DESIGN AND PERFORMANCE OF THE MILLIMETER WAVE DBR GUNN OSCILLATORS

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ABSTRACT

The operation principle and the design method of Distributed Bragg Reflector Gunn oscillators in the millimeter waveband are described based on the theory of coupled-modes in a dielectric grating region, the oscillator is constructed by an inverted-strip dielectric waveguide and an inserted Gunn diode. A practical oscillator with an output of 60~90 mW and 10^{-5}~10^{-6} frequency stability at 36 GHz has been performed, the test results are in agreement with theoretical predictions.

INTRODUCTION

The Distributed Bragg Reflector (DBR) Gunn oscillator which was constructed by a grating of dielectric image guide had been reported by T.Itoh in 1979[1][2], it operated at 9~17 GHz band and was designed based on a prototype of DBR laser[3]. This oscillator possesses some attractive features: (1) Its planar structure is easy producted and benefits the heat diffusing, that suits the millimeter waves especially; (2) A higher Q of the DBR cavity may be obtained even the dielectric with relatively lower permittivity are used; (3) It is tunable electronically by use of the distributed phase-shifters; (4) The multi-diode combining may be performed without trouble of the multi-modes excitation.

In this paper, the dispersion curves k-β diagram for the space harmonic modes of the inverted strip dielectric waveguide (ISDG) are given as shown in Fig.1[4] using the transverse resonant technique and the effective dielectric constant method[5]. The coupling coefficient between two coupled-waves with opposite directions and design parameters such as the stopband width, the reflection and transmission coefficients is derived from the theory of coupled-modes.

In the design procedures, the positive feedback are put on the Gunn diode by means of the reflection with frequency- and mode-selectivities, the oscillation conditions are satisfied carefully. Then an oscillator with an output of 60~90 mW at 36 GHz has been fabricated, and 10^{-5}~10^{-6} frequency stability is performed by means of that the grating are constructed in the decaying layer rather than the guiding layer of ISDG.

OPERATION PRINCIPLE

In the grating region of ISDG as shown in Fig.2, the propagation characteristics are pertubed periodically along the axis by the grooves, so that the magnetic field for all of the TM_{mo} modes can be written as (1) if the strip width W is large enough ($\partial/\partial y=0$) and the waveguide is considered as a lossless medium,

$$\begin{cases} H_y(x,z) = \sum_{m=-\infty}^{\infty} I_m(x)\exp(-j\beta_m z) \\ \beta_m = \beta_o + 2m\pi/\Lambda \ , \ m=0,\pm1,\pm2,\ldots \end{cases} \quad (1)$$

where the phase constant of the dominant-mode (m=o) β_o is very close to that of the surface wave β_{sw} in an unpertubed ISDG, and Λ is the period of grating.

In Fig.1 the k-β curves of forward-wave modes along +z direction ($m \geq o$) are crossed that of backward-wave modes of the -z direction ($m < o$), each cross point describes the coupling condition between two modes. The point A describes the coupling from the dominant mode of forward-wave (m=o) to the backward-wave (m=-1), which corresponds to the stopband of surface wave, and keep the total energy within a bound as like as an end-wall of cavity, so it is a reasonable operating point for an oscillator.

The wave equation for TM modes includes a pertubation inhomogeneous term which make the mode coupling happen in the mathematical sense,

$$\nabla^2 H_y(\bar{r},t) - \mu\varepsilon(\bar{r})\left[\partial^2 H_y(\bar{r},t)/\partial^2 t\right] = \mu\varepsilon_o\,\Delta n^2(\bar{r})\left[\partial^2 H_y(\bar{r},t)/\partial^2 t\right] \quad (2)$$

The periodic pertubation factor $\Delta n^2(\bar{r})$ can be expressed as a Fourier series in respect to z,

$$\Delta n^2(x,z) = \sum_{q=-\infty}^{\infty} a_q(x)\exp(j2q\pi/\Lambda) \quad (3)$$

and the time-harmonic field of TM_{mo} can be expressed in terms of the eigenfunctions $\{\mathcal{H}_y^m(x)\}$ at the operating point A,

$$H_y(x,z)=\sum_{m=-\infty}^{\infty}\frac{1}{2}\mathcal{H}_y^{(m)}(x)\{A_m^{(+)}(z)\exp(-j\beta_m z)+ +A_m^{(-)}(z)\exp(j\beta_m z)\} \quad (4)$$

