TMC Technical Manufacturing Corporation

Piezo · Nano · Positioning PI

Piezo-Driven Active Vibration Control Pushes Limits of Nano-Scale Imaging / Fabrication

Wes Wigglesworth, Technical Manufacturing Corporation
Scott Jordan, PI (Physik Instrumente) L.P.

Abstract

Active vibration isolation technology is a key ingredient for enabling next-generation, 22nm scale lithography. Based on digital signal processing algorithms and responsive piezo technology with the latest ultra-reliability enhancements, patented[i] STACIS active isolators have proven their dependability in mission-critical fab deployment for over a decade. This technology is now also available in small form-factors ideal for emerging applications ranging from advanced microscopies to nanomanufacturing.

Vibration and Throughput: The Yield-Killers

The semiconductor industry is ruled by two unbreakable laws. Moore's Law, Equation 1, describes the exponentiating density of integrated circuit elements with time.

$$\frac{LogicElements}{cm^2} \propto 2^{\left(\frac{Year}{1.5}\right)}$$

Equation 1. Moore's Law observes a doubling of device density every 18 months.

Meanwhile, Equation 2, defines a term describing nanoscale processing in the face of the fundamental economic constraint of "time is money."

$$NanoAutomation^{®} \equiv \lim_{t \to \$} \left(\frac{\partial (nm)}{\partial t} \right)$$

Equation 2. The economic imperative of "time is money" necessitates more devices per cm^2, larger area processing and faster cycle times.

Together, these describe a challenge for process engineers and researchers alike: the tractability of nanoscale processes worsens with relentlessly diminishing scale, yet the process must be economical. This pushes substrate sizes up and cycle times down, both of which are at cross purposes to the exponentiating resolutions required.

Clearly, yesterday's vibration isolation techniques are inadequate for tomorrow's (or even today's) nanoscale processes. Ambient ground motion can obliterate ever-finer pattern details (Figure 1), and conventional soft isolators do not isolate vibrations below 2Hz and do a poor job of responding to on-board vibration driven by rapid processing (Figure 2). By comparison, STACIS provides aggressive attenuation starting at sub-Hz levels and is more than 100 times stiffer, directly benefiting settling.

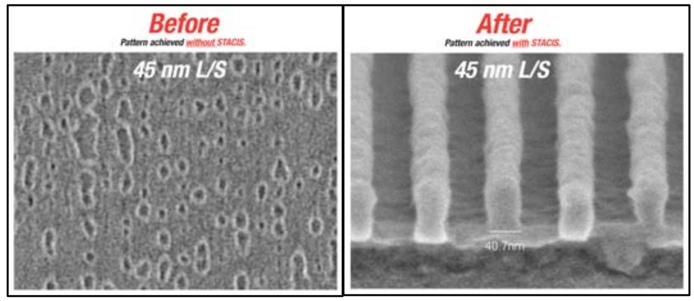

Figure 1. 45nm line-width test patterns produced with an advanced Immersion Lithography System at SEMATECH in Austin, TX.[ii] (Left): Pattern is obliterated by floor vibration. (Right): STACIS isolation enables crisp, accurate photolithography. (Images obtained via SEM.)

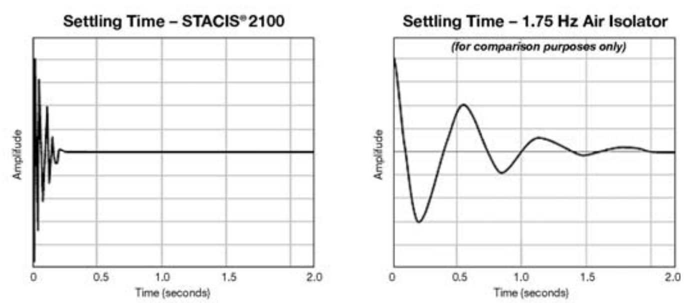

Figure 2. (Right): Settling time in response to on-board disturbance such as substrate loading is greatly improved by STACIS' novel "serial" design, helping cycle rates meet exponentiating throughput demands

The advancing needs of nanoscale processes are reflected in recent low-threshold Generic Vibration Curves (Figure 3)—a serious challenge to site engineers.

