Clean Unit System Platform (CUSP) for Medical/Hygienic Applications

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***Abstract*— *Analyzing conventional cleanrooms, we have proposed and demonstrated how well Clean Unit System Platform (CUSP) works. The CUSP serves as a clean versatile environment having low power-consumption and high cost-performance, and is suitable not only for processing the next generation new devices, but also for cross-disciplinary fields, including medical/hygienic applications. CUSP can provide us with dust- and microbe-free environment as good as US FED 209E class 10 in room-type CUSP, and class 1 with foldable CUSP (F-CUSP). Sleeping in F-CUSP has opened a window for Kinetosomnogram, which, based on the analysis of the peaks in the particle-count and the autocorrelation of them, would contribute to evaluation of sleep quality and/or sleep disorders. The F-CUSP as well as a capsule CUSP that operates with tiny FFU covering minimum volume can reduce the risk of MERS or other diseases mediated by air-borne microbes. With its full line-up, CUSP can outperform conventional super cleanrooms ("main frames") and also provides us with environment suitable, especially, for those people under the risk of suffering from particulate matters (PM) 2.5, airborne microbes, or other foreign materials. The CUSP would be the clean space for all of us.*

Keywords*— *Clean environment, CUSP, kinetosomnogram, microbe-free environment, Tent-type CUSP (T-CUSP).

I. INTRODUCTION

Functional new devices and systems in materials/biological science, information technology, energy, and environment engineering having been of increasing importance, it is inevitable for us to investigate those systems in atom-bit-energy/environment (ABE2) four-dimensional space. Since nano- and micro-sized particles [1] and microbes [2-4] do affect systems, quite so many attentions were paid and versatile tools have been employed. If we take semiconductor factory as an example of those systems, one of such tools is, obviously, a cleanroom [5, 6]. For processing such devices as well as for environment-conscious applications, highly clean, inexpensive systems are needed. Clean versatile environments having small footprint, low power-consumption, and high cost-performance can be realized with clean unit system platform (CUSP) [7-13] for the next generation production system as well as for cross-disciplinary experiments. We can realize the cleanliness of ISO class minus 1 [12] (i.e., the number of all the particles having sizes larger than 0.1 µm is as low as 10^{-1} per cubic meters). The CUSP is now in full line-up, providing us with the high cleanliness, for example, even in a dusty laboratory/office with airborne particle count as high as ~ 1 billions/m^3. Desk-top type CUSP [8, 9, 12], mobile CUSP [11], and lung CUSP (L-CUSP) [13], in which people can stay doing processes, are now available. Multiply-connected CUSP system based upon those would serve as the platform not only for nano-technologies or bio-technologies, but also for the next generation environment-friendly platform for industries.

When we think of our own industrial society, on the other hand, as another example of those systems, we notice that particulate matters (PM) 2.5 [14-16] is definitely among the nano- and micro-sized materials, unfortunately, here in a negative sense, in that people are suffering from them [16]. Clean rooms have long been inevitable for LSI industries, and recently they are also meaning much for biological and food industries, although the level of the cleanliness requirement differs much. For semiconductor industries, US FED 209E class 1 (ISO class 3) is "MUST", but class 10000 is well acceptable for food industries. In hospitals, class 100 is typical cleanliness for operating rooms in hospitals. Thus, for example, for lowering the level of suffering from PM2.5 problems, suitable cleanroom has not been identified yet. Generally, since the cleanrooms have been expensive, only huge industrial companies can afford to introduce them in their manufacturing facilities. For individuals suffering from PM2.5, hay fever (pollinosis), or other respiratory malfunctions, those conventional cleanrooms, unfortunately, would not be the answer, no matter how good the cleanliness they provide is. The conventional cleanrooms are, also, too space-consuming to introduce in their house. Based on the clean unit system platform (CUSP) technology [7-13], which, originally, has been proposed as a platform that unites, or makes a bridge over the gap between, the top-down systems (such as Si-based LSIs, for which the conventional cleanroom plays vital roles) and bottom-up systems like self-organized or biological systems including microbes [2-4,17], in this Letter, we analyze the cleanrooms and propose clean systems suitable for those people under the risk of suffering from PM2.5 [14-16], middle east respiratory syndrome (MERS) [4], or other foreign materials.

