The Internet reports that Tsinghua has broken through the lithography technology chokehold. Calm down!

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Author: Wang Jie, a popular science writer
Source: 知识分子 (*The Intellectual*)
Date: 9/19/2023
Original Mandarin: https://mp.weixin.qq.com/s/Rk1PHji7k6yVvkPHvHvnrw

In the past week, science and technology news has buzzed over Tsinghua University's development of a new principle of producing extremely deep ultraviolet light sources, which can break through the technical problems of the lithography machine. Many people even say that China has already started constructing a lithography factory in Xiongan. There are even pictures showing this (supposed) truth, with everything described in vivid detail.

Many people ask me if it is true. Let me tell you the answer up front: the new light source generation principle is true, but it was proposed as early as 2010. It is still in the principle verification stage and is 15 to 20 years from being truly practical. The Tsinghua University paper that is being hyped this time was actually published in early 2021. I don’t know why it was suddenly dug up and hyped two and a half years later. As for the lithography factory to be built in Xiongan, it is just a rumor and a lie.

Today I just want to use this topic to talk to you about why it is so difficult to build a lithography machine. Is it possible for China to develop the most advanced lithography machines completely independently?

Lithography machines are key equipment used to produce chips. Every computer we use and the chips in every smartphone are produced using lithography machines.

To measure the technological advancement of a chip, the unit of xx nanometers (nm) is used. A nanometer is a unit of length, and 1 nanometer is equal to one billionth of a meter. But wait, didn't Huawei release its latest mobile phone, the Mate 60 pro, two weeks ago? As soon as this mobile phone came out, everyone exclaimed, wow, the chip used in this mobile phone was made with the 7nm process – this is incredible. Let me explain what the 7nm process means. Simply put, the electronic components on the chip, that is, the transistors, are carved out, just like we are carving out characters onto a rubber stamp. On this same area, the more transistors that can be carved out, the more advanced the chip will be. In the field of chips, nm (nanometer) is used to express the advanced level of the chip. The smaller the number, the more advanced the chip is. 10nm is more advanced than 14nm, and 7nm is more advanced than 10nm. Don’t worry about why there are numbers like 5, 7, 10, and 14. There are complex historical reasons behind them.

Chips are carved on silicon wafers using lasers, so the smaller the transistor is to be carved, the shorter the wavelength of the laser is required. The light source used by the most advanced lithography machines in the world is called 极深紫外光 (extreme ultraviolet lithography), referred to as EUV in English, with a wavelength of 13.5 nanometers. It was developed by an American company, but this American company is now acquired by ASML of the Netherlands. However, there is a concept to be clarified here. It does not mean that the 13.5-nanometer wavelength laser can only engrave 13.5-nanometer chips. It can actually engrave 7-nanometer, 5-nanometer, or even smaller process chips.

The light source used by lithography machines that is a little less capable than EUV is deep ultraviolet light, or DUV for short in English. The wavelength is 193 nanometers, which is an order of magnitude larger than EUV. The 7nm process Kirin 9000s chip used in Huawei's latest mobile phone is carved using DUV. Yes, at a wavelength of 193 nanometers, a 7nm chip can be carved using a technology called multiple exposure. But even this kind of 193-nanometer lithography machine is still not available in our country. The only companies in the world that can produce DUV are Japan's Canon and Nikon, and the Netherlands' ASML. Yes, you heard it right, the U.S. can't do it either.

By the way, here is what multiple exposure technology [重曝光技术] is. Let me use the simplest analogy to try to explain. For example, now you have a machine that draws square grids, but the side length of the square grid it can draw is 100 mm. Is there any way you can use this machine to draw square grids? What about square grids smaller than 100 mm? It is possible. The method is that I first draw many connected grids on the paper to form a grid. Then I moved the machine slightly and drew the grids again on the paper. This will produce a new grid. The two grids overlap and the lines will intersect to form a smaller grid. You can try it yourself with a pen on paper.

