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Structural, optical and electrical behavior of millisecond pulse laser damaged silicon-based positive-intrinsic-negative photodiode

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ABSTRACT

In this work, laser induced optical, electrical parameter degradation and morphological damage have been observed in silicon-based positive-intrinsic-negative (PIN) photodiode. Temperature evolution, surface morphology, damaged area and responsivity are monitored for permanent laser induced change. The 1064 nm laser pulses are reported for values of pulse length τ ranging from 1 ms to 3 ms. The loss of responsivity is corresponding to the temperature and damaged area increased on the upper surface, with the increase of laser fluence, the damaged area is increased, resulting in an increase in decline proportion of responsivity. The damage behavior indicated that the millisecond laser-induced electrical and optical parameter degradation in silicon-based PIN photodiode mainly contributed to the removal of the Si_3N_4 coating destroyed, redistribution of dopant and the introduction of defects.

1. Introduction

Positive-intrinsic-negative (PIN) photodiode is one of the most important devices in laser application system, owing to small bulk, light weight, fast response and high sensitivity [1–3]. However, it is likely to be damaged under laser radiation to produce adverse effect on the performance of the PIN photodiode, so the research on the rules of laser damage in PIN photodiode has a certain theoretical and practical significance. Since the 1990s, lots of researches have carried out a lot of research on the interaction between lasers and photodiode, including electrical performance [4–12] and damaged morphology [4–6,12]. The above studies are mostly related to 1064 nm nanosecond pulse laser [4–7,12], 532 nm nanosecond pulse laser [8–10], 580 nm microsecond pulse laser [9] and 157 nm nanosecond pulse laser [11]. Because of the high-power intensity, these lasers will lead to plasma-shielding phenomenon. However, owing to its low power intensity and longer irradiation time, the millisecond pulse laser which can avoid the phenomenon irradiated photodiode can get better results.

The millisecond laser-induced damage in the silicon-based PIN photodiode is investigated in this study. An experimental system of 1064 nm millisecond pulse laser irradiating silicon-based PIN photodiode is established including of on-line monitoring system and off-line measurement system. Temperature evolution, surface morphology, damaged area

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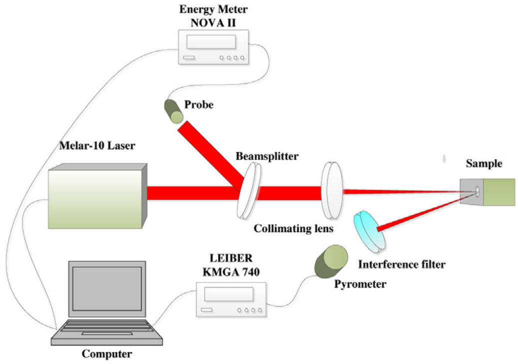

Fig. 1. On-line monitoring experiment configuration diagram of the PIN photodiode irradiated by laser.

and responsivity are analyzed. Meanwhile the damage mechanism of the PIN photodiode electrical and optical parameter degradation caused by the millisecond pulse laser is also explored.

2. Experimental setup

The on-line monitoring system is shown in Fig. 1. An Nd: YAG laser with wavelength of 1064 nm is employed for experiment. The laser pulse width is varied from 1.0 ms to 3.0 ms and the maximal output energy is 10 J. In our experiment, the output laser is focused on the surface of the sample by a lens L1 with focal length 50 mm, the spot radius of focused laser beam is 300 μm. The energy meter takes real-time detection of the incident laser energy. The standard deviation of the pulse-to-pulse energy is 3% or less, and the energy reported here is the average value. An infrared radiation pyrometer is used to measure the temperature evolution of the PIN photodiode. The measurement spot radius is 150 μm, far smaller than the radiation spot, the test results can be considered as temperature evolution of the irradiation spot center in the irradiation process. The off-line measurement system including topography measurement and electric parameter measuring system. Damage morphologies and damaged areas are done with a DMI 5000 M metallographic microscope (made in Leica Camera AG). The off-line electric parameter measurement is shown in Fig. 2. Responsivity is measured by these measurements.

The PIN photodiode used in experiment is type GT102 with a 1 mm photosensitive surface size, which has standard antireflection coating about 80 nm to prevent reflection and to play a passivating role. The thickness of P+, I and N+ region is 1 μm, 200 μm and 1 μm, respectively. The peak wavelength is at about 950 nm, the spectral response ranging from 400 nm to 1100 nm and having higher response spectrum around 1060 nm. The photodiode sample is set on five-dimensional translation stage. The experiment is performed at room temperature in air under normal atmospheric pressure.

3. Results and discussion

Temperature evolutions of the spot center on the upper surface during pulse laser irradiation measured by pyrometer are illustrated in Fig. 3. The value of pulse length τ is 1.0 ms, 1.5 ms, 2.0 ms, 2.5 ms and 3.0 ms, respectively. It can be seen that the time of the temperature reaching to the melting point of 1783 K decrease with the increase of laser fluence, and increase with the increase of pulse length. The shortest damage time is 0.21 ms when the laser fluence is 109.04 J/cm^2 and the pulse length is 1.0 ms. This is because of the largest power density, the instantaneous temperature rises fastest. From all of the temperature evolution curves, we can see the slopes of the curves keep increasing with the time before the temperature reaches to the melting point, 1783 K, and that means the temperature rises higher gradually. This is because of the optical absorption coefficient of Si_3N_4 increasing with the surface temperature increase and the thermal conductivity reducing with the bulk temperature increase. We can also see that the curves having inflection point at the melting point, owing to the latent heat of phase change and the step reflectivity. Then the slopes of the curves keep increasing with the time but smaller than that before the temperature reaches to the melting point. After the irradiation, temperature drops down to the melting

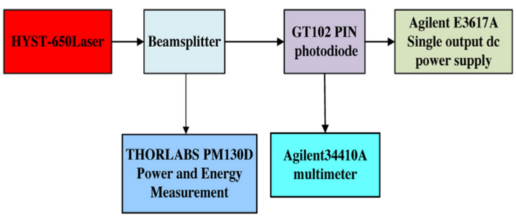

Fig. 2. Off-line electric parameter measurement diagram.