II. EXPERIMENTS AND DISCUSSIONS

The early CUSPs [8-12], which, being originally desk-top clean boxes or chambers to be connected up to form a whole system like LEGO blocks, were not designed to have people inside. However, since there were so many demands that they want do processing inside CUSP utilizing the high cleanliness that CUSP provides, we have upgraded CUSP so that people can stay long in CUSP keeping its superiority to conventional cleanroom unchanged. Figure 1 shows how cleanliness is achieved with habitability in conventional cleanroom and in the CUSP. In the conventional cleanroom (or in clean booth, also), as shown in Fig. 1(a), fan-filter-unit (FFU) on the ceiling inhales the ambient air, filtrates it, and pushes it into the main chamber of the cleanroom, where the filtrated clean air dilutes the dusty air inside. Then the diluted air goes out of the chamber, and the cleanliness arrives in the cleanroom. Thus, the conventional cleanroom is open system in that ambient air comes in and inside air goes out to merge with the ambient eventually. In the conventional cleanrooms the cleanliness is achieved only *indirectly* by diluting the dusty inside air by filtrated clean air (as shown in Fig. 1(a), the FFU, just filtrating the ambient air, never collects the particles in the chamber). The particles (dusts and/or microbes) go outside, being contained in the outgoing air (thus, depending on what are inside, there is a risk that people outside may suffer from them). Further, the conventional cleanroom's FFU, put at the interface between the ambient and cleanroom, keeps on clogging inhaling the ambient air, which is infinite in volume, until it loses its filtrating ability because of the heavy clogging.

On the other hand, in CUSP, as shown in Fig. 1(b), all of the air coming in (to the main chamber) from the outlet of the FFU go back to the inlet of the FFU, i.e., 100% feed-back is done. The CUSP's FFU inhales the return air coming through its inlet, filtrates it and then push it back into the main chamber of the CUSP. Note that the FFU is detached from the ambient air, and so is the main chamber of the CUSP from outside. Thus, the CUSP is closed (isolated) system in that there is no net air-flow exchanged between inside and outside of the CUSP. The ambient air never goes into CUSP as a net air-flow. In CUSP, the cleanliness is achieved *directly* by collecting particles (dusts and/or microbes) inside. Those particles never go outside (therefore, there is least risk that people outside might suffer from those particles). The CUSP's FFU, detached from the ambient air, stops clogging in a finite (actually very short) time when cleanliness is achieved, with the inner air having run though the FFU several times (in a couple of minutes). In the CUSP, a part of the wall is made of a gas-exchange membrane (GEM), through which gas molecules diffuse if there exists concentration gradient across the membrane. Thus, if oxygen concentration becomes low due to O_2 consumption inside CUSP, the oxygen is fed in through GEM from outside.

In CUSP system, thanks to the 100% feedback system, the steady-state airborne-particle-count becomes independent of the ambient particle count in the system and depends little on the filtrating efficiency, □ ,of the fan-filter-unit (FFU), if □ >0.9.It is demonstrated that ISO 3 (US FED 209E Class 1) or higher cleanliness in an inexpensive compact manner with the versatile extensive connected box-units system can be realized [4, 8], no matter how dusty the ambient is. As time goes by, the lowest (or, steady state) particle density n in our CUSP chamber is given by the equation [4, 9],

$$n = \frac{S\sigma}{\gamma F} \tag{1}$$

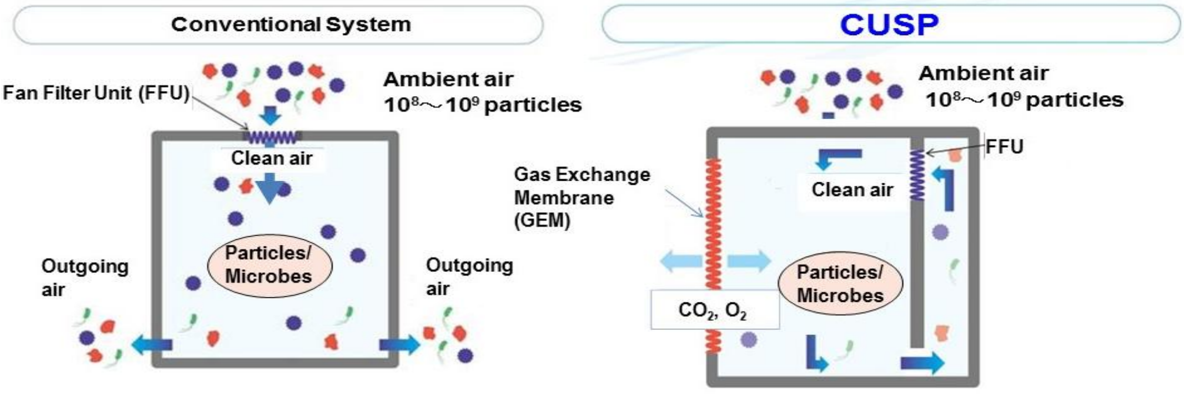

FIGURE 1. HOW TO ACHIEVE CLEANLINESS WITH HABITABILITY, BY CONVENTIONAL METHOD (LEFT) AND BY CUSP (RIGHT).

