1/*f* Noise of GaAlAs IREDs Over a Wide Range of Bias Currents*

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Abstract 1/*f* noise in GaAlAs double hetero junction infrared ray LEDs (IRLEDs) is experimental and theoretical studied over a wide range of bias currents. Experimental results demonstrate that the magnitude of 1/*f* noise is in proportion to the bias current (I_F) in the range below 3 mA, and tends to saturate when the current increases from 3 mA to 5 mA. While, in the current range above 5 mA, the magnitude of 1/*f* noise increases sharply and is proportional to I_F^2. Base on the mechanisms of carrier number fluctuations and carrier velocity fluctuations, a model for 1/*f* noise in GaAlAs IRLEDs is developed. It is discussed from the model that at small currents, 1/*f* noise in GaAlAs IRLEDs comes from trapping and detrapping process between defects in the bulk region of devices (bulk defects) and carriers, which reveals characteristics of bulk defects. While, at large currents, it is due to fluctuations in the surface recombination velocity induced by the surface potential, which is modulated by oxide traps near the space-charge region, at these conditions, 1/*f* noise reveals defects in the active region of devices (actives defects). 1/*f* noise can be used as a sensitive and non-destructive reliability indicator to probe defects in different regions of GaAlAs IRLEDs.

Keywords 1/*f* noise; Infrared ray LED; Fluctuations; Oxide traps

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0 Introduction

As a important short-wave LED, GaAlAs infrared ray LEDs (IRLEDs) have been widely used in communication fields, more and more attentions are being concentrated to its reliability. Nose is a critical factor to affect these devices' application, even reliability. Experimental results[1~4] demonstrate that there is a direct correlation between 1/*f* noise in LEDs and its reliability, and 1/*f* noise can be used to be a nondestructive and sensitive indicator for LEDs' reliability. In literature[1], the magnitude of current 1/*f* noise in LED is proportional to I_F^γ (I_F is bias current, γ is an exponent) with $\gamma \approx 0.7 \sim 1$, while, in literature [2,3], $\gamma \approx 2$. Till now, there is not a whole theory to interpret all those different experimental results, which also limits 1/*f* noise to be used as a diagnostic tool in LED.

In this paper, 1/*f* noise in GaAlAs infrared ray LEDs as a function of bias currents is measured over a wide range of currents. Experimental results demonstrate that at currents below 3 mA, the magnitude of 1/*f* noise is proportional to bias current I_F, while, at currents above 5 mA, it is directly proportional to I_{2F}. Based on the mechanisms of carrier number fluctuations and carrier velocity fluctuations, a model for 1/*f* noise in GaAlAs IRLEDs is developed. It is discussed from the model that at small currents, 1/*f* noise in GaAlAs IRLEDs comes from trapping and detrapping process between defects in the bulk region of devices (bulk defects) and carriers, which reveals characteristics of bulk defects. While, at large currents, it is due to fluctuations in the surface recombination velocity induced by the surface potential, which is modulated by oxide traps near the space-charge region, at these conditions, 1/*f* noise reveals defects in the active region of devices (actives defects). These results give an experimental and theoretical base for 1/*f* noise to be used as a diagnostic tool in GaAlAs IRLEDs.

1 Experiment and results

The devices used in the experiment are some commercial GaAlAs double hetero junction infrared ray LEDs, which are made in China. Low frequency noise is measured by a noise testing and analyzing system of electronic device based on virtual instrumentation[10]. The device under test is

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connected in series with a low noise level resistor. With adjusting the value of this resistor, a wide range current is obtained to make an appropriate noise measurement. After amplified by low noise preamplifier PARC113, the noise is sent to a high speed and real-time data acquiring system controlled by a computer, low frequency noise spectra are obtained and analyzed as a function of the current. The bias circuit for noise measurement is shown in Fig. 1.

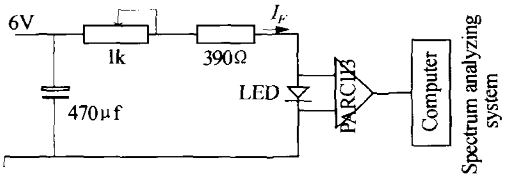

Fig. 1 Bias circuit for noise measurements

Generally, $1/f$ noise of LEDs is consisted of white noise, generation-recombination noise (g-r noise) and $1/f$ noise, which spectra can be expressed as[5]

$$S(f)=A+\frac{B}{f^{\gamma}}+\frac{C}{1+(f/f_0)^2} \tag{1}$$

Here, A is the magnitude of white noise, B and γ are the magnitude and frequency exponent of $1/f$ noise respectively. C and f_0 are the magnitude and frequency exponent of g-r noise respectively. All those parameters represent different physical meanings and reveal different inner characteristics of devices under test. In order to analyze low frequency noise, all those parameters should be known, which are obtained by a method in literature[5].