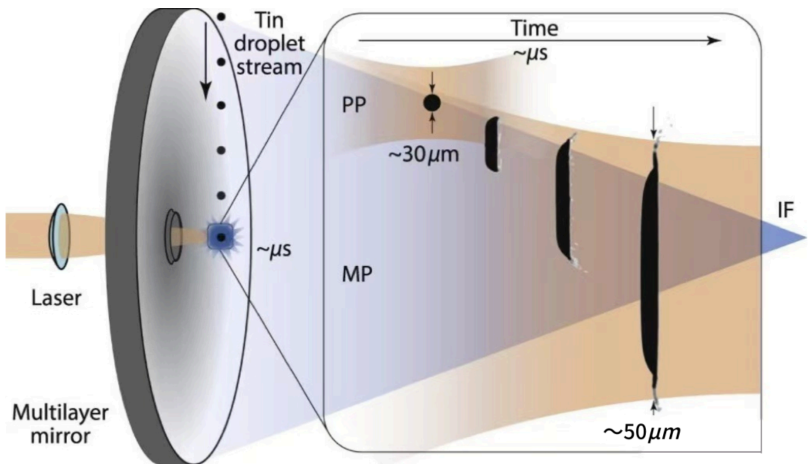
Each time a lithography machine engraves a chip, the process is one exposure. The same goes for using DUV to produce 7nm process chips. Since you aren't able to make these chips with just one iteration, just expose it several times. After each exposure, move a small step before exposing again. This allows for carving out smaller transistors. Of course, this is not without side effects, that is, the possibility of errors is greater. In mass production, many failed chips will be wasted. In professional terms, the yield rate of chips is relatively low and the defect rate is relatively high.

Let's get back to the topic, how difficult is it to build a lithography machine?

Let me first clear up the particularities. The lithography machine is by far the most sophisticated and complex machine that humans are capable of manufacturing. A lithography machine consists of three key parts. The first part is the light source, the second part is the optical system, and the third part is the etching workbench. The technical challenges of each section are comparable to landing on the moon.

Let's talk about the light source first. To generate extremely-deep ultraviolet light with a wavelength of 13.5 nanometers, the current method is to use a high-power laser to bombard a small ball of tin (that is, metallic tin) with a diameter of only 30 millionths of a meter. But this sentence is not enough to describe its difficulty. I need to expand.

First, a laser beam is required to accurately hit a small tin ball moving at a speed of about 200 miles per hour. When the temperature of the small tin ball reaches 500,000 degrees, it will become tin plasma. At this time, a laser beam is used to bombard it. It can produce extreme ultraviolet light with a wavelength of 13.5 nanometers. To produce this UV light continuously and stably requires bombarding small solder balls at a frequency of about 50,000 times per second. There is only one German company in the world that can produce this kind of laser. It took the German company called TRUMPF [通快] ten years to successfully develop it. This laser alone has more than 45,700 parts. But you may not have thought that TRUMPF's laser relies on a Lithuanian company to provide key equipment. Without the light source equipment manufactured by this Lithuanian company, TRUMPF would not be able to do anything. It's like the mantis that stalks a cicada, but there's an oriole looming behind the mantis. The next difficulty is: how to collect this extremely-deep ultraviolet light to form an extremely-deep ultraviolet laser? This is the next key part.



Optical system. The optical system developed for EUV can only be manufactured by one German company in the world, and it is the famous Zeiss [蔡司]. You may have heard that the camera lenses produced by Zeiss are among the best in the world, but comparing camera lenses to the lenses used in EUV optical systems is like the difference between an airplane with propellers spraying pesticides and a jet fighter. This optical system involves at least the following technical challenges: high-precision aspheric surface processing, multi-layer mirrors, high-quality melting, ion beam polishing technology, and extreme precision grinding. You don't need to go into the technical terms just mentioned. You just need to know that the ultimate goal is to produce an absolutely smooth and flat lens. How smooth should it be? It is the smoothness of water droplets in the three-body system, and the fluctuation of the lens is an error of about one atom, which is close to the theoretical physical limit. If we use Zeiss's own promotional metaphor, even if this lens is enlarged to the size of the entire Germany, the fluctuation does not exceed 0.1 mm. If a virus falls on this mirror, it will be like a hill rising up to 100 meters high. Therefore, this optical system must work in a vacuum without any interference. But having a light source and lens is not enough. It is just like having a carving knife for engraving. The next step is to carve tens of billions of transistors on a silicon chip the size of a fingernail.