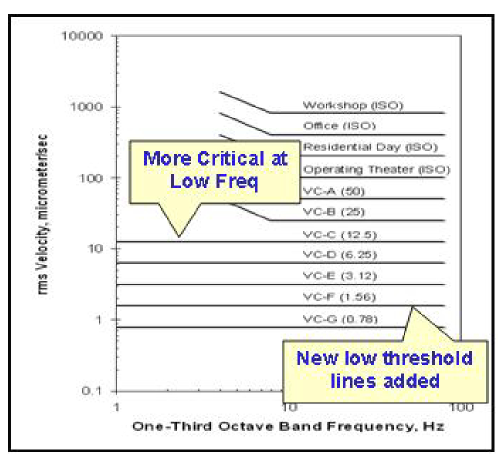

Figure 3. New, more stringent Generic Vibration Curves. Courtesy IEST RP-012, Inst. of Environmental Sciences, Rolling Meadows, IL

The STACIS Advantage

STACIS active isolators sense the onset of vibration in six degrees of freedom and actively nullify it via canceling actuation of stiff, piezoelectric actuators acting vertically and horizontally. A real-time digital signal processor performs the necessary calculations rapidly, providing high bandwidth cancellation (0.6-250Hz) and virtually eliminating latencies to minimize settling times and greatly reduce or eliminate the impact of low frequency vibration.

With their inherent stiffness, high load capacity and clean, airless operation, these isolators are popular for both OEM incorporation into leading-edge tools and for deployment beneath isolation platforms for sensitive equipment like optical and e-beam metrology and photolithography tools. And in addition to filling an essential need in the latest fabs, STACIS isolators enable older and noisier fabs to accommodate state-of-the-art tools while providing flexibility of tool placement and floor layout (Figure 4). Tools that already incorporate internal isolation of some sort benefit from STACIS as well, as its unique hard-mount properties make it compatible with the tool's existing on-board isolation techniques.

Additionally, smaller form-factor STACIS isolators are now available for use with smaller instrumentation such as SEMs and advanced microscopes outside the semiconductor fab (Figure 5).

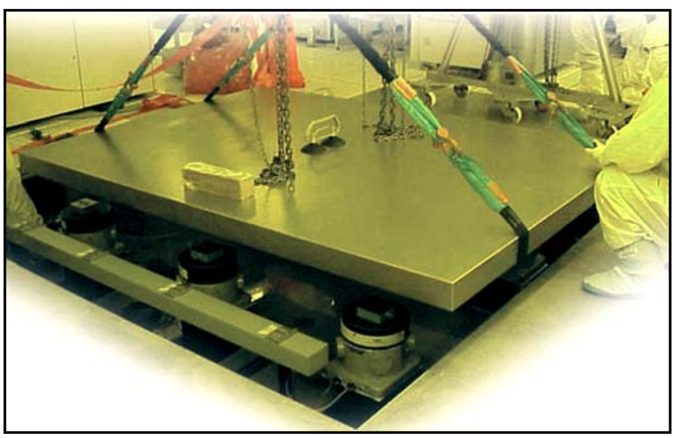

Figure 4. STACIS actuators supporting a photolithography scanner's isolation platform.

The Reliable Heart of STACIS: PI's Piezo Actuators

Piezo actuators are layered structures of specialized PZT ceramic interleaved with electrodes. An applied voltage causes a bulk change in the ceramic's length, allowing the actuators to be used for fast, high-force real-time position control in the nanoscale realm. The solid-state nature of PZT material sets them apart from classical actuators. They require no maintenance or lubricants, and if designed and operated properly, they provide basically unlimited lifetime because there are no parts to wear. This and the fact that they solely run on electricity (with zero power required for position hold) greatly reduces operating and facilities costs and addresses thermal drift processes. Their essentially unlimited resolution and high responsiveness and force have made them essential to many classes of instrumentation and production equipment, and recent innovations have broken through traditional travel limitations, providing millimeter travels with sub-nanometer resolution (Figure 9).

Figure 5. STACIS active isolation is newly available in smaller form-factors for instrumentation such as SEMs.

In principle and electrical characteristics, piezo actuators resemble ceramic capacitors, and like ceramic capacitors they can be reliable and long-lived. In creating STACIS, TMC partnered with PI to incorporate PI piezo actuators which feature unique technologies to extend actuator life significantly beyond traditional benchmarks.

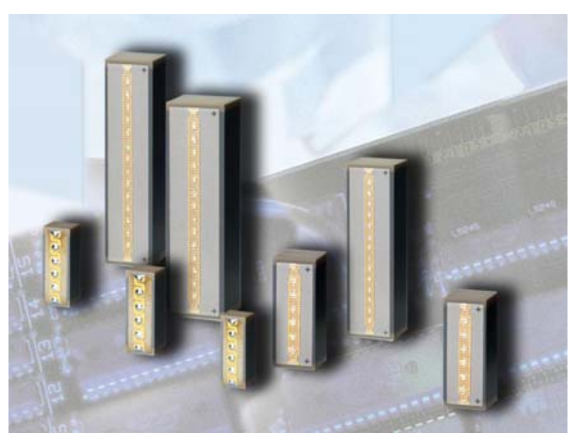

Figure 6. PICMA® actuators feature patented all-ceramic encapsulation to significantly increase lifetime in challenging conditions.