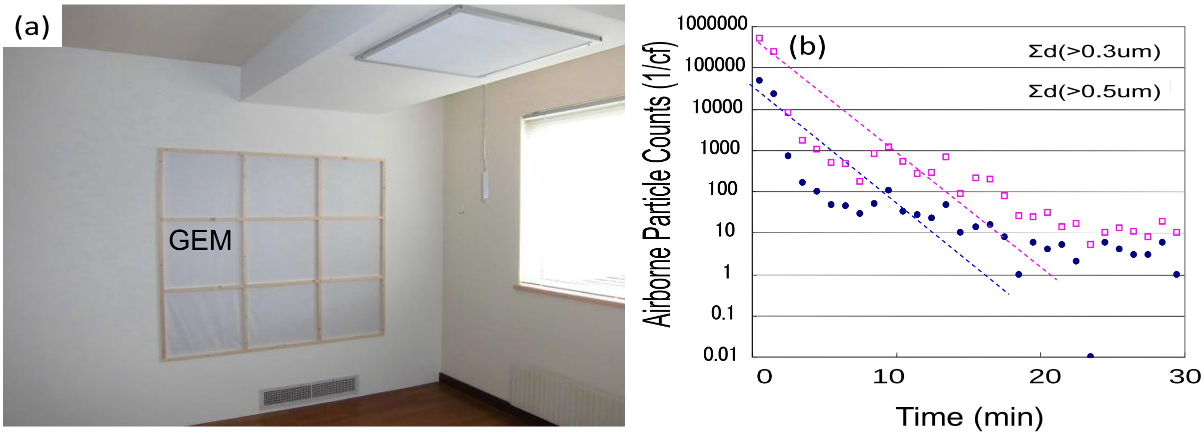

FIGURE 2. (A) ROOM TYPE CUSP ("SEISHOIN") AND (B) THE PARTICLE COUNT IN SEISHOIN AS FUNCTION OF TIME.

where *S* is the area of inner surface, σ the number of particles coming out per unit inner area per unit time, and *F* the flow rate of the FFU. The steady-state particle-density, thus, the cleanliness in CUSP chamber, is independent of the ambient particle -density, which tells us that small *σ*, not *γ* close to unity, is of importance. In Figure 2 (a) is shown an example of a real implemented CUSP, where the aforementioned 100% feed-back is built into an existing room as a part of reform of a house. The white square on the ceiling is the FFU, which can be located anywhere as long as the 100% feed-back is made. The nine-segmented white square on the back left wall is the gas-exchange-membrane (GEM). In this case, we have used commercially available typical Japanese "*shoji-gami*", which is a paper, first used in 11th Century, having 1000 years of tradition. Because the *shoji-gami* is used in this case, we name this CUSP "*Seishoin*" (literally, clean "*Shoin*") after "*Shoin-dsukuri*" (an old Japanese room-style having *Shoji* in a neat way). In Fig. 2 (b) the blank squares corresponds to the number of airborne particles, whose size is 0.3 μm or larger, per cubic feet. On the other hand, the solid circles shows the number of airborne particles, whose size is 0.5 μm or larger, per cubic feet, i.e., the US FED 209E cleanliness class, in the CUSP as a function of time after FFU is switched on. The CUSP has volume of 24m^3 and FFU (PureSpace 10, AS ONE Corp.) enables air-flow of 11m^3/min. at power as low as 67 W, and as shown in Fig. 2, the cleanliness becomes better than class 10 in less than 20 minutes. We can say that non-power-hungry high cleanliness can easily and inexpensively be brought into rooms in *your* house, since CUSP is very versatile and penetrating technology, now even a tent is empowered with CUSP, and is coming up as a Tent-type CUSP (T-CUSP), or, in Japanese context, as an evolutionary form of *Kaya* (mosquito net), another Japanese tradition. The material of this tent is GEM, itself, i.e., for the T-CUSP which is shown in Fig. 3, the interface between inside and outside is made of GEM, enabling the maximum gas-exchange efficiency. We put futon mat and an FFU inside T-CUSP, as shown in Fig. 3 (a), and Fig. 3 (b) is appearance of the when in use. Now we investigate what happens and also what we can observe when people sleep in ordinary manner in clean space realized by T-CUSP.

