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Summary

The semiconductor industry has been working to develop high power extreme ultraviolet light sources for the last twenty years. Light is used to manufacture chips with progressively smaller feature sizes. To continue reducing feature sizes (Moore's law), the industry needs to switch from 193 nm deep ultraviolet (DUV) light sources to 13.5 nm extreme ultraviolet (EUV) light sources. Existing EUV light sources do not produce enough light to support manufacturing, and as a result the switch to EUV has been delayed. Zplasma has developed a new light source technology that meets the critical need for a high power source. Zplasma Stable Discharge Produced Plasma (Stable DPP) is differentiated by the use of Sheared Flow Stabilization (SFS) to stabilize the plasma. This is the first and only technology that stabilizes the plasma used to generate EUV light. Stable plasma results in light pulses ten to one hundred times longer than those produced by the unstable plasmas of other sources. The source uses no tin and has a controlled end to each pulse that does not produce the high-energy debris and molten tin sputtering that have been obstacles for other light sources. We have prototyped and demonstrated the physics of Stable DPP in the lab. Zplasma is seeking funding and development partners to scale our prototype up to the high power light source the industry needs.

Industry Application

The semiconductor industry uses light to produce integrated circuit chips in a process called photolithography. Silicon wafers are coated with a resist material and exposed to light projected through a mask, then chemically processed to form the features of the chip. As the size of the required features gets smaller, the light required is of shorter and shorter wavelengths. The dominant technology today is 193 nm DUV produced by an argon fluoride laser. The next generation light source is 13.5 nm EUV produced by heating xenon or tin plasmas. To continue Moore's law without EUV, the industry has been adopting complicated and expensive resolution enhancement techniques to produce features much smaller than the wavelength of the light used. The rising costs of resolution enhancement mean that Moore's law will end unless a viable high power EUV source is developed. The machines that move silicon wafers through the manufacturing process are called steppers. The two main manufacturers of steppers are ASML (Netherlands) and Nikon (Japan). Both ASML and Nikon created EUV stepper designs. ASML has produced and sold six NXE:3100 EUV steppers to industry research facilities, all of which are equipped with low power light sources for research and development. All high-volume manufacturing is still done with 193 nm or older equipment. The semiconductor industry needs a new EUV light source that produces enough power to increase the number of wafers per hour produced by an EUV stepper and enable manufacturing to switch to EUV.

Light Sources

EUV light is produced by generating and heating plasma in one of three different ways. A Discharge Produced Plasma (DPP) source uses a high voltage discharge through a gas plasma. A Laser Produced Plasma (LPP) source uses a laser to vaporize a material, usually molten tin. A Laser Discharge Plasma (LDP) source is a combination of both methods. DPP sources with unstable plasmas cannot generate enough light at practical pulse repetition frequencies, limiting DPP sources to low power metrology. LPP and LDP light sources can operate at higher frequencies, but they require complex systems to handle the molten tin, and in operation produce debris that contaminates the optical collector. Three companies have tried to build high power EUV light sources. Gigaphoton (Japan) developed an LPP source said to be capable of 20 watts. Xtreme (Germany, now being liquidated by parent Ushio) shipped an LDP source producing 6 watts with the NXE:3100 unit at IMEC (Belgium). Cymer (USA, now owned by ASML) shipped an LPP source producing 10 watts with five of the NXE:3100 units. After ten years of development, Cymer is now reporting 55 watt operation for limited times, but stepper operation is still at research levels. ASML's mass production target is 105 watts of light source power to produce 70 wafers per hour, with a desired source power of 200 watts. A new way of producing EUV light at high power levels is needed to enable the manufacturing switchover to EUV.

Research History

In 1998 the Department of Aeronautics and Astronautics at the University of Washington in Seattle, USA, began construction of the ZaP Flow Z-Pinch Experiment. Funded by the US Department of Energy, the experiment was designed to investigate the effects of Sheared Flow Stabilization (SFS) on a Z-pinch. A Z-pinch is formed when an electrical current flowing in a plasma forms a magnetic field that then compresses the plasma into a small-diameter or "pinched" configuration. Plasmas emit light at wavelengths dependent on the working gas and plasma temperature, so all Z-pinches emit light. SFS uses plasma moving at different speeds in different places to prevent plasma instabilities from growing, like cars in the center lane of a freeway being prevented from changing lanes by higher speed traffic on both sides. Other Z-pinches are unstable, so the pinch lasts only about 100 nanoseconds before becoming unstable, producing a burst of high-energy debris as it flies apart. Professors Uri Shumlak, Brian Nelson, and colleagues observed that with SFS, the Z-pinch formed lasts ten to a hundred times longer than other Z-pinches, then has a controlled end. Realizing that with xenon gas SFS produces a long pulse of EUV light at a wavelength of 13.5 nanometers, and that the semiconductor industry needed light sources of this type, the university filed for and was granted two patents.

Zplasma Formation

The UW ZaP experiment had demonstrated a technology, but it needed to be reduced in size to be optically compatible with a stepper. Working with Henry Berg, an entrepreneur-in-residence at the university, Nelson and Shumlak created a design for a 200 watt commercial light source based on the SFS technology, then designed a proof of concept prototype to prove that the physics work. The overall pinch size in the prototype is 100,000 times smaller than the pinch in the ZaP experiment. With the same pinch formation overhead as other DPP sources, ten to one hundred times more light is produced per pulse. This meets the high power requirements of silicon lithography while running at achievable pulse repetition frequencies. Longer, less intense EUV pulses allow the electrodes to be cooled. The Zplasma source does not produce the high-energy debris that unstable plasmas produce, so collection optics are not contaminated. The plasma exhaust flows orthogonally away from the optical path. Everything needed other than SFS is a standard part of existing light sources on the market today. Zplasma is seeking funding and development partners to create an EUV light source that delivers 200 watts of EUV light to the stepper's intermediate focus and for the first time allows EUV lithography to be used in high-volume manufacturing.