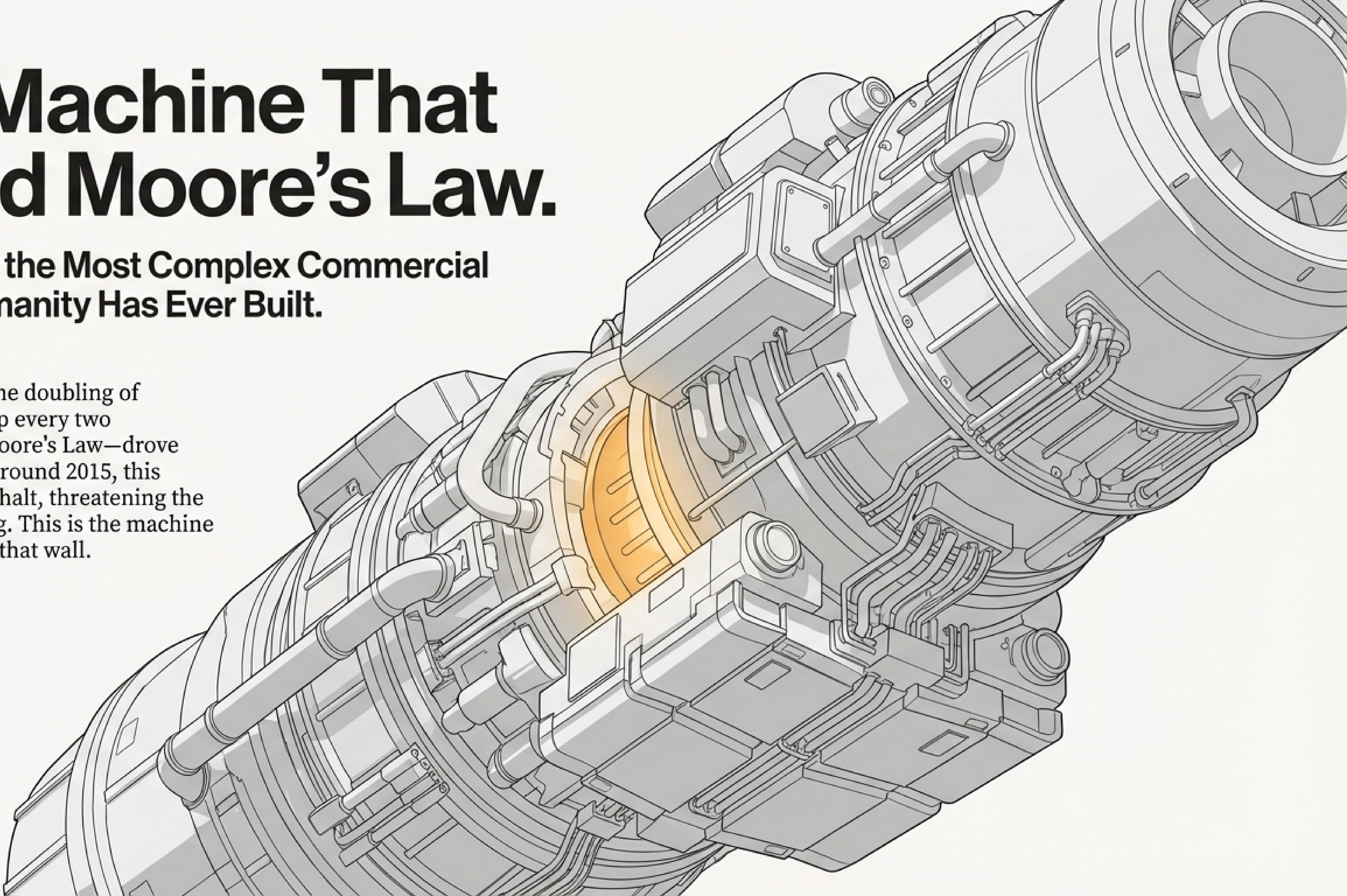
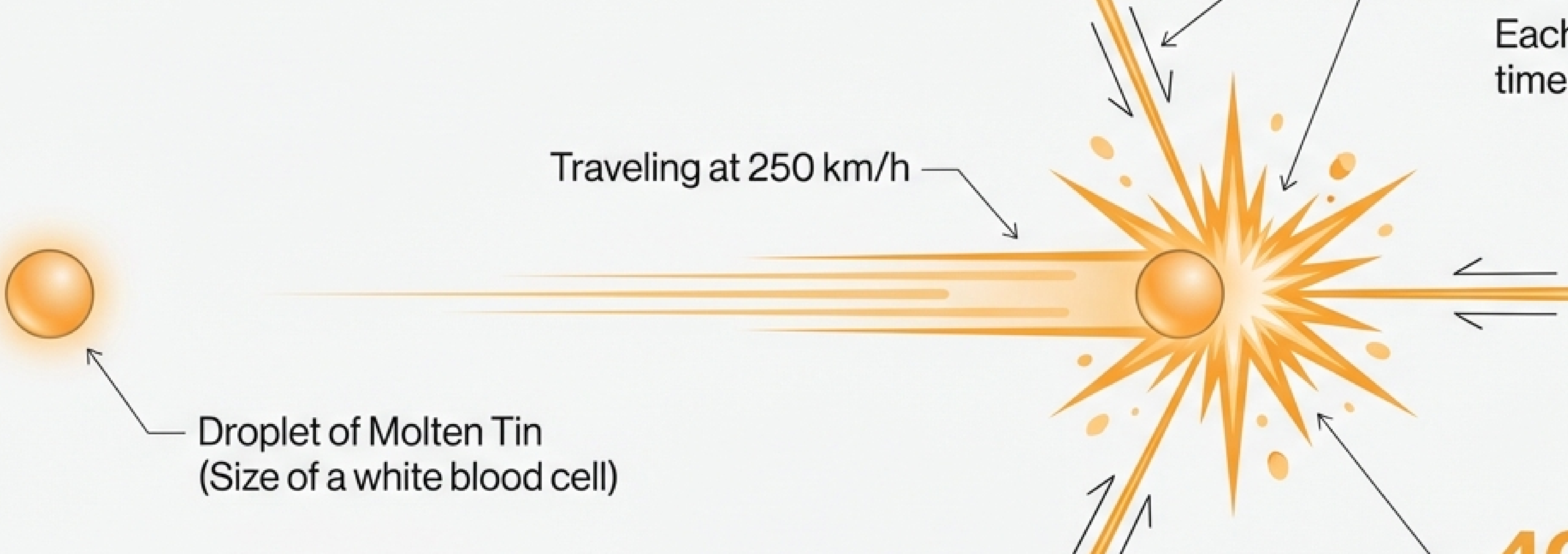
The Machine That Saved Moore's Law.

The Story of the Most Complex Commercial Product Humanity Has Ever Built.

For over 50 years, the doubling of transistors on a chip every two years—known as Moore's Law—drove the tech industry. Around 2015, this progress came to a halt, threatening the future of computing. This is the machine that broke through that wall.



Engineering on an Unimaginable Scale.



50,000

Droplets Every Second.

Each is hit by a laser three times in just 20 microseconds.

