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METHOD TO IMPROVE THE QUALITY OF MOIRÉ SIGNALS BY ±FIRST-ORDER MOIRÉ FRINGES

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Received 30 April 2001

ABSTRACT: *In an amplitude grating system of small grid pitch, the diffractive effect is distinctive. Its energy will be about 10–40% of the total energy. The diffractive light is the root cause of deterioration of the contrast and sinusoidal property of the Moiré signal. The relations between the phase of ± first-order Moiré fringes and other factors, such as the gap of the grating pair, are analyzed. It is proposed to use ± first-order Moiré fringes to obtain high-quality signals.* © 2001 John Wiley & Sons, Inc. Microwave Opt Technol Lett 31: 91–93, 2001.

Key words: *Moiré fringe; grating pair; phase*

1. INTRODUCTION

Most Moiré fringe measurement systems of small grid pitch use a normal incident system with short-focal photoelectric receiving or direct receiving. This kind of system is simple, but the sinusoidal property of the Moiré fringe signal is not good. In particular, the poor contrast of the fringe makes the signal unstable. All of these factors affect the reliability of the measuring system. At present, most of the measuring systems are amplitude grating Moiré fringe systems, so it is necessary to improve the quality of the signal.

In an amplitude grating system of small grid pitch, the diffractive effect is distinctive. Its energy will be about 10–40% of the total energy. The diffractive light is the root cause of deterioration of the contrast of the Moiré signal and sinusoidal property.

How to eliminate the useless diffractive orders and employ the useful diffractive orders to improve the quality of Moiré fringe signals are important aspects of the research on Moiré fringe [1–3]. The authors have studied the characteristics of +first- and −first-order Moiré fringes, and propose that we can use ±first-order Moiré fringes effectively to improve the quality of the Moiré signal.

2. THEORY

2.1. Moiré Optical Field of Grating Pair. In a general amplitude grating Moiré fringe system, the Moiré pattern of incoherent light is a kind of beat phenomenon of the modulated optical field of the grating pair. It can be explained to be the component whose frequency is smaller than that of the original beat of the system (i.e., the spatial frequency of the grating). In a grating system, diffraction plays the main role, and the Moiré fringe is the interference fringe of the diffractive light. It can be expressed by the equation [4]

$$I = B_0 + \sum_{m=-\infty}^{\infty} B_m \exp\left[C_m - 2\pi m\left(\frac{x_1}{\omega_1} - \frac{x_2}{\omega_2}\right)\right] \quad (1)$$

where B_0 is the background intensity of the Moiré optical field, B_m is the amplitude of the mth diffractive fringe, and ω_1, ω_2 are the grating constants of the grating pair.

2.2. Phase Relation of +First- and −First-Order Moiré Fringes of Diffractive Grating Pair. Figure 1 is a grating pair which is composed of two gratings with the same grating constant ω and gap t. AB is a bundle of light. We assume an arbitrary point O in grating G_1 as a zero-phase point, and establish a coordinate system with O as the origin. Its x-axis is perpendicular to the rulings of G_1, and the y-axis is parallel to the rulings of $G_1 \cdot CN \perp G_1$. The coordinate of N is (x, y).

In this system, it is easy to prove that, if the sum of p_i and q_i of their order sequence (p_i, q_i) is equal (i and j are integers), for example, $p_1 + q_1 = p_2 + q_2 = r$, both of the diffractive light will exit in the same direction. This direction is the same as that of the $p + q = r$th-order diffractive light from a single grating. This group of light is defined as the r group. Only for the direction of incident light and emergent light is the effect of the grating pair with two identical pitch and parallel rulings equivalent to that of a single grating with the same pitch. The r group can be represented by $(p, r - p)$, where $r = p + q$.

In Figure 1, the phase will change δ_B after the incident light AB passes through G_1. The pth-order diffractive light of G_1 passes through the gap of t, and the phase change is $(2\pi/\lambda)(t/\cos\beta)$. Then it passes through G_2, and the phase of the $(r - p)$th-order diffractive light will change δ_C. So the phase of the emergent light of order sequence $(p, r - p)$ at C can be written as follows:

$$\Phi_C = \Phi_B + \delta_B + \frac{2\pi}{\lambda}\frac{t}{\cos\beta} + \delta_C \quad (2)$$

where Φ_B is the phase of incident light at B before it passes through G_1.