In recent years, PI has invested in its own ceramics factory, PI Ceramic, specifically to drive piezo quality and reliability technologies, since third-party ceramics had been the number-one cause of product failure. Now one of the world's largest manufacturing facilities for ultraprecision instrumentation-grade piezo ceramics, PI Ceramic has introduced many significant and award-winning[iii] reliability innovations. For example, piezo ceramics have been vulnerable to the ingress of water molecules along the layers from ambient humidity. This can limit the lifetime of conventional piezo actuators. Until recently, unsatisfactory attempts to encapsulate the layered ceramics using polymer paint were the best technologies available. With PI's patented PICMA® actuators (Figure 6)[iv], *all-ceramic* encapsulation provided a significant leap forward, improving MTBF in humid conditions by approximately three orders of magnitude (Figure 7)[v].

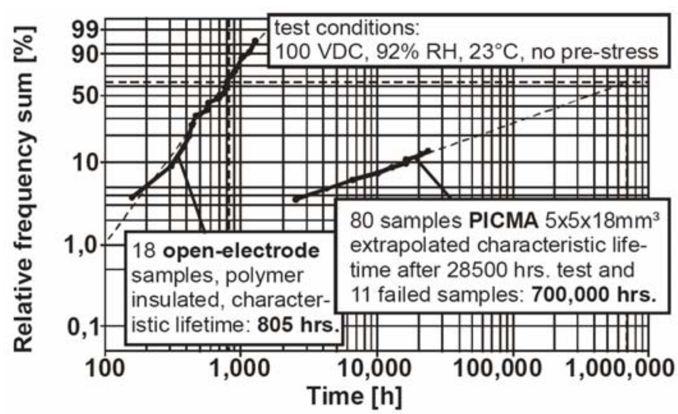

Figure 7. PICMA®'s patented construction improves MTBF by approximately three orders of magnitude in humid conditions, versus conventional polymer-encapsulated construction.

Piezo lifetime can also be measured in cycles. Figure 8 shows a typical performance-consistency result in open-loop actuation of a PICMA® actuator before and after more than a billion cycles. A PICMA® actuator being tested for a space application is viewable online and has amassed 3.22×10^{12} cycles[vi].

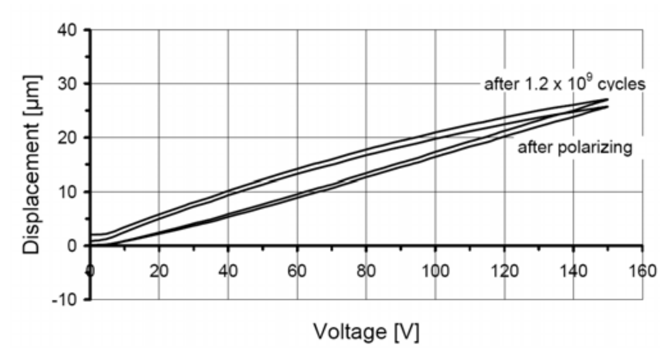

Figure 8. Open-loop piezo actuator motion characteristics remain highly consistent after more than a billion cycles.

Having its own ceramics development and fabrication capabilities has resulted in other benefits besides improved reliability and consistency versus third-party piezo offerings. Importantly, the ability to partner with companies with demanding needs, like TMC, is greatly facilitated by PI's ability to innovate in piezo ceramics. The ability to develop entirely new concepts in piezo ceramic actuation is also of significant import, with novel developments like PI's patented all-ceramic NEXACT® actuators (Figure 9), which provide 20 millimeters of travel with a high, 10N push-pull force, power-off position hold capability and resolution to 0.03nm – ideal for sensitive alignment applications such as nanoimprint lithography.

Figure 9. NEXACT® is an example of piezoceramic innovation, providing 20mm travel with 0.03nm resolution and 10N force.

Conclusion

Two innovative industry leaders teamed up to solve not only challenging present day problems but to pave the way for the next generations of some of the world's most important industrial processes. With STACIS, tool and facilities engineers concerned with vibration isolation in the face of Moore's Law's unceasing demands can take a rest. And STACIS' new, smaller form factors will prove to be enablers for a diverse array of new fields ranging from optical tweezers to nanomaterial studies.

References

[i] U.S. Patent Nos.5660255 and 5823307 (STACIS)
[ii] Impact of Vibration on Advanced Immersion Lithography, TMC application note, http://www.techmfg.com/appnotes/SematechAppnote.htm
[iii] PI Actuator Wins Circle Of Excellence Award, Photonics Spectra, January, 2005, http://www.photonics.com/Content/ReadArticle.aspx?ArticleID=18114
[iv] U.S. Patent 7,449,077
[v] P. Pertsch, S. Richter et al, Reliability of Piezoelectric Multilayer Actuators, Actuator 2006, Bremen, AXON, 2006 pp. 527-529
[vi] PICMA® endurance testing online: http://stm8.artov.isc.cnr.it/BepiColombo/