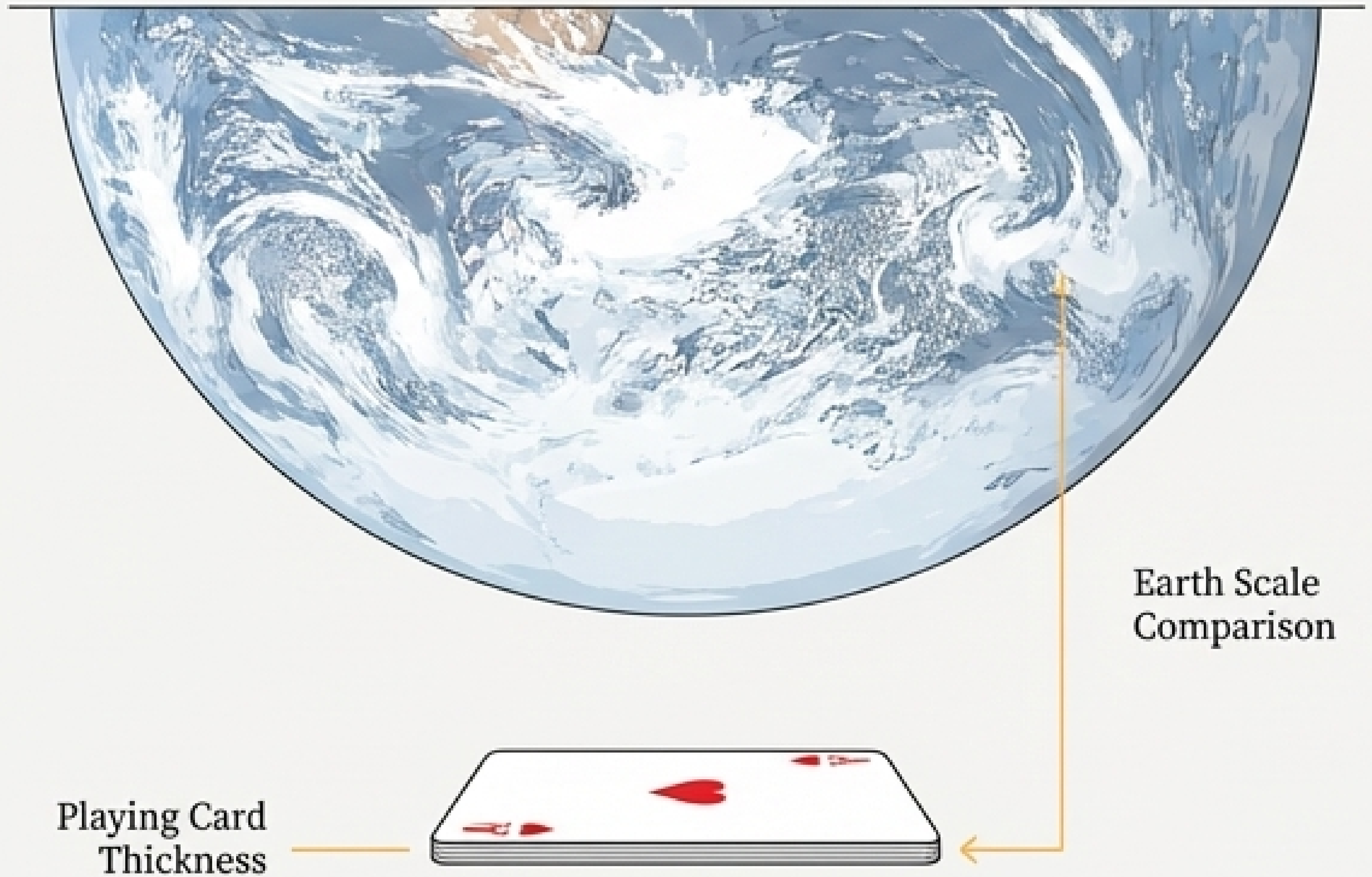
40x Hotter Than the Sun

Each hit heats the tin to over 220,000 Kelvin, creating a plasma that emits EUV light.

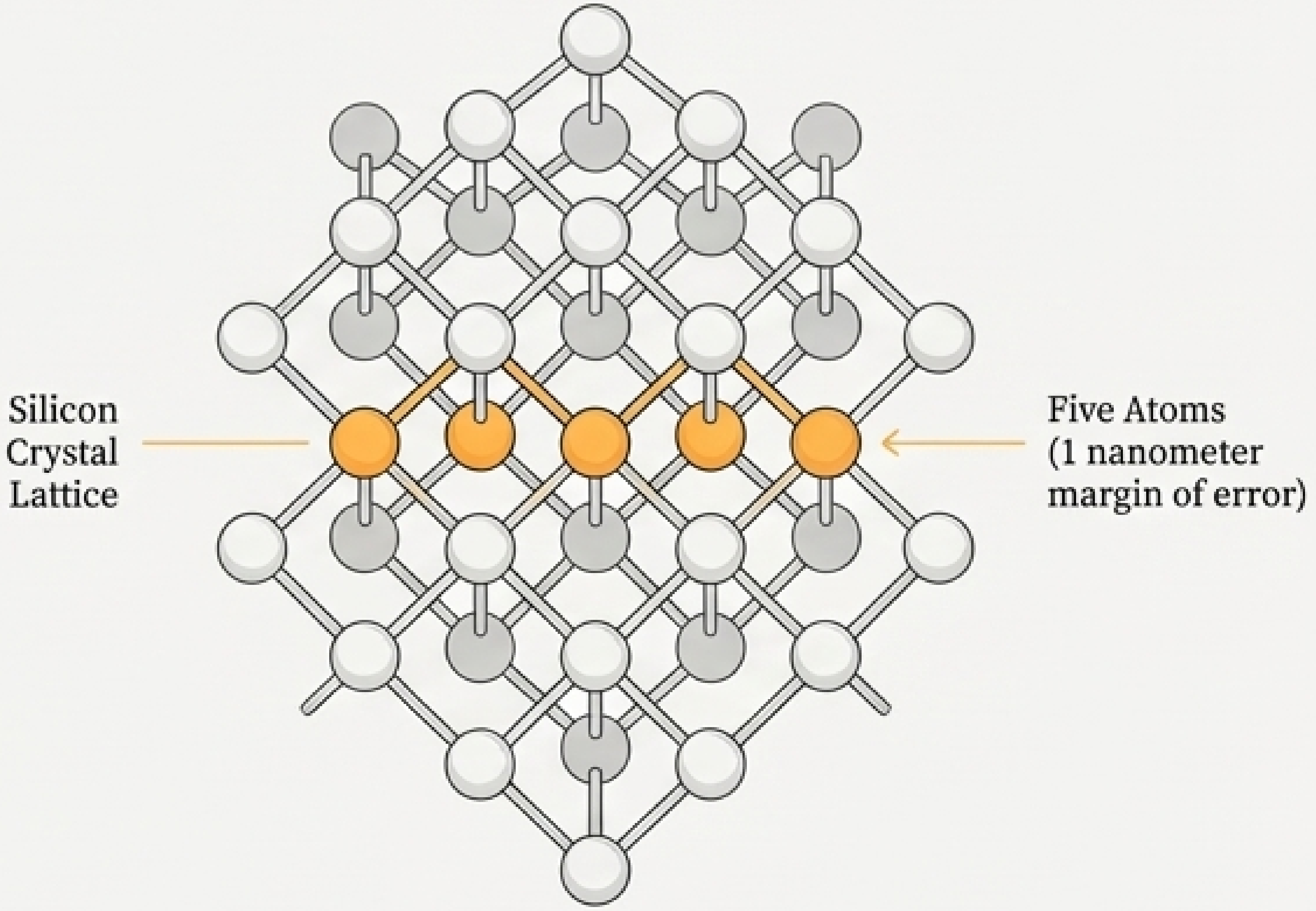
> "How often do you miss a laser shot? We don't miss them."
>
> – ASML engineer

A Universe of Precision.

The machine's mirrors are the smoothest objects ever created. If you scaled one to the size of the Earth, the largest bump would be no thicker than a playing card.