The phase at point C of light passing through G_1 and G_2 can be expressed by the fractional position and fractional displacement [5, 6] as follows:

$$\Phi_C = K_p + \frac{2\pi}{\lambda}(x \sin\alpha'' + y \sin\alpha') + \frac{2\pi}{\lambda}\frac{t}{\cos\beta} + 2\pi rf + 2\pi p\rho \quad (3)$$

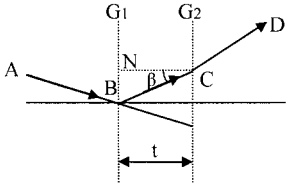

Figure 1 Light ray of diagram of grating pair

where f and ρ are the fractional position and fractional displacement of point C, respectively. K_p is a phase function related to the structure of the grating pair. It is a constant for a definite grating pair. α'', α' are the angles between AB and the principal median plane, and AB and the secondary median plane, respectively. When the rulings of the two gratings are parallel, they equal zero.

Since, in amplitude grating diffractive systems, most energy concentrates on 0, $\pm$first-order diffractive light, we focus on the research of $(0,+1)$, $(+1,0)$, $(0,-1)$, and $(-1,0)$-order light beams. The interference fringes of $(-1,0)$ and $(0,-1)$ diffractive light are called $-$first-order Moiré fringes. The interference fringes of $(+1,0)$ and $(0,+1)$ diffractive light are called $+$first-order Moiré fringes.

The diagram of $+$first-order and $-$first-order Moiré fringes is shown in Figure 2. G_1 and G_2 have the same grid pitch. Their rulings are parallel. There is a small angle θ_j between their normal lines. L is the imaging lens. $(0,-1)$ and $(-1,0)$-order Moiré fringes focus on F_{-1}; $(0,+1)$ and $(+1,0)$-order Moiré fringes focus on F_{+1}.

Since the phases of $(0,+1)$ and $(0,-1)$-order fringes at G_2 are equal, the phase relation of signals at F_{-1} and F_{+1} depends on the phase relation of $(-1,0)$ and $(+1,0)$-order light beams at the exit plane. From Eq. (3), Figure 2, and the grating equation, the phase difference of Moiré fringes at F_{-1} and F_{+1} is expressed by the equation

$$\Delta\Phi = \frac{2\pi t}{\lambda}[\cos(\theta_j - \theta_{-1}) - \cos(\theta_j + \theta_{+1})] + 2m\pi + \Delta' - \frac{2\pi t \cos\theta_j}{\omega}\left[\frac{\sin\theta_{-1}}{\cos(\theta_{-1} - \theta_{+1})} + \frac{\sin\theta_{+1}}{\cos(\theta_j - \theta_{+1})}\right] - \frac{2\pi t}{\lambda}\cos\theta_j \sin\theta_i\left[\frac{\sin\theta_{+1}}{\cos(\theta_j - \theta_{+1})} + \frac{\sin\theta_{-1}}{\cos(\theta_j - \theta_{+1})}\right] \quad (4)$$

where m is an integer, and Δ' is the phase difference caused by F_{-1} and F_{+1} not being in the same plane. When θ_i and θ_j are fixed, Δ' does not change.

From Eq. (4), it can be seen that the phase difference $\Delta\Phi$ is decided by a gap of the grating pair, the incident angle θ_i on the grating pair, and the parallelism θ_j of G_1 and G_2. For a given grating pair, we can make the phase of the Moiré fringe at F_{-1} and F_{+1} opposite by adjusting these parameters. Then the signals are received by the two phototriodes placed at F_{-1} and F_{+1}, and are put into a differential amplifier. A high-quality Moiré fringe signal with high contrast and low noise can be obtained.

3. EXPERIMENTS

The dynamic motion of the Moiré fringe of long grating must have a stable and uniform velocity. In order to achieve repeated measurement, the index grating should move a long distance. This will make the experimental setup complicated. So we use a radial grating pair on a circle dividing the equipment to measure the relations of the phase difference versus the factors in Eq. (4).