Precision instrument workbench. In order to carve tens of billions of transistors, we need a console with extremely high precision. It is difficult for me to find an accurate metaphor to describe the difficulty of manufacturing it. This console is composed of 55,000 high-precision parts, and these parts rely on patented technologies provided by – at the very least – Japan, South Korea, Taiwan, the United States, Germany, and the Netherlands. It would not work without any one of them.

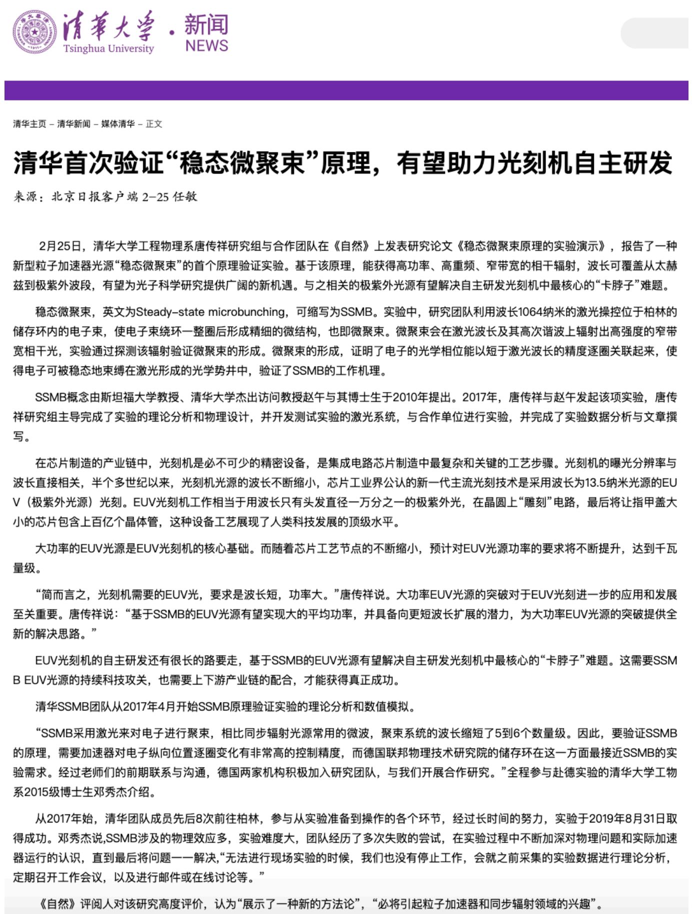
Generally, the above captures the difficulty of manufacturing the most advanced lithography machine in the world. Its research and development history is roughly like this. In 1997, Intel Corporation and the U.S. Department of Energy jointly invested in a company and began to develop EUV lithography machines. In 6 years, the company developed most of its core patented technologies. However, neither Intel nor the U.S. Department of Energy intended to build lithography machines themselves, because they feel that building lithography machines does not actually make money. It is better to license the core technology to a foreign company and let them build lithography machines. Later, the Dutch company ASML obtained the authorization for these core technologies, and with the help of companies such as Samsung and TSMC, it finally produced the first prototype of an EUV lithography machine in 2010. And then afte nine more years of tests, optimizations, and upgrades, the first EUV lithography machine that could be officially put into commercial production was finally produced in 2019, a process which spanned a total of 22 years.

However, although the EUV lithography machine is produced by ASML in the Netherlands, it is nothing more than an assembly plant. Only 15% of the parts are produced independently, and the other 85% of the parts are imported. And because the U.S. Department of Energy owns almost all core patents for lithography machines, ASML's production of lithography machines requires authorization from the U.S. Department of Energy. This is why if the U.S. government says it is not allowed to sell lithography machines to China, the Dutch ASML company can only listen to it. It can be said that an EUV lithography machine is surrounded by seven or eight countries in a circle, jamming ASML's neck.