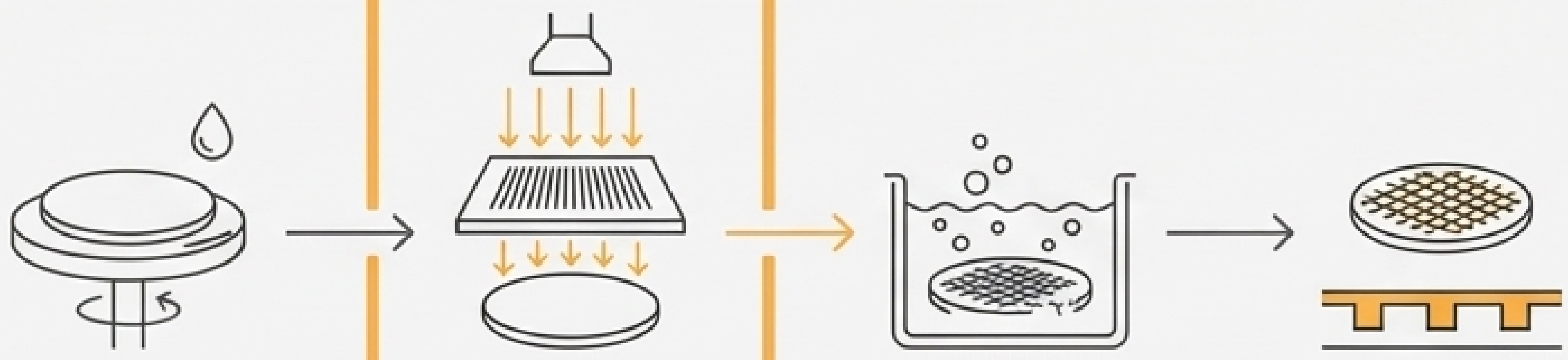
It overlays one chip layer onto another with an accuracy of one nanometer. That is a margin of error of just five atoms.



All while parts accelerate at over 20 Gs—five times the acceleration of a Formula 1 car.

The Wall at the End of Moore's Law

The Process: Photolithography



Coat
A silicon wafer is coated with a light-sensitive material (photoresist).

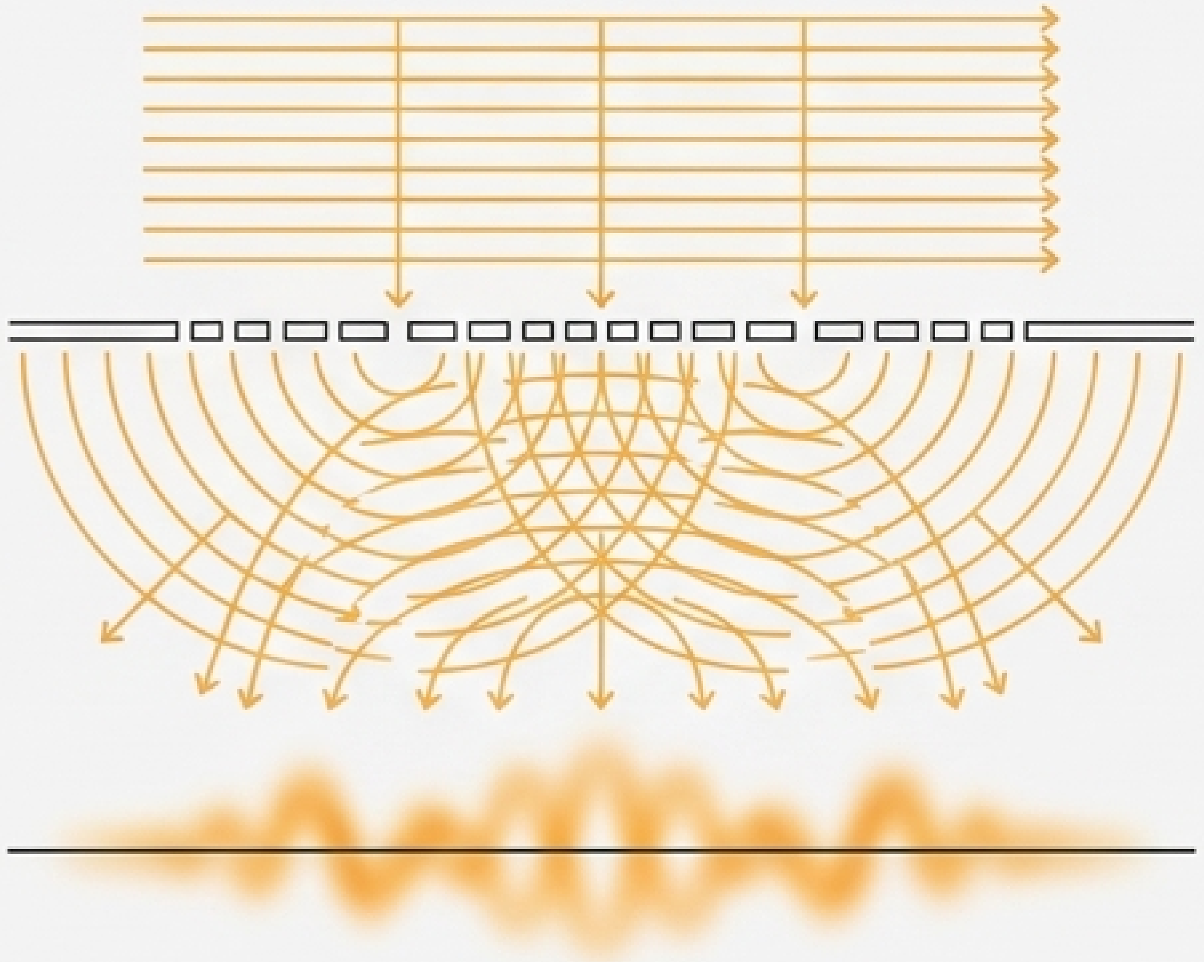
Expose
Light is shone through a patterned mask, weakening the exposed photoresist.

Etch
The weakened pattern is etched into the silicon.

Deposit
A metal like copper is deposited into the etched lines.

The Problem: Diffraction

Shrinking transistors requires printing smaller features. As the features on the mask approach the wavelength of the light used, physics gets in the way.



The Tyranny of Wavelength

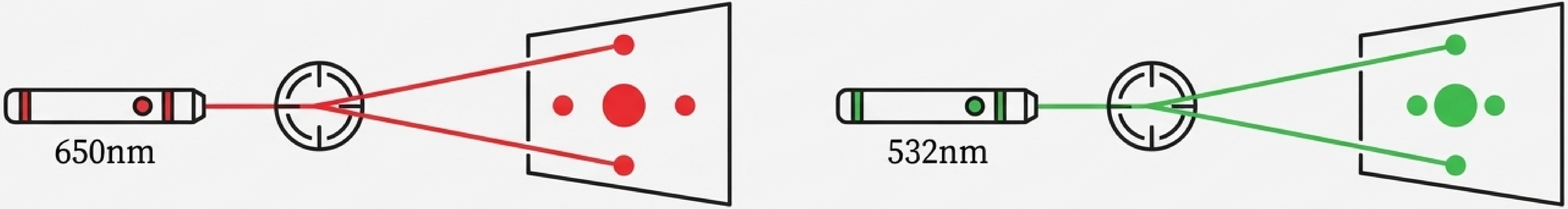
Critical Dimension
(the smallest feature you can print)

λ (Wavelength)
The key variable. Shorter wavelength = smaller features.

$$CD = k_1 * \frac{\lambda}{NA}$$

Rayleigh Equation
A process-related factor.

NA (Numerical Aperture)
The light-gathering ability of the lens system. Has a hard physical limit.