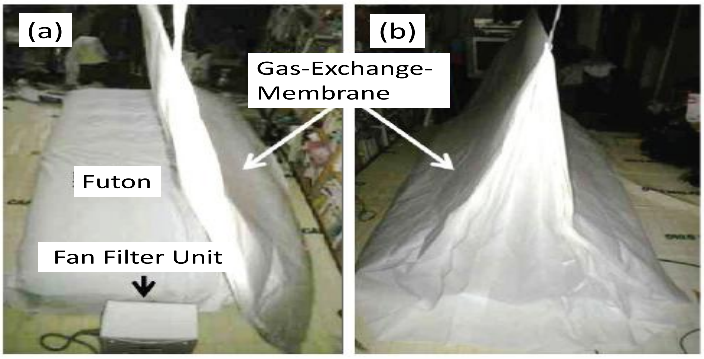

FIGURE 3. TENT-TYPE CUSP (T-CUSP), (A) CONFIGURATION AND (B) APPEARANCE WHEN IN USE.

Note that super cleanrooms have been used almost exclusively for semiconductor device processing, and it would be a ridiculous thing to even try to sleep in super cleanroom with ordinary bedclothes. With T-CUSP, it has become quite affordable to sleep in clean-space. Figure 4 is the result of sleeping in the T-CUSP. Shown in Fig. 4 (a1) is the time-dependence of the particle count, *f(t)*, inside T-CUSP, when the user (A. I.) had a good sleep, and Fig. 4 (a2) that of a night when he had shallow sleep. The particle count of the ambient is a typical value, i.e., hundreds of thousands per cubic feet as shown in Fig. 4 (a) at *t*=0. In Figs. 4 (a1) and (a2) the particle count, in average, is two to three orders of magnitude smaller than that of the ambient particle count (dust level), which means sleeping in the T-CUSP would surely be good for respiratory organs of the user in that they operate under almost zero load with respect to particles in the inhaled air. The second thing we note is that there are a bunch of spikes in the particle count. They are due to the movement the user made while he was sleeping, since he used such ordinary bedclothes (no clean suit, of course) that they shake off many dust into the air inside the T-CUSP. Thus, the spike shows the user is in move at that time, which information can be used for personal safety confirmation, for example, of a patient in a hospital. The third thing we should note is that the information contained in the pulse train of those peaks may be used for checking the sleep quality or presence of sleep disorders. As mentioned above, denoting the pulse count, in Fig. 4 (a1) or (a2), *f(t)*, the autocorrelation is given by

$$R(\tau)=\frac{1}{T}\int_0^T f(t)f(t+\tau)d\tau \qquad (2)$$

and is plotted in Fig. 4 (b1) for f(t) in Fig. 4 (a1), and in Fig. 4 (b2) for that in Fig. 4 (a1). Here T is set to be the half of the total sleep time. The night that the user noted that he had a good sleep gives a smooth autocorrelation spectrum, as shown in Fig. 4 (b1), in which two peaks are observed, i.e., one at 90min. and the other at 180 min., corresponding presumably due to the presence of REM and non-REM sleep. Note that for the night of shallow sleep, there exist (within an envelope having two peaks as are in Fig. (b1)) many substructures as seen in Fig. 4 (b2). Since there is a correspondence between the particle-count analysis and the user's subjective evaluation of the sleep quality, it would be possible to extract useful information on the sleep quality from the time-dependence of the particle count and its autocorrelation. Thus, we name this analysis *Kinetosomnogram*, which, based on the analysis of the peaks in the particle-count and the autocorrelation of them, would serve for evaluating sleep quality or disorders as effectively as ECG does for diagnosing heart diseases.