If China wants to break through the technological blockade and independently produce lithography machines, it needs to achieve complete independent innovation in all three key parts. All we can say now is that in the first light source section, we see a little bit of hope.

In 2010, Zhao Wu, an ethnic Chinese professor at Stanford University and a distinguished visiting professor at Tsinghua University, worked with his doctoral students to propose a new principle for generating extremely-deep ultraviolet light sources. This principle is called "steady-state micro-bunching." The English abbreviation of SSMB is the use of huge particle accelerators to generate extremely deep ultraviolet light. In 2017, Professor Tang Chuanxiang's team at Tsinghua University worked with colleagues in Germany to complete the theoretical analysis and physical design of the experiment, develop a laser system for the test experiment, and conduct verification of certain principles. In February 2021, their paper was successfully published in the journal *Nature* [1]. Professor Tang's doctoral student Deng Xiujie is the first author, Professor Tang and another professor from the Helmholtz Center for Materials and

Energy Research in Berlin, Germany, are the corresponding authors. By the way, here is a general rule in the academic circle. The first author generally refers to the person who has made the greatest contribution to the research topic, while the corresponding author is the person in charge of the topic and the beneficiary of the results.



清華大學 Tsinghua University . 新闻 NEWS

清华主页 – 清华新闻 – 媒体清华 – 正文

清华首次验证“稳态微聚束”原理，有望助力光刻机自主研发

来源：北京日报客户端 2–25 任敏

2月25日，清华大学工程物理系唐传祥研究组与合作团队在《自然》上发表研究论文《稳态微聚束原理的实验演示》，报告了一种新型粒子加速器光源“稳态微聚束”的首个原理验证实验。基于该原理，能获得高功率、高重频、窄带宽的相干辐射，波长可覆盖从太赫兹到极紫外波段，有望为光子科学研究提供广阔的新机遇。与之相关的极紫外光源有望解决自主研发光刻机中最核心的“卡脖子”难题。

稳态微聚束，英文为Steady-state microbunching，可缩写为SSMB。实验中，研究团队利用波长1064纳米的激光操控位于柏林的储存环内的电子束，使电子束绕环一整圈后形成精细的微结构，也即微聚束。微聚束会在激光波长及其高次谐波上辐射出高强度的窄带宽相干光，实验通过探测该辐射验证微聚束的形成。微聚束的形成，证明了电子的光学相位能以短于激光波长的精度逐圈关联起来，使得电子可被稳态地束缚在激光形成的光学势井中，验证了SSMB的工作机理。

SSMB概念由斯坦福大学教授、清华大学杰出访问教授赵午与其博士生于2010年提出。2017年，唐传祥与赵午发起该项实验，唐传祥研究组主导完成了实验的理论分析和物理设计，并开发测试实验的激光系统，与合作单位进行实验，并完成了实验数据分析与文章撰写。

在芯片制造的产业链中，光刻机是必不可少的精密设备，是集成电路芯片制造中最复杂和关键的工艺步骤。光刻机的曝光分辨率与波长直接相关，半个多世纪以来，光刻机光源的波长不断缩小，芯片工业界公认的新一代主流光刻技术是采用波长为13.5纳米光源的EUV（极紫外光源）光刻。EUV光刻机工作相当于用波长只有头发直径一万分之一的极紫外光，在晶圆上“雕刻”电路，最后将让指甲盖大小的芯片包含上百亿个晶体管，这种设备工艺展现了人类科技发展的顶级水平。

大功率的EUV光源是EUV光刻机的核心基础。而随着芯片工艺节点的不断缩小，预计对EUV光源功率的要求将不断提升，达到千瓦量级。

“简而言之，光刻机需要的EUV光，要求是波长短，功率大。”唐传祥说。大功率EUV光源的突破对于EUV光刻进一步的应用和发展至关重要。唐传祥说：“基于SSMB的EUV光源有望实现大的平均功率，并具备向更短波长扩展的潜力，为大功率EUV光源的突破提供全新的解决思路。”