To keep shrinking features, the industry had to use shorter and shorter wavelengths. By the late 1990s, they were stuck at 193nm Deep UV (DUV) light, and Moore’s Law was about to hit a brick wall.

A Radical Idea, Laughed Off Stage

1980s | Japan

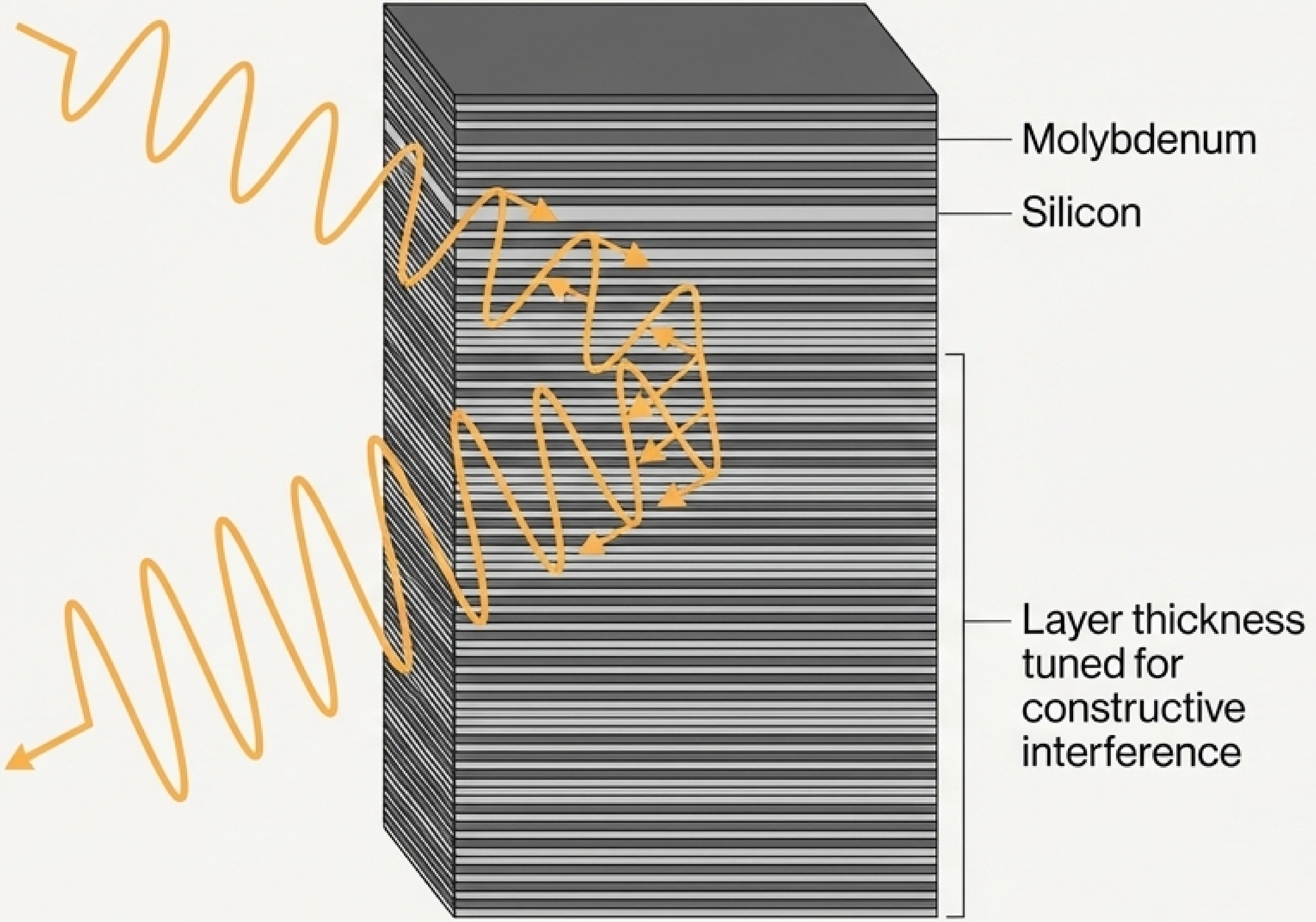
Hiroo Kinoshita proposes using ~10nm X-rays. The problems were immense: lenses and even air absorb this light, requiring a vacuum and special mirrors. After presenting his first successful image in 1986, the audience regarded it as a “big fish story.”

1987 | USA

Andrew Hawryluk at Lawrence Livermore National Lab independently proposes using X-ray mirror technology for lithography.

> “I was literally laughed off the stage… they came up to the microphone and told me basically why it wouldn’t work, how stupid an idea it was.”

Bending Light Without a Lens



Normal mirrors don't work. EUV light is absorbed.

The solution: Dozens of alternating layers of materials like Molybdenum and Silicon, each less than a nanometer thick.

Each layer reflects a tiny fraction of the light (<1%). By precisely controlling the thickness, all these tiny reflections add up through constructive interference.

The catch: Even with this breakthrough, maximum theoretical reflectivity is only ~70%. After bouncing off multiple mirrors, you are left with just a few percent of the original light.