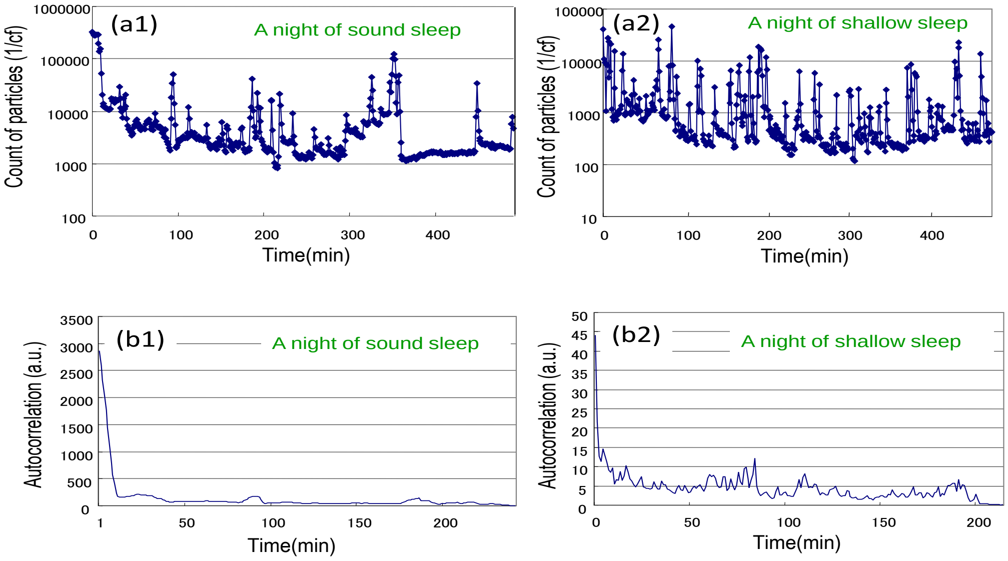

Figure 4. Time-dependence of airborne particle count when the author (A.I.) slept in the T-CUSP: (a1) for a night when the author (A. I.) had good sleep, and (a2) for another night with shallow sleep.

Tent-type CUSP's latest result is shown in Fig. 5, where the particle count is plotted as function of time when the author (A. I.) had slept for about seven and a half hours. The initial particle count, which is equal to the ambient particle count, is 200,000 per cubic feet.

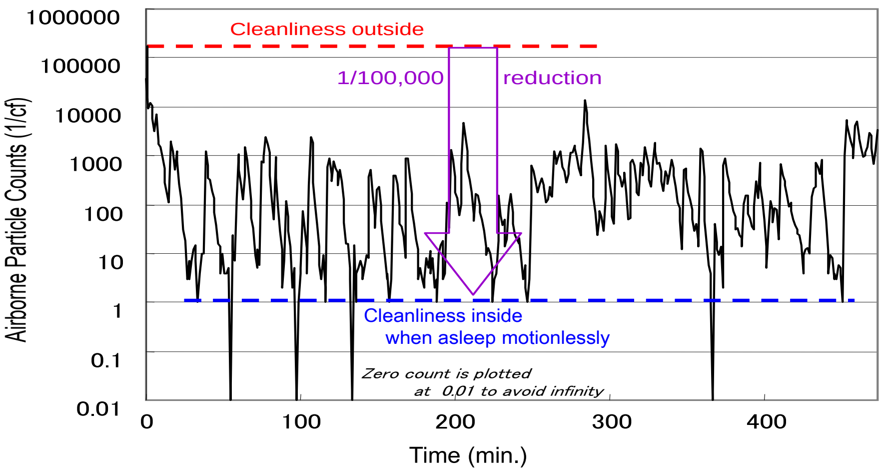

FIGURE 5. FOLDABLE CUSP (F-CUSP) LATEST RESULT. US FED 209D CLASS 1 IS ACHIEVED.

Once the FFU of the T-CUSP switched on, the particle count inside rapidly decreases by two orders of magnitude in a couple of minutes. The lowest particle-counts observed are zero, which, being unplottable, are plotted in Fig. 5 at 0.01/cf, for a certain convenience. In addition to those zero counts, particles counts as low as 1/cf are also frequently observed, which means that when a user is sleeping motionlessly, the air in the upgraded T-CUSP reaches at cleanliness as good as US FED 209E class 1, which is two orders of magnitude better cleanliness than that in an operating room in hospitals and is five orders of magnitude cleaner than the ambient air. Thanks to the upgraded T-CUSP, it now becomes just simply affordable to sleep in super clean space. Such high cleanliness of the latest F-CUPS would be optimum for the aforementioned upcoming *Kinetosomnogram*. An important thing is that the FFU used in the latest T-CUSP experiment, being the same one that used for the experiment whose results are shown in Fig. 4, has been in use almost every day for two years since April, 2013, which has proven the long lifetime of CUSP's FFU as is predicted above based on the CUSP's significant feature of the isolated 100% feedback system as discussed in Fig. 1(b).

