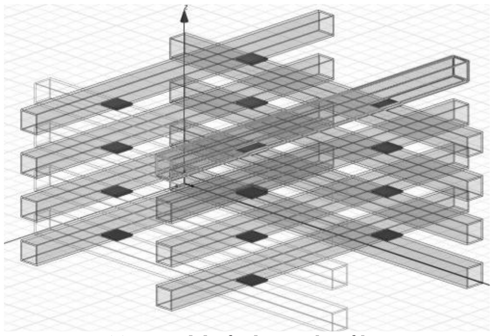


Figure 1. Meltbrow technology to produce non-woven fabric.

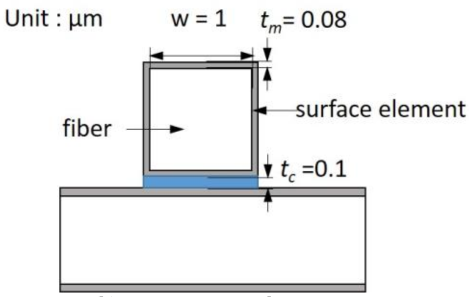


(a) Sample 1 (no heat treatment) (b) Sample 2 (with heat treatment)

Figure 2. Microstructure of the non-woven fabric.



(a) Model of 8 layers thin fiber



(b) Cross-sectional view

Figure 3. Thin fiber model with contact element

Fig. 2 shows the SEM image of the non- woven thin type fabric, sample 1 (no heat treatment) and sample 2 (with heat treatment). Application of heat treatment raised up the density and in part the fibers are welded at the cross points, suggesting that the resistance of contact element becomes low. On the other hand, details of resistance at contact points impacting the sheet resistance are still not clear. Therefore electric measurements and analysis should help such understanding.

III. Simulation Condition

In order to clarify the noise suppression mechanism of high noise suppression performance of thin fibers. Fig. 3 shows the simulation model of the non-woven thin type fibers with surface element around them. Randomly oriented real fibers are modeled into a well-curb of parallel crosses with square windows [7] and stacked as thin to thin fiber structures. Each fiber is considered as an insulator of infinite length and has a square cross-section [10]. Its relative dielectric constant is 1, relative permeability is 1, and the resistivity is infinite.

The thin fibers are arranged at intervals space of 9.2 µm and are paralleled with each other in every layers. With every two layers, contact element of square shape is inserted between them. The 2nd layer is placed orthogonally with respect to the 1st layer, also the 3rd layer is placed orthogonally with the 2nd layer and paralleled with the 1st layer. Similar to the 1st and 2nd layers, the 3rd and 4th layers are arranged in a grid-like shape.

The cross section of the thin fibers are modeled as 1 µm × 1 µm squares. Furthermore, the contact element between the fibers is arranged to discuss the contact condition between fibers. The contact element is shaped with the length of 1 µm, width of 1µm, and height of 100nm. The conductivity σ_s of surface element of fibers can be changed independently to the conductivity σ_c of the contact element.

The surfaces of these all fibers are coated with a metal film of the same thickness. The sheet resistance was changed from 10^{-1} to 10^{3} Ω by changing the resistivity.

Sheet resistance R_s is expressed as

$$R_s = \rho_s / t_s , \tag{1}$$

where t_s is the thickness of the non-woven fabric. ρ_s is the value obtained by the volume–average resistivity of the metal and gaps between fibers in the case where the shielding sheet is regarded as a continuous conductive sheet.

$$\rho_s = \rho_m \frac{V_{nw}}{V_m} , \tag{2}$$

where ρ_m is the resistivity of the non-woven fabric, V_{nw} and V_m are the volume per unit area of the non-woven fabric and the surface element, respectively.

The shielding effectiveness in the case where a plane electromagnetic sinusoidal wave is vertically incident to an infinitely wide shielding sheet is analyzed using the full wave simulator (HFSS Ver. 17, Ansys co.).

The shielding effectiveness (in dB) *SE* is defined as

$$SE = -10\log(P_{w/} / P_{w/0}) \quad [\mathrm{dB}], \tag{3}$$

where $P_{w/}$ and $P_{w/o}$ are the transmission power of the plane wave with and without the shield sheet, respectively.