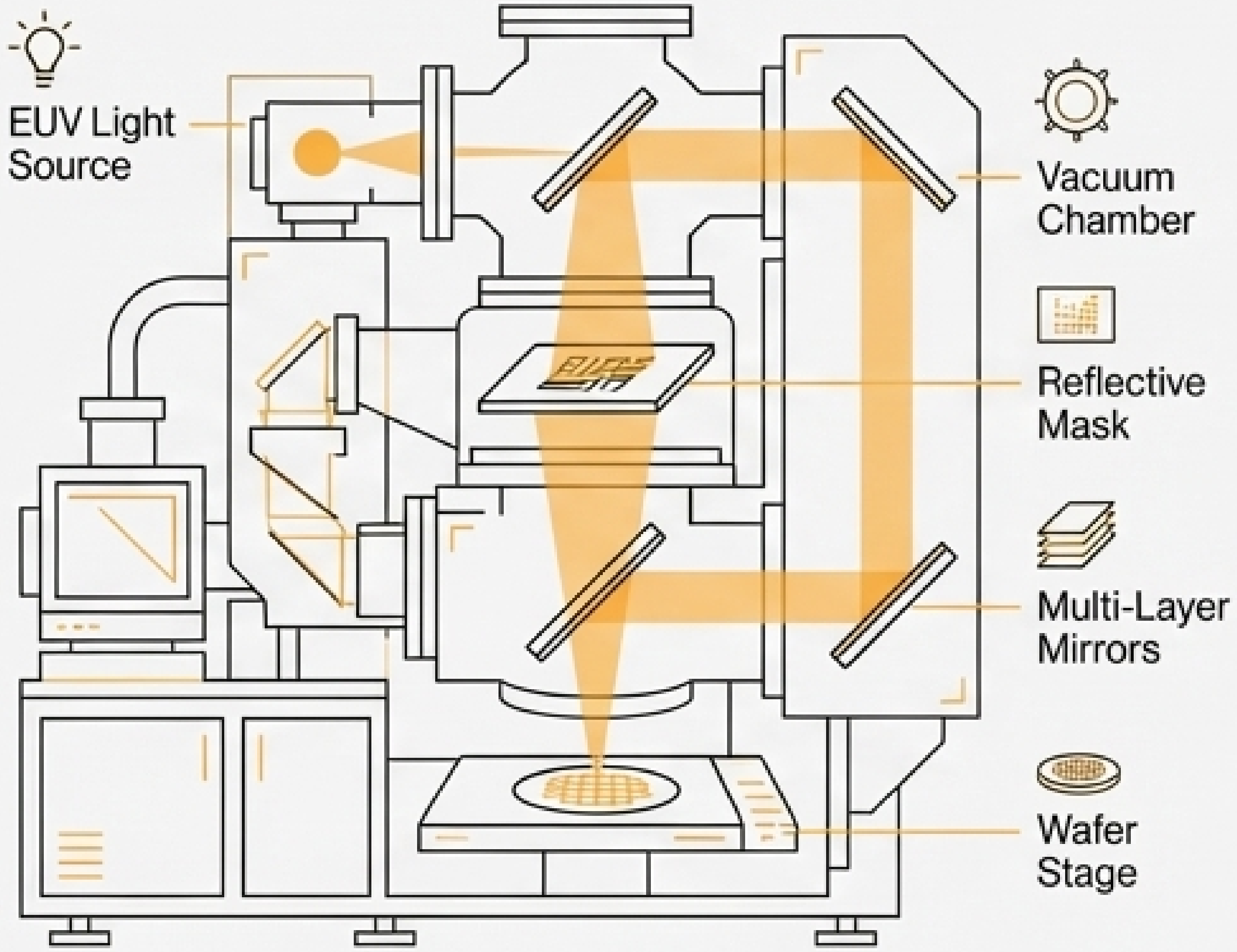
The First Glimmer of Hope: The ETS

By the late 1990s, US government funding was cut. Fearing the end of Moore's Law, chipmakers like Intel, AMD, and Motorola invested $250 million to continue the research.

The Achievement

By 2000, the consortium produced the first fully functioning EUV prototype.

It proved EUV could print 70nm features.



The Flaw

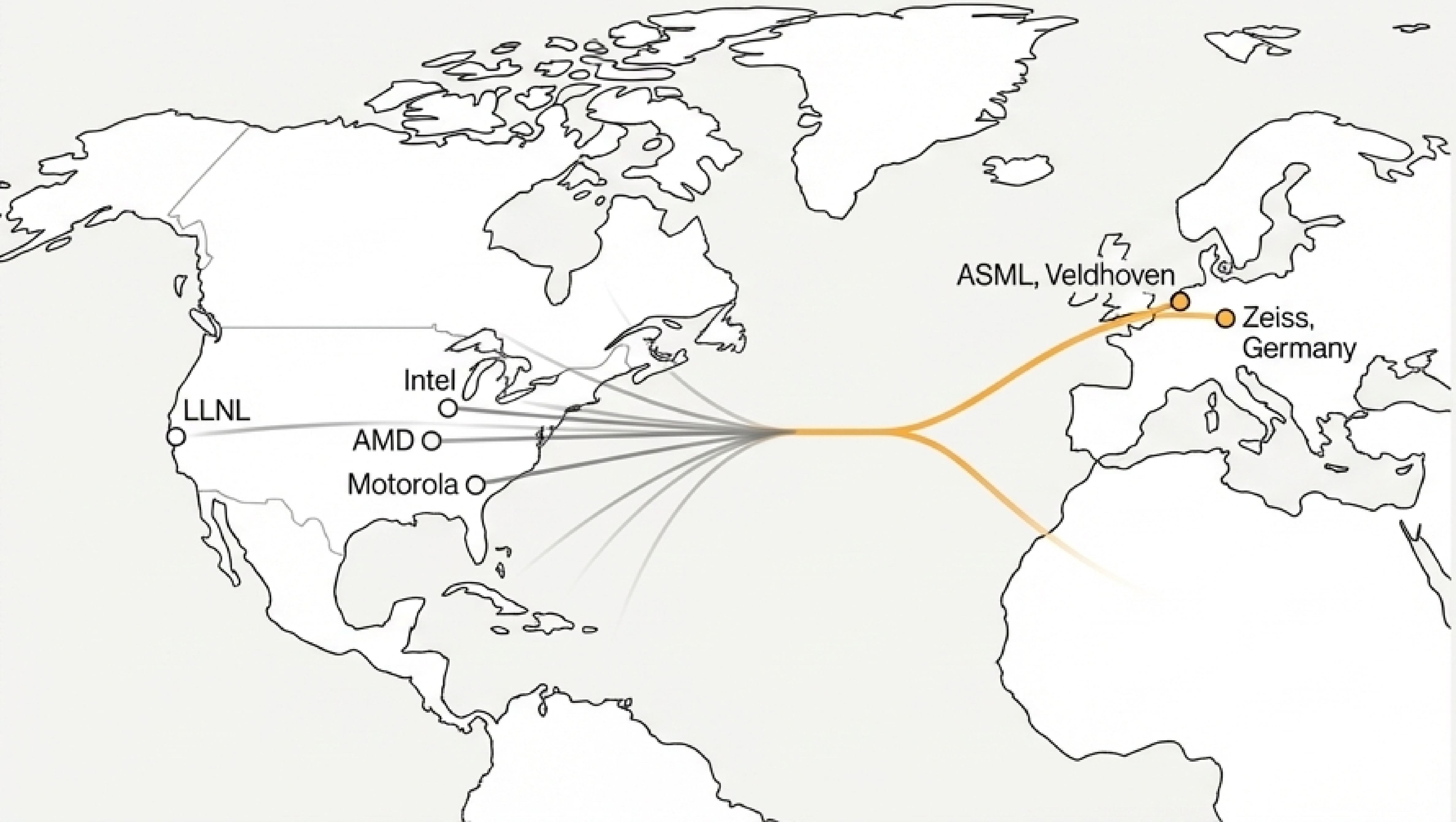
It was far too slow, printing only 10 wafers per hour. A commercial machine needs to print hundreds.

Reason: With 8 mirrors and a reflective mask, only 4% of the initial light reached the wafer. They needed a source at least 10x more powerful.

› While EUV technology itself is a done deal, there were six zillion engineering challenges to make it a fab-line reality.

One Company Left Standing

Faced with “six zillion engineering challenges,” American companies walked away one by one. The problem seemed too big, the path to profitability too uncertain.