The schematic diagram of the experimental setup is shown in Figure 3. The gratings used here are two concentric small grid pitch radial gratings. Their total rulings are 324,000 lines, and the grid pitch is 0.02 mm. The light source is a 6 V 5 W voltage-stabilized instrumental bulb. In order to improve the contrast of the Moiré fringe and reduce the influence of divergence of the light source, the system needs a parallel beam vertically projected on the grating pair. So the filament must be placed in the focus of collimator lens L_1 and parallel to the rulings of the gratings. By calculation [4], we use a spiral filament whose diameter is 1 mm and length is 5 mm. Thus, the emergent light is a plane wave. The diameter of the phototriode is 2.5 mm, and its peak wavelength is 0.85 μm. The scaled grating revolves around its axis oo' uniformly. The diameter of L_2 must be large enough to receive all of the light emerging from the grating pair. Its focal length must be long enough that the 0, $\pm$first-order Moiré fringes are separated to place the phototriodes. According to the principle of geometrical optics, the calculated parameters of L_1 are diameter $>$ 30 mm, focal length $>$ 60 mm. The lens we used here has diameter $=$ 60 mm and focal length $=$ 100 mm.

Light from the bulb collimated by L_1 projects on the grating pair. The Moiré fringes focus on the phototriodes which are in the focal plane of L_2. The $+$first- and $-$first-order Moiré fringes are symmetrically located at the two sides of the zero-order fringe. The phototriodes are placed at F_{-1} and F_{+1} to receive the $+$first- and $-$first-order Moiré fringes. Then the signals are treated, and their phase difference can be read accurately. The relation curves of the phase difference $\Delta\Phi$ versus Δt are shown in Figure 4 under two circumstances.

4. CONCLUSION

It can be seen that the measured results agree with the theoretical analysis. The parallelism of the two gratings, the incidental angle on the grating pair, and the change of the gap of the two gratings, are the main causes of the phase difference. When θ_i = constant, the change of θ_j produces a small influence on $\Delta\Phi$, as shown in Figure 4(a). When θ_j = constant, the change of θ_i produces a great influence on $\Delta\Phi$ as shown in Figure 4(b). The relation of $\Delta\Phi$ versus Δt is linear. We can obtain two antiphase Moiré fringes by adjust-

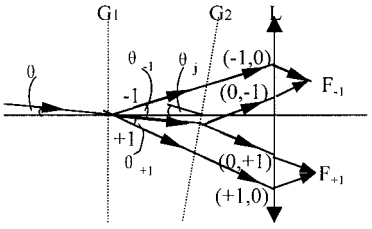

Figure 2 Diagram of $+$first- and $-$first-order Moiré fringes

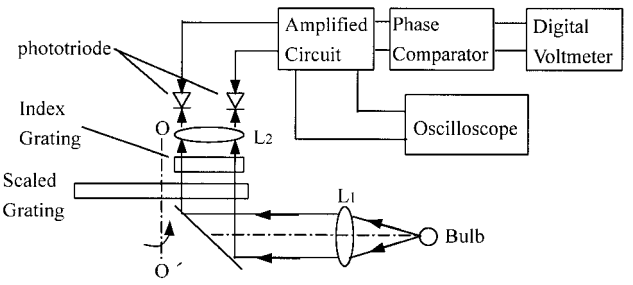

Figure 3 Block diagram of experimental setup

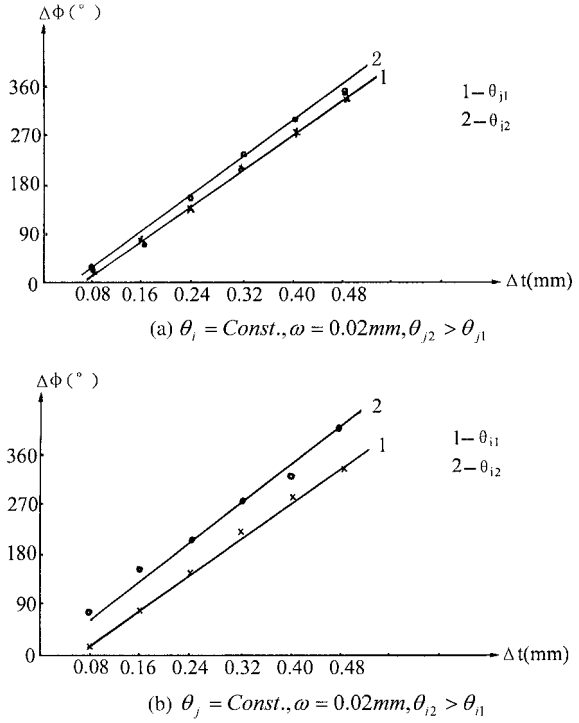

Figure 4 Experimental results of $\Delta\Phi$ versus Δt under different circumstances