Finally, let's discuss our latest capsule CUSP (C-CUSP), which, being a derivative of T-CUSP, is developed for portable use, especially for travel abroad for conferences. Figure 6 (a) shows a picture of C-CUSP being used at a hotel room by the author attending an international conference where risk of MERS is said to be existing. The FFU is tiny, but as shown in Fig. 6 (b) the particle count of the air the user breathes is much lower than (roughly 1/20 of) that of the ambient air. The reduction ratio might not be so impressive when compared with other CUSPs discussed above, but, to think of its handiness, portability and weight as light as 900g, C-CUSP is recommendable for those who are traveling away. Although only a compact space is there above his/her upper body, the user can enjoy non-invasive, non-contact natural sleeping in clean air, being free from nuisance of using a mask, under lower risk of suffering from MERS or other diseases mediated by airborne microbes.

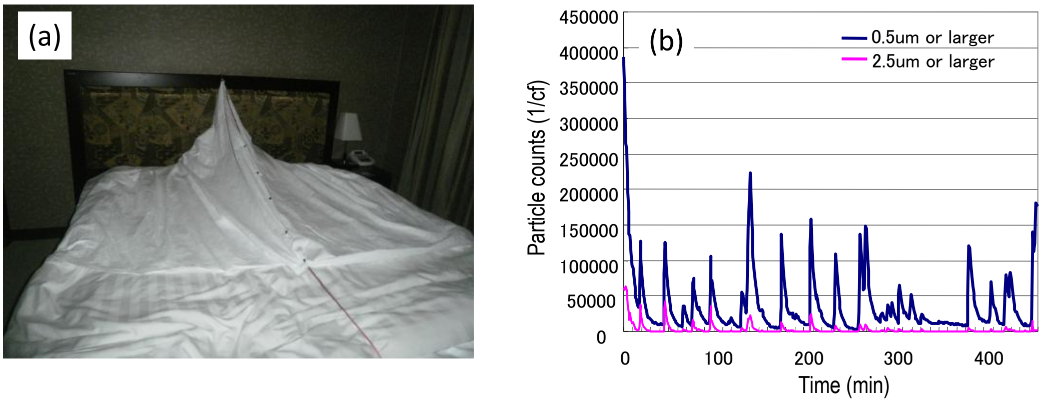

FIGURE 6. (A) A PICTURE OF A PORTABLE F-CUSP (C- CUSP) BEING SET AT A BED OF A HOTEL THAT THE AUTHOR STAYED FOR A CONFERENCE DURING A PERIOD OF MERS PRECAUTION. THE TRIANGULAR PART AND ITS SKIRTS ARE C-CUSP, WHICH CAN BE OPERATED WITH TINY FFU THANKS TO MINIMUM VOLUME AROUND HEAD, AND (B) PARTICLE COUNT IN C-CUSP WHEN THE AUTHOR SLEPT INSIDE

III. CONCLUSION

We have proposed and demonstrated Clean Unit System Platform (CUSP). The CUSP serves as a clean versatile environment having low power-consumption and high cost-performance, and is suitable not only for processing and manufacturing the next generation new devices, but also for cross-disciplinary fields, including medical/hygienic applications. In this context, physics of enabling highly clean environment in less expensive, compact manner has been getting increasingly of importance. The CUSP can provide us with dust- and microbe-free environment as good as US FED 209E class 10 for room-type CUSP (“*Seishoin”*), and class 1 for Tent-type CUSP (T-CUSP). Sleeping in T-CUSP provide you with non-invasive, non-contact measurement of your sleeping quality, and has opened a window for *Kinetosomnogram*, which, based on the analysis of the peaks in the particle-count and the autocorrelation of them, would contribute to evaluating sleep quality and/or sleep disorders. The capsule CUSP that operates with tiny FFU covering minimum volume will help people on journey to reduce the risk of MERS or other diseases mediated by airborne microbes. Based on its low cost high-performance, the CUSP outperforms the conventional super clean-room (“main frame”) and also provides us with environment suitable, especially, for those people under the risk of suffering from PM2.5, airborne microbes, or other foreign materials. CUSP would be the clean room for all of us.

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