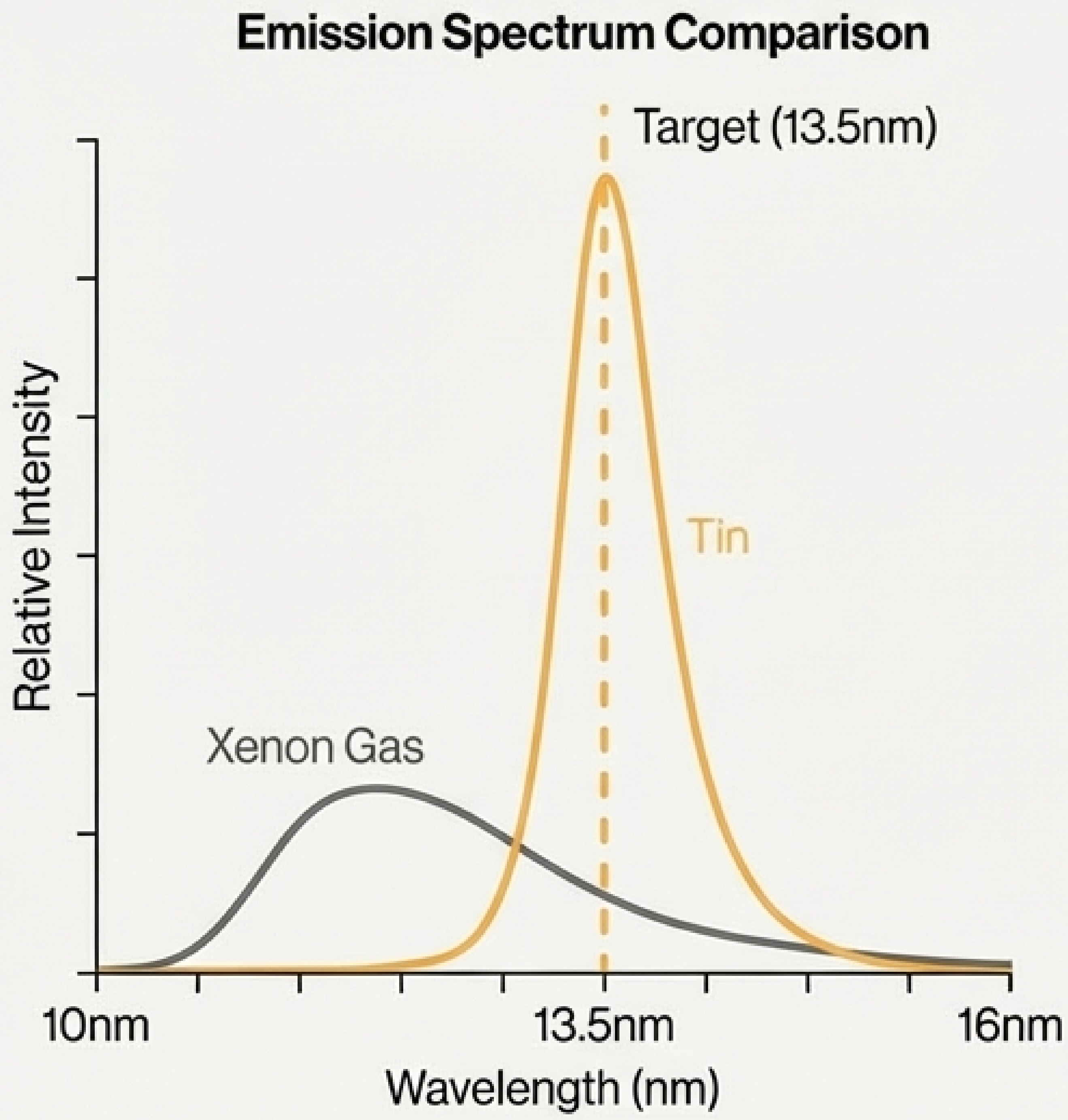
The Contender: ASML

- A single company from a small town in the Netherlands takes on the challenge.
- Spun off from Philips in the 1980s with little more than a shed.
- Partnered with German optics specialist Zeiss to handle the mirrors, while ASML focused on the light source.
- Led by champions like Martin van den Brink, who saw EUV as the only way forward.

Building an Artificial Sun on Earth.

How do you generate EUV light at the exact 13.5nm wavelength wavelength that the Silicon/Molybdenum mirrors reflect best?

The method:
Laser-Produced Plasma.



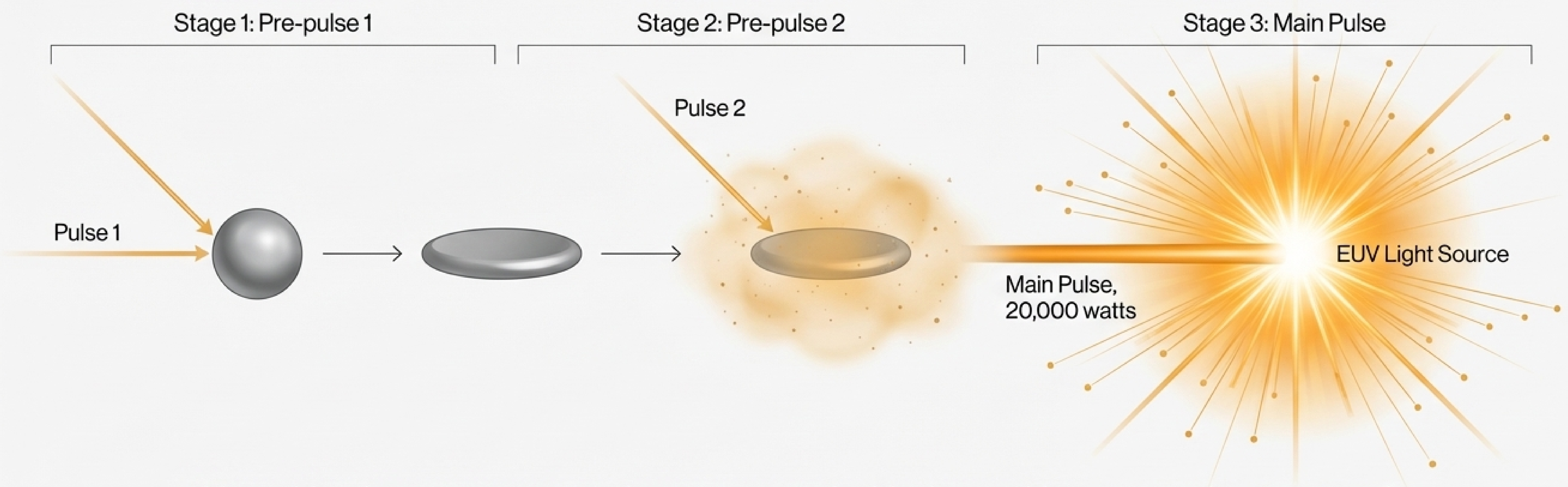
The Target Material

- **Option 1: Xenon Gas**
  Used by the ETS. Very low conversion efficiency (~0.5%). Most energy was wasted creating light at the wrong wavelength, and leftover gas absorbed the useful light.
- **Option 2: Tin**
  Problem: As a solid, it creates massive debris that coats the priceless mirrors. But, its emission peak is perfectly aligned with 13.5nm, making it 5-10 times more efficient.

The "Crazy Idea": Don't use a solid block of tin. Shoot one tiny, 20-micron droplet at a time.

From Droplet to Pancake to Supernova.

A single laser blast on a dense tin droplet was inefficient. Most of the generated EUV light was reabsorbed by the tin itself before it could escape.

