A Low-Cost High-Performance Cleanroom Enclosure

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***Abstract*—A conventional laboratory room was converted into a cleanroom for laser microfabrication. These simple techniques resulted in a measured class 100 environment at the surface of the optical table, well beyond the class 1000 design goal. The total conversion costs were approximately 40% the cost of a comparable commercial modular cleanroom, sufficiently inexpensive for the devlopment of microfabrication instructional laboratories.**

***Index Terms*—Cleanroom, laser fabrication, microelectronics.**

I. Introduction

MICROMACHINING is a rapidly evolving collection of techniques for the production of miniaturized structures and devices. With these small features, it is necessary to perform these techniques in dust-free enclosures and cleanrooms, minimizing contamination and improving process yield. During development of the University of Louisville's Laser Microfabrication Facility, it became clear that a cleanroom enclosure was necessary [1]. This facility is used for both research projects and student training, with student usage accounting for much of the allocated time. Enclosing the laser and optical delivery system would improve process yield, increase lifetime of the dielectric coating on the lenses, and furnish valuable cleanroom experience for the students. A modular cleanroom with class 100 performance would cost approximately \$18 000, however, and would be an awkward fit in the available laboratory space. It was necessary to meet or improve this performance on a budget of less than \$10 000. Achievement of class 100 performance, at 40% of the cost of a comparable commercial unit, is described below. This type of cleanroom construction is simple, flexible, highly cost effective, and well suited for inclusion in existing laboratory rooms.

II. Design Considerations

Neither the available time nor budget for the cleanroom conversion were sufficient for typical modular cleanroom construction, in which the HEPA filters are mounted in the ceiling and the wall is raised several centimeters from the floor. In addition, the flat surface of the optical table would generate turbulence in a vertical laminar airflow. A horizontal laminar airflow, in contrast, would generate much less turbulence across the table. The air returns under the table and back to the filter through large ducts in the wall underneath the HEPA filters (Fig. 1). The horizontal surface of the table, a liability in a vertical laminar airflow, then becomes an essential component in a horizontal laminar airflow. This horizontal barrier was extended to the lower edge of the HEPA filter with acrylic plastic sheets, suspended from an overhead support. These sheets were necessary to prevent contamination of the laminar airflow by upwelling air along the side of the table. A large sheet of acrylic plastic, suspended above the table, is the upper boundary to the laminar flow region. This design was mechanically simple, since the HEPA filters could be mounted in a temporary wall. Sealing the existing walls and floor, and replacing the ceiling tiles with cleanroom tiles, completed the required room changes.

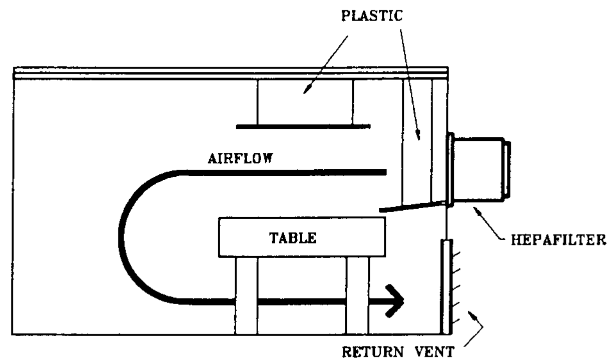

Fig. 1. Schematic of air circulation in cleanroom.

The necessary room modifications are shown in Fig. 2. Three new temporary walls were installed to form an inner room with the laser microfabrication system and an entrance vestibule. This wall arrangement was necessary to guarantee continued access to a mechanical room containing building ventilation equipment. Doors of heavy polyethylene curtains were placed between the entrance vestibule and the inner and outer rooms. Five HEPA filters were placed end-to-end along the longer wall, giving a 0.6 m $\times$ 6.0 m (2' $\times$ 20') HEPA filter array. There is a separate HEPA filter mounted just above the entranceway to the inner room. Each of these filter units is self-contained with its own prefilter and blower [2].

III. Construction Details

The existing room was a typical general-purpose laboratory with a tiled linoleum floor, concrete block and gypsum board walls, and acoustic tile ceiling. Air ducts exhausted directly onto the optical table. Conversion to a clean enclosure required

Manuscript received November 25, 1997; revised December 7, 1998. This work was supported by the University of Louisville and the EPSCoR program of the U.S. Department of Defense under Grant DAAH04-96-1-0418.

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Publisher Item Identifier S 0018-9359(99)04001-7.

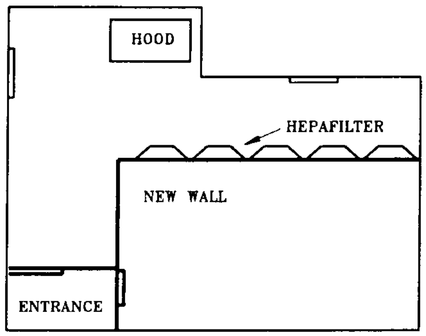

Fig. 2. Plan view of cleanroom.

