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Review Article

A Brief Introduction to Excimer Lasers: Fundamental Study

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ABSTRACT

Lasers are devices that produce intense beams of light which are monochromatic, coherent and highly collimated. The unique property of laser is that its light waves travel very long distances with very little divergence. Spatial coherence is typically expressed through the output being a narrow beam which is diffraction-limited, often a so-called pencil beam. Laser beams can be focused to very tiny spots, achieving a very high irradiance or they can be launched into beams of very low divergence in order to concentrate their power at a large distance. Excimer lasers are gas lasers that emit pulses of light with duration of 10 ns to several 10 ns in the ultraviolet spectral range. They are the most powerful lasers in the UV. While a lot of different excimer laser transitions have been used to generate light pulses at various wavelengths between 126nm and about 660 nm, the most commonly used excimer lasers are krypton fluoride, argon fluoride and xenon chloride. UV excimer lasers have emerged as the enabling tool in improving display performance and advancing product innovations such as faster pixel switching rates, reduced power consumption, weight and thickness or paper-like mechanical flexibility which are critical to keep pace with ever-changing customer demand. Excimer lasers are used in a variety of industrial applications that take advantage of the broad spectrum of output specifications. By far, the largest industrial application of excimer laser is found in micro-lithography. In this application the wavelengths of the excimer laser 248 nm, 193 nm and 157 nm are a precondition to achieve the optical resolution required to print pattern of 180 nm down to 70 nm. This paper deals with the detailed properties and applications of excimer lasers in material processing.

Keywords: Laser, Excimer laser, Principle, Properties, General view and Applications.

1. INTRODUCTION

Lasers are devices that produce intense beams of light which are monochromatic, coherent and highly collimated. The unique property of laser is that its light waves travel very long distances with very little divergence. Spatial coherence is typically expressed through the output being a narrow beam which is diffraction-limited, often a so-called pencil beam. Laser beams can be focused to very tiny spots, achieving a very high irradiance or they can be launched into beams of very low divergence in order to concentrate their power at a large distance[1]. Temporal coherence implies a polarized wave at a single frequency whose phase is correlated over a relatively large distance beam. A beam produced by a thermal or other incoherent light source has an instantaneous amplitude and phase which vary randomly with respect to time and position and thus a very short coherence length. Most so called single wavelength lasers actually produce radiation in several modes having slightly different frequencies, often not in a single polarization. And although temporal coherence implies monochromaticity, there are even lasers that emit a broad spectrum of light or emit different wavelengths of light simultaneously. There are some lasers which are not single spatial mode and consequently their light beams diverge more than required by the diffraction limit. However all such devices are classified as lasers based on their method of producing that light, stimulated emission. Lasers are employed in applications where light of the required spatial or temporal coherence could not be produced using simpler technologies[2].

Excimer lasers are gas lasers that emit pulses of light with duration of 10 ns to several 10 ns in the ultraviolet (UV) spectral range. They are the most powerful lasers in the UV. While a lot of different excimer laser transitions have been used to generate light pulses at various wavelengths between 126nm and about 660nm, the most commonly used excimer lasers are krypton fluoride (KrF, 248 nm), argon fluoride (ArF, 193 nm) and xenon chloride (XeCl, 308 nm). Recently also the very short wavelength of the fluorine laser (F_2, 157 nm) experiences increasing interest and applications[3]. The name excimer comes from excited dimer. The first experimental evidence of excimer lasing was obtained by N. G. Basov et al. in 1970. They did use a high current electron beam to excite liquid Xe[4]. The Xe_2 excimer laser emitted around 172 nm. With this experimental proof the excimer lasers were invented as a new class of lasers. For the important excimer lasers of today the name excimer laser is used only by convention since here excited complexes of rare gas monohalides rather than excited dimers form the active medium. Also exciplexes exist with some stability only in the excited state. The exciplexes are formed by Ar, Kr or Xe with F or Cl. The most important are ArF, KrF, XeCl and XeF[5].

2. PROPERTIES OF GENERAL LASER

Monochromaticity means "One color". To understand this term, examine "white light" which is the color interpreted in the mind when we see all colors together. When "white light" is transmitted through a prism, it is divided into the different colors which are in it and laser radiation does not have all those color, because it has only one same wavelength and phase. And Mono-chromaticity also means that laser has a high intensity of the light within the very small wavelength. So it can have a high energetic level in microscopic region. Actually, the temperature of the Laser radiation is higher than Sun. Radiation comes out of the laser in a certain direction and spreads at a defined divergence angle. This angular spreading of a laser beam is very small compared to other sources of electromagnetic radiation and described by a small divergence angle. Since, laser radiation divergence is of the order of milli-radians, which means almost negligible, the beam is almost parallel and can be sending over long distances. So, laser radiation is highly directional. Laser radiation is composed of waves at the same wavelength, which start at the same time and keep their relative phase as they advance. So, when two or more laser radiations can make regular interference each other. So, laser radiation has a coherency[6-7].