The frequency of the plane wave is 1 GHz, and the amplitude is 1 V m^{-1}. The angle of the input electric field is set by 90 degree, 45 degree or 30 degree, respectively.

IV. Shielding Effectiveness

Fig. 4 and Fig. 5 shows the 2 layers model volume current distribution of surface element on fiber with input electric field of 90 degree and 45 degree, respectively. With 90 degree electric field input, along the direction of electric field, the direction and strength of current in top fiber doesn't change. Therefore, there nearly no current flowed from one fiber to another. It's evident that the contact element would not give the contribution to function of noise suppressor. On the other hand, with 45 degree electric field input, strength of current through top fiber and under fiber both are nearly same.

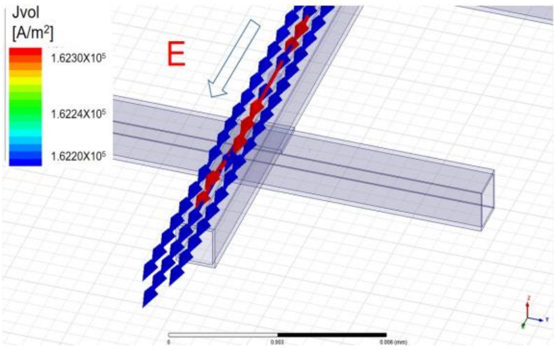


Figure 4. The volume current distribution of surface element around fibers with 90 degree electric field input.

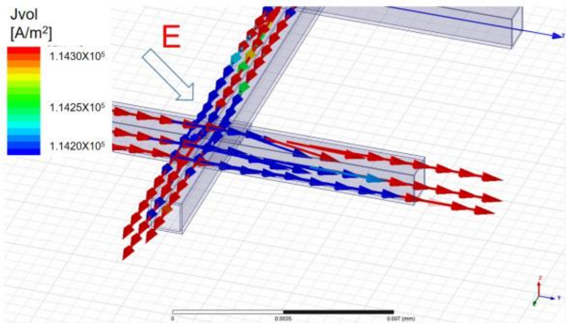


Figure 5. The volume current distribution of surface element around fibers with 45 degree electric field input.

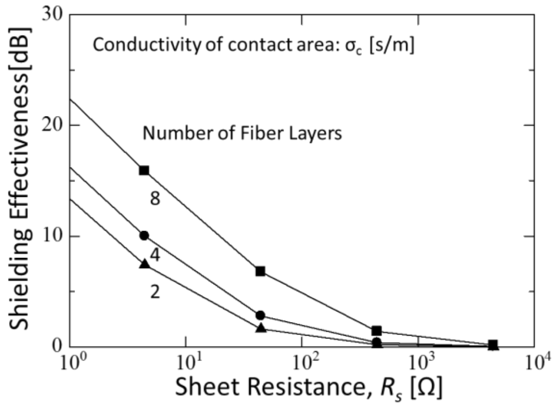


Figure 6. The sheet resistance of the SE with constant contact element conductivity (σ_c=38 [S/m]).

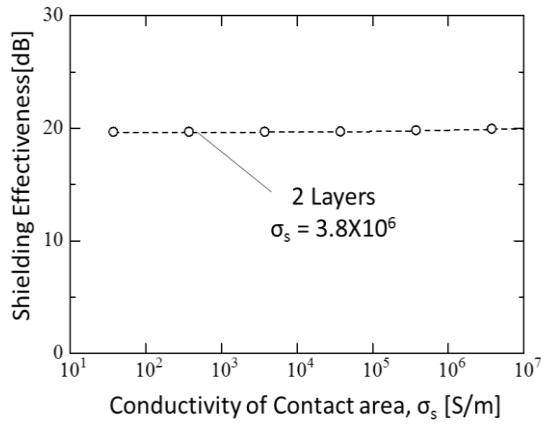


Figure 7. The contact area conductivity dependence of the SE with constant metal conductivity (σ_s=38 [S/m]).