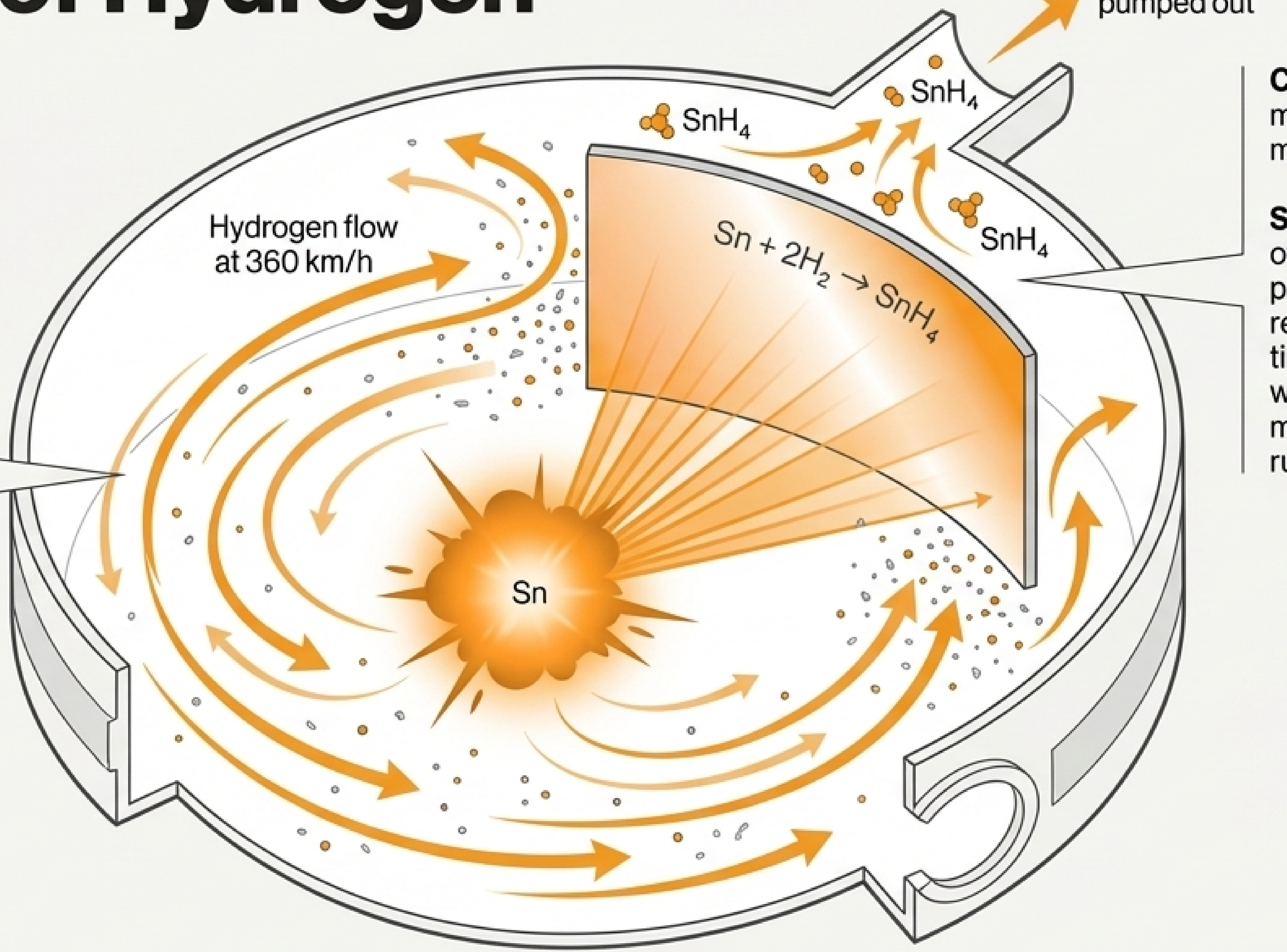


This multi-pulse process creates tiny supernovas inside the machine, 50,000 times a second.

Taming the Sun with a Hurricane of Hydrogen

Challenge: The hydrogen gets heated by the plasma and isn't a perfect cleaning solution.

Solution: Flush the chamber with cool hydrogen faster than a Category 5 hurricane. The final trick: adding a minuscule, precisely controlled amount of oxygen to the system, which kept the collector clean for much longer and made the machine commercially viable.



Challenge: Protect the multi-million dollar collector mirror from tin debris.

Solution: A high-speed flow of hydrogen gas slows tin particles and chemically reacts with any deposited tin to form stannane gas, which is pumped out. The machine cleans itself as it runs.

The High-NA Era: A €350 Million Marvel.

Cost: North of **€350 million**

Logistics: Shipped in 250 containers across 7 Boeing 747s

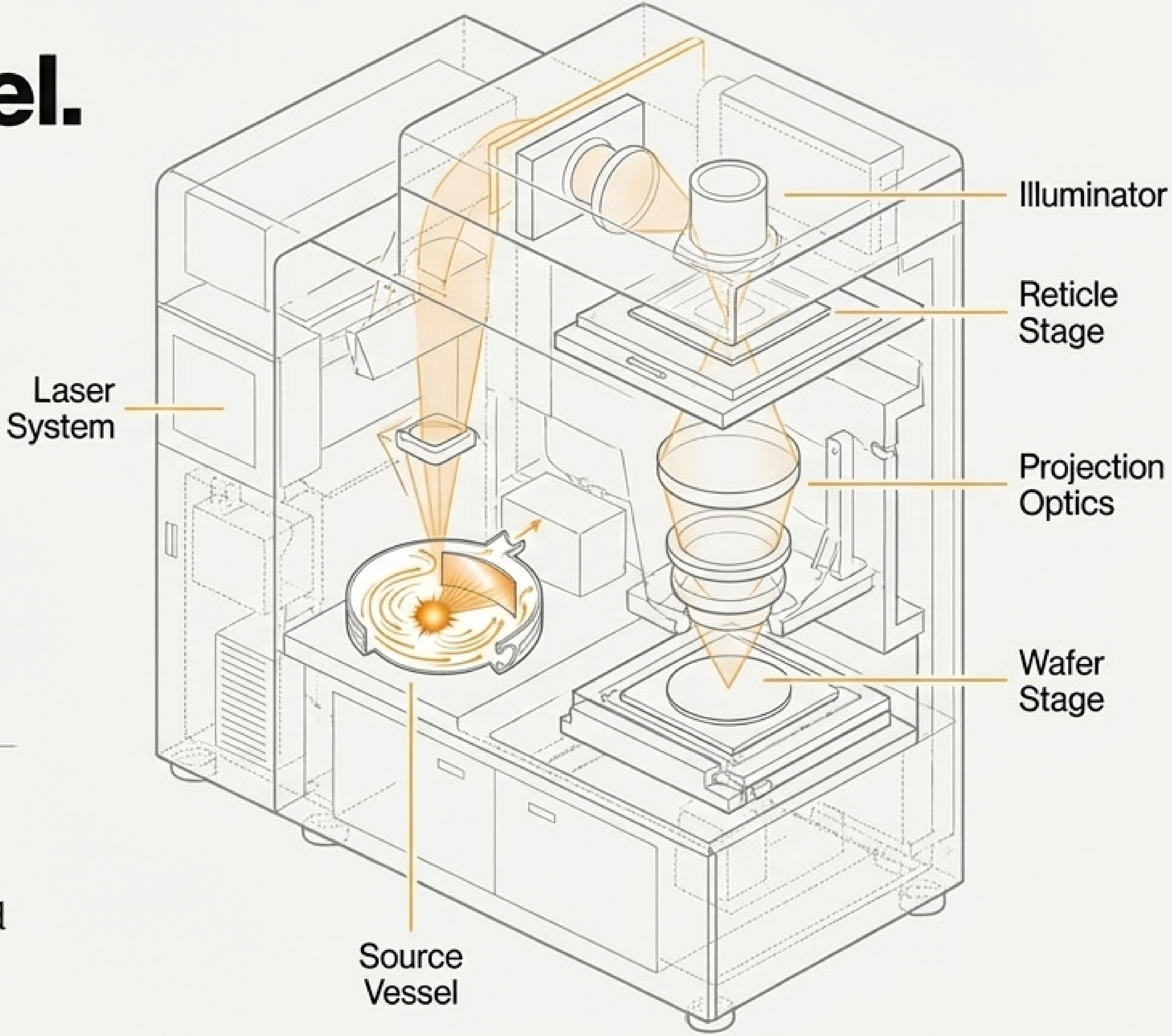
Performance: Prints features down to 8 nanometers