3. GENERAL VIEW OF EXCIMER LASERS

The term excimer refers to a molecular complex of two atoms which is stable only in an electronically excited state. These lasers, which are available only as pulsed lasers, produce intense output in the ultraviolet and deep ultraviolet. The lasers in this family are XeFl (351 nm), XeCl (308 nm), KrF (248 nm), KrCl (222 nm), ArF (193 nm), and F2 (157 nm). They are used extensively in photolithography, micromachining, and medical applications. At first glance, the construction of an excimer laser is very similar to that of a transverse-flow, pulsed CO_2 laser. Fig. 1 shows excimer laser ablation set-up. However, the major difference is that the gases in the system are extremely corrosive and great care must be taken in the selection and passivation of materials to minimize their corrosive effects. A system built for CO_2 would fail in minutes, if not seconds. The principal advantage of an excimer laser is its very short wavelength. The excimer output beam can be focused to a spot diameter that is approximately 40 times smaller than the CO_2 laser beam with the same beam quality. Furthermore, whereas the long CO_2 wavelength removes material thermally via evaporation, the excimer lasers with wavelengths near 200 nm remove material via ablation, without any thermal damage to the surrounding material. Fig. 2 shows the energy level diagram of excimer laser[8].

4. APPLICATIONS

UV excimer lasers have emerged as the enabling tool in improving display performance and advancing product innovations such as faster pixel switching rates, reduced power consumption, weight and thickness or paper-like mechanical flexibility which are critical to keep pace with ever-changing customer demand[9]. Aiming at driving cost-efficient material and process development in display and microelectronics industries Coherent has invented the VarioLas family of excimer surface processing systems[10].

Excimer lasers are used in a variety of industrial applications that take advantage of the broad spectrum of output specifications. By far, the largest industrial application of excimer laser is found in micro-lithography. In this application the wavelengths of the excimer laser 248 nm, 193 nm and 157 nm are a precondition to achieve the optical resolution required to print pattern of 180 nm down to 70 nm. The laser light is used to expose the photo-resist on the wafer. The scanners illumination system, which today must provide various illumination settings such as annular or quadrupole is well adapted to the excimer laser beam. The excimer’s low spatial coherence helps to avoid speckle interference phenomena in the image. The refractive imaging lens of the scanner demands a very narrow output spectrum of less than 0.5 pm, FWHM in order to avoid chromatic aberrations. Another prominent application, which is dominated by the excimer laser, is the use for annealing of TFT flat panel displays. In this process the laser is used to transfer amorphous silicon into poly-crystalline silicon which is then used to build up transistors and driver circuits. Only excimers deliver the wavelength (308 nm) and the required output power (300 W) to cost efficiently process the substrates. High power XeCl excimer lasers are also applied for the surface treatment of metal alloys like cast iron as used in cylinder liners of combustion engines. The ablation process using 308 nm wavelengths leads to opening of graphite spherulites which then act as an oil reservoir and greatly reduce wear and oil consumption[11].

The unique output characteristics of an excimer laser offer distinct advantages in many applications. For example, UV wavelengths enable processing at a higher spatial resolution than visible and IR lasers. This is because the smallest feature size that can be produced is limited by diffraction and diffraction increases linearly with wavelength. The UV photons produced by an excimer also interact differently with most solid materials compared with longer wavelength photons. The focused beam from a visible or infrared laser processes a material by heating it until some has boiled off or vaporized. Typically, this heating also affects the surrounding material that has not been directly irradiated, resulting in peripheral thermal damage and less precise process control. In contrast, the inherently high energy of UV photons causes them to directly break the atomic or molecular bonds within a material in a process called photo ablation.

With short laser pulses, this can be a relatively cold process with little or no effect on the surrounding material. This ability to process with a very high spatial resolution is further enhanced by the fact that most solid materials have very high absorption in the UV. As a result, the laser light only penetrates a very shallow depth into the material. This, along with the short pulse duration, means that each pulse removes just a thin layer of material, thus providing excellent depth control[12].

Excimer laser ablation is a surface structuring technique based on the interaction of intense excimer laser pulses with a material. These lasers operate in the UV where polymers typically show high absorption. This results in electronic excitations which on their turn initiate both thermal and nonthermal processes leading to a dissociation of the polymer and subsequently local ejection of material. The presence of nonthermal reactions is responsible for a clean, well-defined geometry of the ablated zone. The lateral dimensions of the removed polymer are determined by the laser beam size, while the depth of the hole depends on the laser intensity. Typically the lateral resolution is limited to a few microns while the ablation rate can be as low as a few tens of nanometer. These properties make polymers a very suitable substrate material for excimer laser ablation[13, 14].