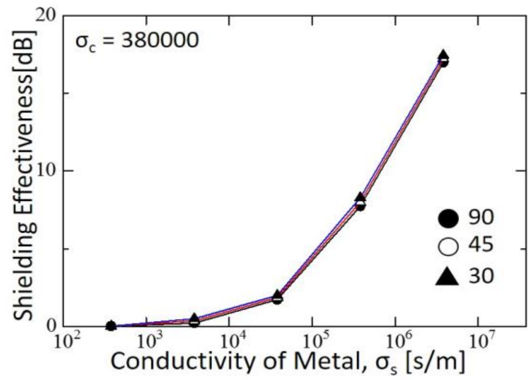


Figure 8. The conductivity of metal dependence of the SE with constant contact element conductivity in two layers model.

Fig. 6 shows the sheet resistance dependence of the SE with constant contact area conductivity σ_c of 38 S/m. The shielding effectiveness increases with the fiber layer increase. Fig. 7 shows the contact area conductivity dependence of the SE with constant metal conductivity σ_s of $3.8{\cdot}10^6$ S/m. The shielding effectiveness does not change with changing the contact element.

With 90, 45 and 30 degree electric field input, Fig. 8 shows the surface element conductivity dependence of the SE with constant contact element conductivity in two layers model. The shielding effectiveness increases with the conductivity of metal increases, which means lower resistance generates high effect of shielding effectiveness. Even with the different angle of input electric field, the shielding effectiveness becomes nearly same at the same point of conductivity of surface element around fibers. Therefore, it's a need to consider the unit resistance of the model with different angle electric field input, which affect the shielding effectiveness.

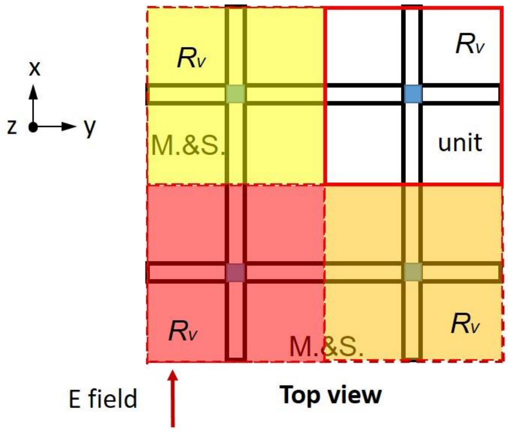


Figure 9. The definition of resistance in unit of 90 degree electric field input.

Fig. 9 shows the definition of resistance in unit of 90 degree electric field input. This collected condition has a square part to collect the unit resistance of the two layers model, the point to calculate the resistance is the square part includes the four contact element and the electric field is just vertical to the side of this square part. In Fig. 9, the square area is divided into four same small square part R_v, as a result, the value of R_v is only related with the parameter metal conductivity σ_s, this is the evidence that the shielding effectiveness does not change with changing the contact element. The calibration of 45 degree and 30 degree are still on going.

From these results, it is expected that each layer shields independently of other layers in the far field. However, it remains as major open question to analyze individual and statistical nature of contact resistance of numerous contact points in the sub-micron scale.

V. Conclutions

A new noise suppressor made from metal-coated non-woven fabric has been developed and studied by measurements and electromagnetic simulation. A simulation model of the non-woven fabric made of thin synthetic fibers has been developed and simulation environment has been set by different conditions.

Effect of contact element has been clarified experimentally for the first time as the sheet resistance becomes the less and accordingly the loss ration becomes higher as the pressure during fabrication increases, and as the heat treatment is applied to weld the fibers.

The model of the only thin fibers have been constructed in order to clarify the noise suppression mechanism of high noise suppression performance of thin fibers. The contact element between the fibers is arranged to discuss the contact condition between fibers. The angle of the input electric field is set by 90 degree, 45 degree or 30 degree, respectively. As a result, the shielding effectiveness increases with the fiber layer increase and does not change with changing the contact resistance. With the input of different angle electric field, the shielding effectiveness becomes nearly same at the same conductivity of surface element around fibers.

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