ing the gap of the grating pair t. Then, under the condition of a given grating pair, we can obtain a high-contrast and good sinusoidal Moiré signal. This is useful in practical grating measurement systems.

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RESEARCH ON DYNAMICS IN MODULATION-DOPED GaAs/$Al_xGa_{1-x}As$ HETEROSTRUCTURES

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Contract grant sponsor: National Natural Science Foundation of China.
Contract grant numbers: 69871016.

Received 3 May 2001

ABSTRACT: *We discuss the dynamics of the forced modulation-doped $Al_xGa_{1-x}As$ heterostructure device governed by the coupled differential equations, which is operative in the state far from thermodynamic equilibrium. Biased with an appropriate dc field, the system exhibits two states: spontaneous current oscillation and fixed points. Under an ac driving force imposed on a dc bias, the dynamical system shows the expected characteristics of frequency locking, quasiperiodicity, and chaos, which are sensitive to the amplitude and frequency of the external applied microwave field. In particular, the basins of attraction of both an ordinary attractor and a chaotic attractor are presented.* © 2001 John Wiley & Sons, Inc. Microwave Opt Technol Lett 31: 93–95, 2001.

Key words: *chaos; heterostructure; negative differential conductivity*

1. INTRODUCTION

Negative differential conductivity (NDC) and electrical current instabilities in modulation-doped semiconductor heterostructures have been extensively investigated in the last three decades [1–2]. A basic physical mechanism about the self-sustained oscillation has been presented in [2]. For a GaAs heterostructure, the real space transfer of hot electrons from high-mobility undoped GaAs to low-mobility heavily n-doped $Al_xGa_{1-x}As$ layers occurs, leading to an N-shaped current–voltage characteristic. It is also found that the interaction between the self-sustained oscillation and an external periodical force can result in various interesting phenomena, such as frequency locking, quasiperiodicity, and chaos [3–8].

Layered semiconductor heterostructures ae chosen to be studied because of their current importance, both in basic research and in microelectronics applications. Since Aoki, Kobayashi, and Yamamoto [4] first observed the chaotic behavior in n-type GaAs semiconductors in 1982, the nonlinear chaotic dynamics in semiconductors have become of considerable interest both in experiment [5, 6] and in theory [6, 7]. Because modern electronic devices may encounter serious chaotic noise which prevents normal operation, it is important to understand how a nonlinear device responds to the external fields.

In this paper, we mainly focus on the numerical simulations of the dynamical equations to investigate the dynamical behavior of $Al_xGa_{1-x}As$ heterostructures depending on the frequency and amplitude of the external applied microwave field. Numerical simulation indicates that both a periodically oscillation attractor and a fixed-point attractor can coexist under an appropriate dc bias. The basins of attraction of period 3 and chaotic attractors are also computer simulated.

2. STATIC CHARACTERISTICS

In our simple model, the nonlinear electron transport processes are described by the differential equations which have been derived in [9]. To simplify matters, equations are expressed in a dimensionless form by defining dimensionless quantities as $X = n_1/N_D$, $Y = \mu_1 E_{\|}/V_{ds}$, $Z = \phi_B/K_B T_L$, and $T = t/\tau_E$.

The static current density–field characteristic is shown in Figure 1. The fixed points of the dynamical system are denoted by *. The real space transfer of electrons leads to NDC as the bias voltage value U_0 exceeds 36.7 V, where the dynamical system shows spontaneous current (voltage) oscillation at frequencies of 100 GHz. The load line (the straight line) is shifted in parallel with the varying applied bias voltage. Consequently, a suitable dc bias that lies within the