The low frequency noise spectra of a GaAlAs IRLEDs are obtained by measuring the voltage noise across DUT (devices under test) biased at a current. All these measurements are made at a wide frequency range from 0.5 Hz to 300 kHz. With adjusting the value of the resistor in series, we get the low frequency nose at a wide range current from 0.5 mA to 13 mA. Fig. 2 gives the experimental results of PSD (power spectrum density) of these noises vs frequency at bias currents are 0.5 mA, 2.5 mA, 4.5 mA, 6.0 mA, 7.0 mA and 8.0 mA. It is clear that there are only $1/f$ noise and white noise in those samples and the PSDs are all flatting at the frequency above 1 kHz, which means white noise and frequency range of our measurement is far enough to cover $1/f$ noise. In order to find out the relationship between $1/f$ noise and bias currents, the magnitude of $1/f$ noise at the same frequency range, from 0.5 Hz to 300 kHz, is calculated according to the equ (1) with the method in literature[5], that is to say, the measured data are time series and must be transformed into PSD, and then all these noise parameters in equ (1) are determided by the united algorithm of gradient optimization and linear series development. As a result, $1/f$ noise parameters (B) at every bias current are obtained. Fig. 3 gives the result of B at all these bias currents, in which it is found that at the bias current I_F below 3 mA, the magnitude of $1/f$ noise B is proportional to I_F^{γ}, $\gamma=0.9957$ (I_F is bias current, γ is an exponent). With bias current I_F increasing, the magnitude of $1/f$ noise tends to saturate. Tillis I_F above 5 mA, B increases sharply and is directly proportional to I_F^{γ} with $\gamma=1.9857$.

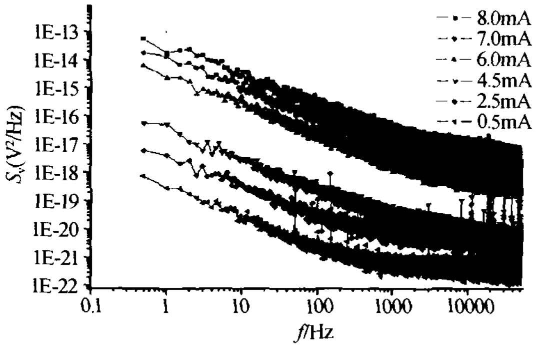

Fig. 2 Low frequency noise spectra vs frequency at various bias currents

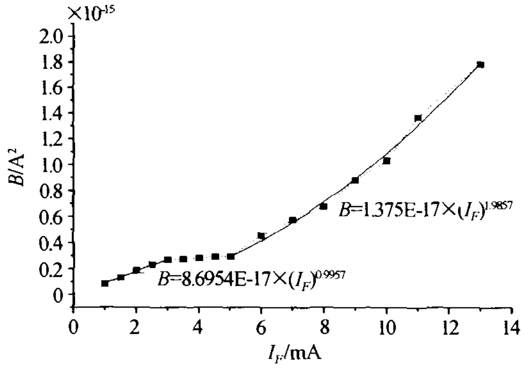

Fig. 3 The magnitudes of $1/f$ noise (B) vs various bias currents

2 Discussion

Fig. 3 shows there are three different regions in bias currents in which the $1/f$ noise reveals different characteristics . At bias currents below 3 mA, the magnitude of $1/f$ noise is proportional to I_F^{γ}, $\gamma=0.9957$, it agrees with results in literature[1]. At low bias, carriers are shortly injected and confined in the active region. The current passing junction is dominated by diffusion current. During diffusing, carriers can also be trapped and detrapped randomly by defects in the bulk region. These exchanges between carriers and defects not only cause carrier number fluctuations, but also change defect charges that induce carrier velocity fluctuations through Coulombic scattering. Therefore, this kind of $1/f$ noise belongs to diffusion $1/f$ noise and can be described as follows[8]

$$S(f)=\frac{\alpha q I_F}{f\tau} \tag{2}$$

Here, $S(f)$ is the $1/f$ noise power spectral density (psd), α is Hooge parameter, q is the electron charge, I_F is the bias current, τ is the minority carrier lifetime, f is frequency. So $1/f$ noise at this current range reveals bulk defects.

With bias current increasing, more and more carriers are injected into junction, the gradient of carrier concentration decreases. Meanwhile, it weakens diffusion process, increases tunneling process by which carriers pass though potential barriers, and recombination process by which carriers are trapped by defects near the junction. All those mechanisms counteract each other. As a result, the magnitude of $1/f$ noise tends to saturation as the current keep increasing from 3 mA to 5 mA.