Silicon carbide (SiC) is a wide-gap semiconductor that has unique material properties suitable especially for high temperature, high power and high frequency applications. However, SiC device fabrication has to face various technological difficulties. Among them, one of the crucial steps appears to be doping[15]. The high melting point and the limited diffusion of impurities in SiC have greatly restricted the use of ion implantation and furnace annealing commonly employed in the silicon microelectronics industry to incorporate and activate the dopants. As an alternative to classical thermal heating, excimer laser processing was demonstrated to be suitable for doping of SiC in various experimental conditions, including laser annealing of ion implanted SiC[16], laser induced diffusion of dopant from gas or solid sources and laser crystallization of doped-SiC films deposited by CVD. The use of highly powerful pulsed laser beams in the nanosecond duration regime allows one to deposit a large amount of energy in short time onto the near-surface region, while maintaining the substrate essentially at room temperature. Under suitable conditions, the irradiation leads to surface melting of SiC to a depth not exceeding a few hundred nanometers, and its rapid solidification from the bulk, allowing the dopant to be incorporated by liquid phase diffusion. In addition, by taking advantage of the highly non-equilibrium nature of the melt/ regrowth process, complete electrical activation of the dopant could be achieved, as shown for silicon. It has also to be mentioned that recent works suggest the possibility of suppressing the ion implanted defects and activate the dopant in SiC by high temperature excimer laser annealing in solid phase[17].

Polyimide is a thermally stable aromatic polymer with excellent insulation characteristics and is widely used as a protective material in microelectronics and optoelectronics. Traditionally, in integrated circuit fabrication, polymer film is removed and subsequently a metal layer is evaporated as electrical connection. Recently, there has been considerable interest in large and permanent decrease in electrical resistivity of polyimide films after ultraviolet laser irradiation. In particular, polyimide can be turned into electrical conductor with sufficient spatial resolution. Coupled with the 0.1 µm spatial resolution and 0.1 Ω cm resistivity obtained with excimer-laser irradiation, new potential applications may be considered for these newly developed materials, such as forming electrical connections or rewiring defective integrated circuits in microelectronics and optoelectronics[18].

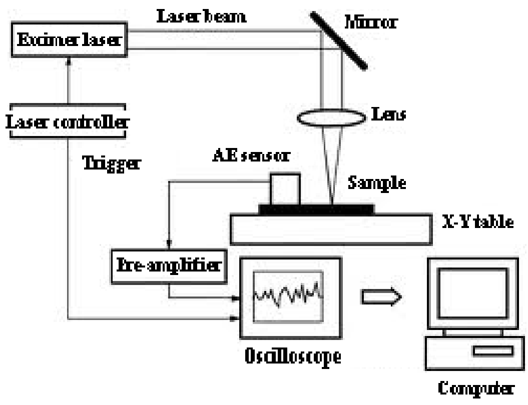

Fig. 1: Excimer laser ablation set-up

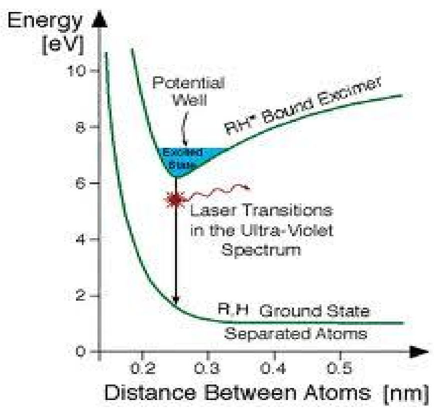

Fig. 2: Energy level diagram of excimer laser

5. CONCLUSIONS

A laser is a device that emits electromagnetic radiation through a process of optical amplification based on the stimulated emission of photons. The wavelength of laser light is extremely pure when compared to other sources of light and all of the photons that make up the laser beam have a fixed phase relationship with respect to one another. The term excimer refers to a molecular complex of two atoms which is stable only in an electronically excited state. These lasers, which are available only as pulsed lasers, produce intense output in the ultraviolet and deep ultraviolet. The principal advantage of an excimer laser is its very short wavelength. The excimer output beam can be focused to a spot diameter that is approximately 40 times smaller than the CO_2 laser beam with the same beam quality. Furthermore, whereas the long CO_2 wavelength removes material thermally via evaporation, the excimer lasers with wavelengths near 200 nm remove material via ablation, without any thermal damage to the surrounding material. Excimer laser ablation is a surface structuring technique based on the interaction of intense excimer laser pulses with a material. These lasers operate in the UV where polymers typically show high absorption. This results in electronic excitations which on their turn initiate both thermal and nonthermal processes leading to a dissociation of the polymer and subsequently local ejection of material.

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