EUV光刻机的自主研发还有很长的路要走，基于SSMB的EUV光源有望解决自主研发光刻机中最核心的“卡脖子”难题。这需要SSMB EUV光源的持续科技攻关，也需要上下游产业链的配合，才能获得真正成功。

清华SSMB团队从2017年4月开始SSMB原理验证实验的理论分析和数值模拟。

“SSMB采用激光来对电子进行聚束，相比同步辐射光源常用的微波，聚束系统的波长缩短了5到6个数量级。因此，要验证SSMB的原理，需要加速器对电子纵向位置逐圈变化有非常高的控制精度，而德国联邦物理技术研究院的储存环在这一方面最接近SSMB的实验需求。经过老师们的前期联系与沟通，德国两家机构积极加入研究团队，与我们开展合作研究。”全程参与赴德实验的清华大学工物系2015级博士生邓秀杰介绍。

从2017年始，清华团队成员先后8次前往柏林，参与从实验准备到操作的各个环节，经过长时间的努力，实验于2019年8月31日取得成功。邓秀杰说,SSMB涉及的物理效应多，实验难度大，团队经历了多次失败的尝试，在实验过程中不断加深对物理问题和实际加速器运行的认识，直到最后将问题一一解决,“无法进行现场实验的时候，我们也没有停止工作，会就之前采集的实验数据进行理论分析，定期召开工作会议，以及进行邮件或在线讨论等。”

《自然》评阅人对该研究高度评价，认为“展示了一种新的方法论”，“必将引起粒子加速器和同步辐射领域的兴趣”。

In March 2022, Professor Tang Chuanxiang and Dr. Deng Xiujie published another paper of the same name in China's "Acta Physica Sinica"《物理学报》 [2]. Maybe they themselves did not expect that more than a year later, for unknown reasons, on around September 13th, 2023, I don't know which self-media posted a video with a title like "Incredible! Tsinghua University's SSMB-EUV light source was born, with power 40 times that of EUV lithography machines." Then, like a fire, various self-media platforms began to use various titles starting with phrases like "unbelievable" to attract attention. The speculation about Tsinghua University's SSMB plan made me dumbfounded.

What I hope everyone can calm down about is that we are still a long way from realizing the production of extremely-deep ultraviolet lithography machines, so don't let this get to your head. First of all, Tsinghua's official website states that in 2021, Professor Tang Chuanxiang has applied to the National Development and Reform Commission to list the SSMB experimental device as a major national science and technology infrastructure during the 14th Five-Year Plan.

However, I didn't find any news about the project. Note that this kind of civilian scientific research project is not a military project and does not need to be kept confidential. All project approvals need to be publicized. In other words, at least so far, this project has not even been approved.

Even if we are a bit optimistic, the project will be launched next year. It would be difficult to build a scientific research facility of this level within five years. Then after it is completed, we will be more optimistic: conduct a successful test in 3 years, and then spend another 5 years building a commercial light source. That's 13 years later. But can the other two key parts of the lithography machine be completed in these 13 years? There is not even a shadow (of evidence) of this yet.

Moreover, we don't know if the Americans and the Dutch will have developed a more advanced next-generation lithography machine in 13 years. Then, we would have to continue to pursue that machine.

Finally, I want to say something that I personally don't like:

Within 20 years, it is impossible for any country in the world to be able to completely independently build a lithography machine that represents the most advanced level in the world, and the United States is no exception.

Of course, this only represents my personal opinion, and I really hope to be debunked.

Why I want to express this point of view is because I really don't want the lessons of the past to repeat themselves. The Chinese are very smart, but this does not mean that we Chinese are people made of special materials. All the world's ethnicities are human beings. Humans, homo sapiens, there is almost no genetic difference between Chinese and foreigners. We are not dumber than foreigners, but we are not much smarter than foreigners.

Being practical and realistic is the right way to develop science and technology. For ultra-precise and complex machines like lithography machines, seeking the greatest range of international cooperation is the best solution.

Reference materials

[1]https://www.nature.com/articles/s41586-021-03203-0
[2]https://wulixb.iphy.ac.cn/article/doi/10.7498/aps.71.20220486