When the bias current is above 5 mA, the magnitude of $1/f$ noise is proportional to I_F^γ, $\gamma=1.9857$, which agrees with results in literatures[2,3]. At high currents, carriers passing though junction are dominated by tunneling mechanism and confined in active region. Besides radiative recombination, carriers can be easily recombined through oxide traps near the junction without radiation. This non-radiative recombination modulates surface potential and causes fluctuations of surface recombination current. According to the theory of carrier number fluctuations[8], the psd of this $1/f$ noise, $S_s(f)$, can be written as

$$S_s(f)=cs/f \tag{3}$$

Where s is the surface recombination velocity, c is a constant. The surface current can also be written as[9]

$$I_s=qspA_s\exp\left(qV_1/kT\right) \tag{4}$$

Here, V_1 is the voltage at such a spot in space-charge region that the concentration of major and minority carriers are equal, A_s is the effective area of the recombination region, k is Boltzmann constant, T is absolute temperature. The current though junction and its psd can be described as[8]

$$I=I_0\exp\left(qV/mkT\right) \tag{5}$$

$$S_I(f)=(qpA_s)^2\exp\left(2qV_1/kT\right)S_s(f) \tag{6}$$

Where V is the applied voltage across the diode, I_0 is inverse saturation current, m is the current ideality factor of the junction. Substituting eqn (3), eqn (4) and eqn (5) into eqn (6), we get

$$S_I(f)=(pqA_s)^2\left(\frac{I}{I_0}\right)^{\frac{2mV_1}{V}}\frac{cs}{f} \tag{7}$$

According to equ. (7), to surface current ($m=2$), the magnitude of $1/f$ noise in a symmetry junction ($V_1=0.5$V) is proportional to the bias current I_F^2, which agrees with our experimental results.

From above results, it is known that at high frequencies, $1/f$ noise is masked by white noise, only at low frequencies, a typical $1/f$ noise reveals. All those experimental results demonstrate that there are only flick noise and white noise in all range of test frequencies, without g-r noise (Fig. 2). As a diode, $1/f$ noise sources can be located at the junction region and the bulk region, the former is due to surface recombination velocity fluctuations between carriers and traps adjacent to junction region, which is induced by interface traps and surface traps, while, the latter comes from ohmic contact or bulk resistance[6~8]. In GaAlAs IRLEDs, the relationship between $1/f$ noise and bias current is different in different range of bias current, the magnitude of $1/f$ noise is proportional to I_F^γ with different γ. In the bias current range bleow 3 mA, $\gamma\approx1$ and $1/f$ noise belongs to diffusion $1/f$ noise that is caused by bulk defects. While, in the bias current range above 5 mA, $\gamma\approx2$ and $1/f$ noise belongs to recombination $1/f$ noise that is caused by active defects. So $1/f$ noise measurements in different bias current range can be used to diagnose different $1/f$ noise sources, bulk defects or active defects, in GaAlAs IRLEDs.

3 Conclusions

Low frequency noise in GaAlAs double hetero junction infrared ray LEDs (IRLEDs) is measured over a large range of the bias current. Experimental results demonstrate that the magnitude of $1/f$ noise is proportional to the current (I_F) at small currents (below 3 mA), and tends to saturate when the bias current increases from 3 mA to 5 mA. With the bias current keep increasing above 5 mA, the magnitude of $1/f$ noise increases sharply and is directly proportional to I_F^2. Base on the mechanisms of carrier number fluctuations and carrier velocity fluctuation, a model for $1/f$ noise in GaAlAs double hetero junction infrared ray LEDs is developed. It is discussed from the model that at small currents, $1/f$ noise in GaAlAs infrared ray LEDs comes from trapping and detrapping process between bulk defects and carriers, which belongs to diffusion 1/*f* noise, at large currents, it is due to fluctuations of the surface recombination velocity induced by the surface potential, which is modulated by oxide traps near the space-charge region. So 1/*f* noise measurements can be used to diagnose different 1/*f* noise sources. These results also give an experimental and theoretical base for 1/*f* noise to be used as a diagnostic tool in GaAlAs double hetero junction infrared ray LEDs.

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宽范围偏置电流下的GaAlAs红外发光二极管1/*f*噪声特性

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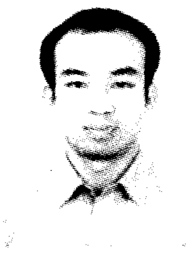
摘　要　在宽范围偏置条件下，测量了GaAlAs红外发光二极管(IRLED)的低频噪声，发现1/f噪声幅值与偏置电流的γ次方成正比，在小电流区，$\gamma\approx1$，在大电流区$\gamma\approx2$. 基于载流子数涨落和迁移率涨落机制建立了一个GaAlAs IRLED 1/f噪声模型，该模型的分析表明，低电流区GaAlAs IRLED的1/f噪声源于体陷阱对载流子俘获和发射导致的扩散电流涨落，高电流区的1/*f*噪声源于结空间电荷区附近氧化层陷阱对该处表面势的调制而引起载流子表面复合速率的涨落. 该研究结果为1/*f*噪声表征GaAlAs IRLED的可靠性提供了实验基础与理论依据.

关键词　1/*f*噪声；红外发光二极管；涨落；氧化层陷阱



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