Throughput: Produces ~185 wafers per hour

The Precision Budget

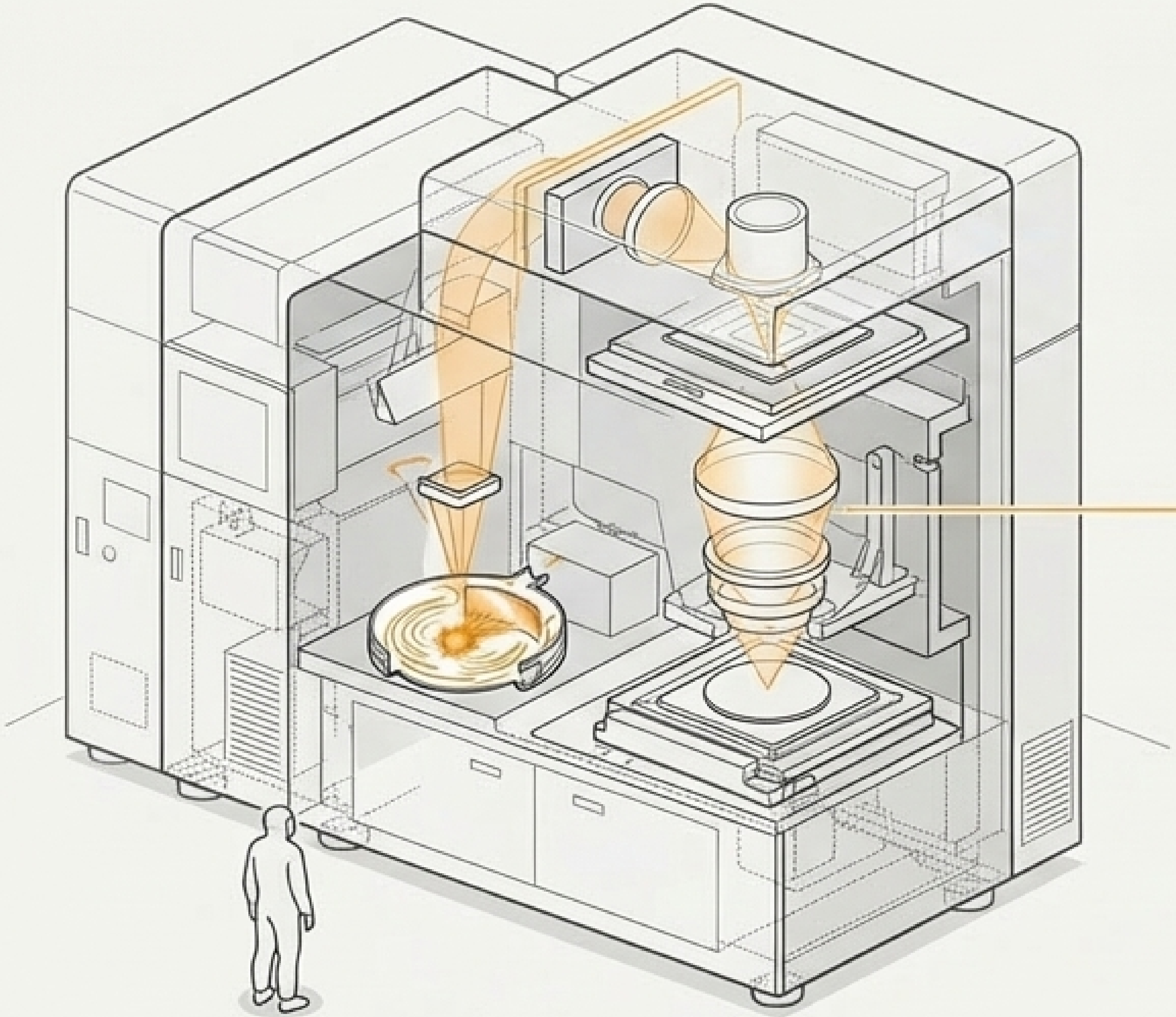
The total budget for overlay error (misalignment between layers) is **one nanometer**. This single nanometer is divided into even smaller fractions for each engineering team.

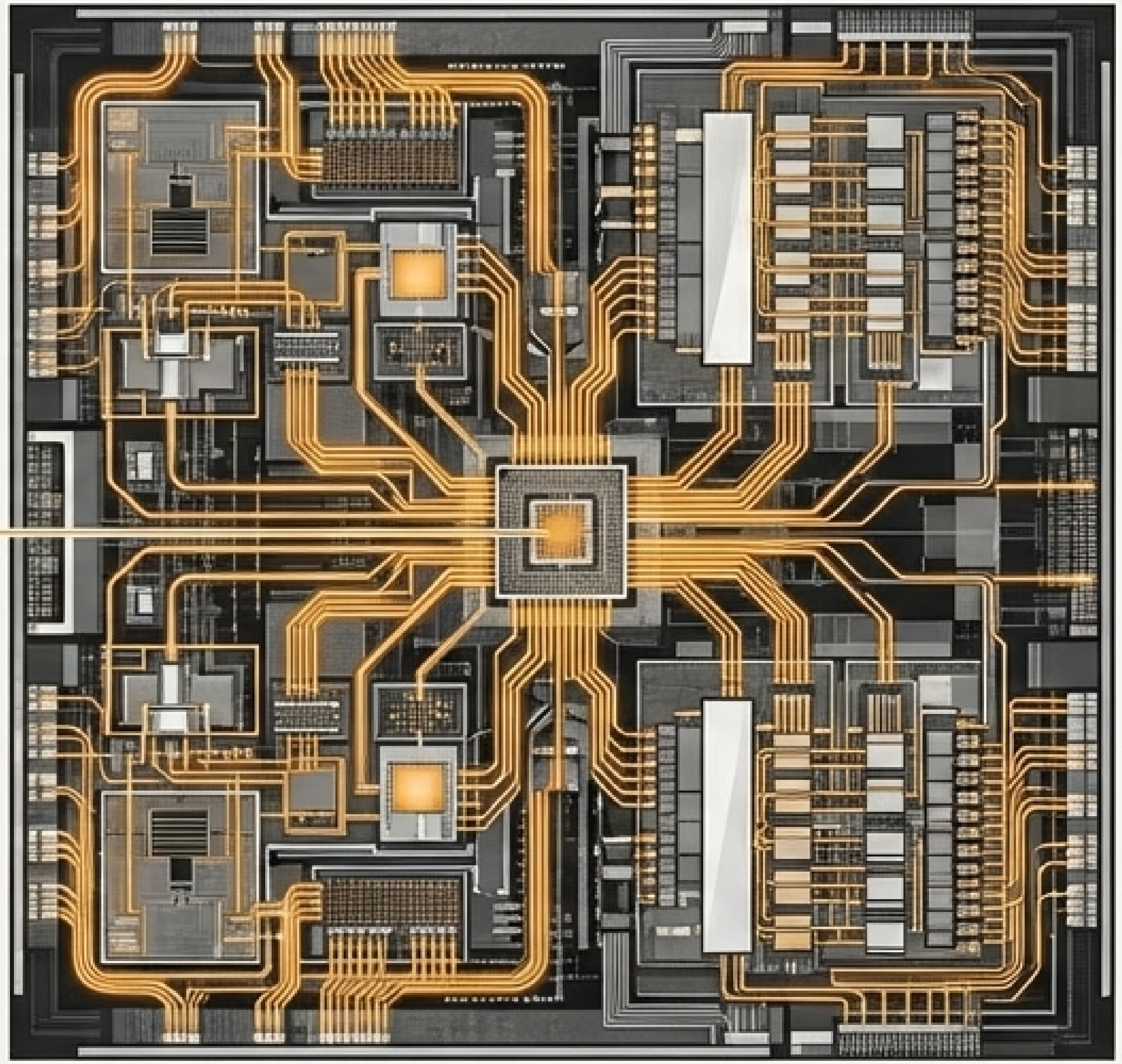
"You have to fight for your part of the nanometer."



The Smaller You Go, The Larger It Gets.

It's a fundamental irony of modern engineering: to make the tiniest things at scale, you need the largest, most complex machines. Every advanced chip in your smartphone, your computer, and the data centers that power the internet is made using EUV lithography. This machine is the single chokepoint and enabler for the entire digital world. That power the internet is made using EUV lithography.





“The reasonable man adapts himself to the world; the unreasonable one persists in trying to adapt adapt the world to himself. Therefore, all progress depends on the unreasonable man.”

– George Bernard Shaw

For three decades, the reasonable path was to declare EUV impossible. Progress depended on the unreasonable persistence of people who refused to believe it.