TABLE I
PROJECT COSTS

Component	Costs
HEPA Filters	\$3,000
Strut System	\$2,000
Ceiling Tiles	\$700
Wall Panels	\$700
Paint	\$100
Acrylic Sheet	\$300
Miscellaneous	\$300
TOTAL:	\$7100

construction of two new walls, installation of the HEPA filter modules, relocation of ventilation ducts, replacement of the ceiling tiles, and sealing of the floors and walls.

The ceiling tiles were mounted in a standard T-rail and were replaced with tiles specifically produced for cleanrooms [3]. Air ducts were moved into the existing room outside the clean enclosure. A hard acrylic coating, typically applied to halls and other high-traffic areas, was applied to the floor by the University's custodial crew. Baseboard moulding and edges of electrical outlets were sealed with silicone caulk. The walls were painted with epoxy paint, sealing the old surface behind a flexible membrane [4].

New interior walls were constructed of rigid panels bolted to a steel strut framework, which was itself bolted to the existing walls [5]. The HEPA units were mounted on horizontal ribs, with each unit being separately removable. A square duct, 45.7×45.7 cm^2, was mounted approximately 2 cm above the floor below each HEPA filter unit. While the more usual design is a low, flat duct at floor level, these tall, square ducts should result in less floor contamination from floor traffic in the outer room. The wall panels were made of Alumolite, a rigid lightweight panel made of thin painted aluminum bonded to an inner core of corrugated plastic [6].This material is easily machined, and has a clean durable finish.

The entrance vestibule and changing area was built in a similar fashion. There is one HEPA filter unit mounted just outside the entrance to the inner room. Both the entrance and exit doors were made of a thick polyethylene curtain, split to allow easy access. Available plastic and plated steel chairs were cleaned and installed in the entrance vestibule.

The overall cost of the cleanroom was \$7100, itemized in Table I below. Total conversion costs exclusive of the HEPA filter units was \$4100, less than half the cost of a comparable commercial enclosure with acrylic plastic panels.

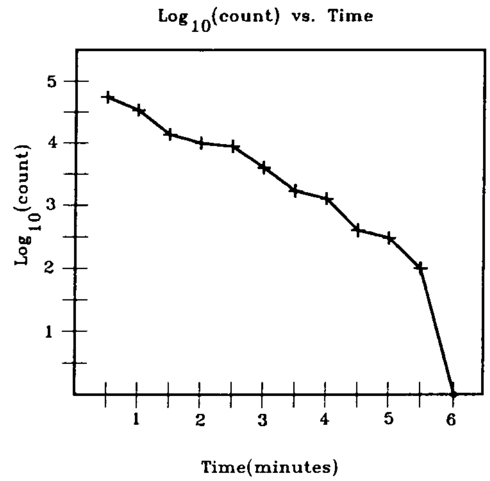

Fig. 3. Particle concentration versus time.

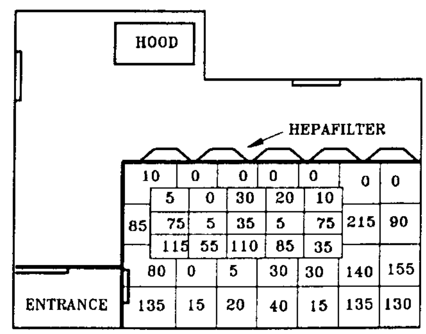

Fig. 4. Particle concentration in cleanroom.

IV. PERFORMANCE TESTS

Qualitative measurements with small pieces of paper show that the inner room was at at positive pressure with respect to the vestibule, itself at positive pressure with respect to the outer room. With no equipment in the room, the air quality at the table surface quickly reached class-100 or better (Fig. 3). These measurements were made with a Met-One Model 228.5 Particle Concentration Meter, sensitive to particles 0.5 μm or larger [7]. A map of air quality in the room is shown in Fig. 4. Note that everywhere in the room the measured cleanliness is on the order of class 100 or better. Measurements at floor level were similar, even with a person deliberately moving in the airflow upstream of the meter. Based upon these measurements, the design goal of class 1000 at the table surface was easily exceeded.

Compared to a conventional cleanroom, the HEPA filters used in this installation will likely require more frequent changes due to the lack of an efficient prefilter. The manufacturer estimates a lifetime of several years, however, even with no additional prefiltering. Filter changes are estimated to cost about \$250 per filter.

V. CONCLUSION

This project succeeded in its goal of producing an inexpensive clean enclosure delivering clean, filtered air to the fabrication point of the laser microfabrication facility. The design effectively met all design criteria, including stringent constraints upon available time and financial resources. Long-term operating costs, such as filter replacements, may be higher than for conventional methods. This design is sufficiently simple that all required construction and maintenance can be carried out by one or two students. It is a viable design for producing cleanrooms on a very limited budget.

REFERENCES

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[3] Clean-Room Products, Inc., Ronkenkoma, NY.
[4] Chemical Resistant Neoprene Sealant, Acramax Technologies, Media, PA.
[5] Unistrut Corporation, Itasca, IL 60143.
[6] Laminators, Inc., Hatfield, PA.
[7] Model 228 Particle Concentration Meter, Met-One, Grants Pass, OR.

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