If the field amplitude varies with z slowly, then a pair of coupled differential equations for mode amplitudes of the s_{th} components $A_s^{(\pm)}(z)$ are derived for the structure of longitudinally symmetrical grating with period $\Lambda=p\pi/\beta_0'$ (p=1,2,...) based on the orthogonality of eigenfunctions,

$$dA_s^{(\pm)}(z)/dz = -K_s A_s^{(\mp)}(z)\exp(\pm j2(\Delta\beta)z) \quad (5)$$

where $\Delta\beta=\beta_s-p\pi/\Lambda=\beta_s-\beta_0'$ is the difference of phase constants, the strong coupling occurs when $\Delta\beta=0$ which corresponds to Bragg condition

$$\Lambda=p\pi/\beta_s=p\lambda_{gs}/2 \quad (6)$$

and λ_{gs} is the guide wavelength for s_{th} mode; the coupling coefficient

$$K=K_s=(\omega\mu/4)\int_{-a}^{0}\frac{j\,a_p(x)}{n^2(x)}\left[\mathcal{H}_y^{(s)}(x)\right]^2 dx$$
$$=\frac{2\pi^2 s^2 \quad n_1^4(n_1^2-n_0^2)}{3p\lambda n_2^3(n_1^2+n_0^2)}(a/t)^3\left[2-\frac{(3\lambda/a)}{2\pi(n_2^2-n_1^2)^{1/2}}+\frac{3(\lambda/a)^2}{4\pi^2(n_2^2-n_1^2)}\right] \quad (7)$$

The solutions of eq.(5) with the homogeneous reflection condition at terminal z=L that $A_s^{(-)}(L)=0$ are obtained,

$$\begin{cases} A_s^{(-)}(z)\exp(j\beta_s z)=-jA_s^{(+)}(0)\left[\dfrac{K\exp(j\beta_0' z)\,sh(\alpha\overline{z-L})}{\Delta\beta\ sh(\alpha L)-j\alpha\,ch(\alpha L)}\right] \\ A_s^{(+)}(z)\exp(-j\beta_s z)=A_s^{(+)}(0)\left[\dfrac{-\exp(-j\beta_0' z)}{\Delta\beta\ sh(\alpha L)-j\alpha\,ch(\alpha L)}\right]\cdot \\ \qquad\cdot\left[\Delta\beta\,sh(\alpha\overline{z-L})+j\alpha\ ch(\alpha\overline{z-L})\right] \end{cases} \quad (8)$$

However it can be reduced under the Bragg condition[6],

$$A_s^{(-)}(z)=A_s^{(+)}(0)\left[\ sh(K\overline{z-L})/ch(KL)\right]$$
$$A_s^{(+)}(z)=A_s^{(+)}(0)\left[\ ch(K\overline{z-L})/ch(KL)\ \right] \quad (9)$$

Then the reflection and transmission coefficients can be deduced respectively as

$$R_0=A_s^{(-)}(0)/A_s^{(+)}(0)=\ th(KL)$$
$$T_L=A_s^{(+)}(L)/A_s^{(+)}(0)=1/ch(KL) \quad (10)$$

As shown in (9), the forward-wave $A_s^{(+)}(z)$ is attenuated with respect to z by the transference of energy from the forward-wave to the backward-wave continully, so its phase constant must be a complex as

$$\beta'\approx\beta_0'\pm j\alpha$$
$$\approx(p\pi/\Lambda)\pm j\left[K^2-(n_{eff}/v_c)^2(\omega-\omega_0)^2\right]^{1/2} \quad (11)$$

where $n_{eff}=\beta_{sw}/k_0\approx\beta_0/k_0$ is the effective index of refraction; v_c is the velocity of light; ω_0 is the Bragg frequency at middle of the stopband, and corresponds to the unperturbed value of $\beta_0'\approx p\pi/\Lambda$. So a short section of grating of ISDG likes as a mirror with high reflectivity at input terminal z=0 for the Bragg frequency $\omega=\omega_0$.

The width of stopband in which the mode-coupling from m=0 to m=-1 are effectively occured can be determined also as following

$$(\Delta\omega)_{stop}=2v_c K/n_{eff}\approx 2\omega_0 K/\beta_0 \quad (12)$$

DESIGN METHOD

The structure of a DBR Gunn oscillator as shown in Fig.3a includes the input- and output- sections of grating of ISDG and a segment of uniform ISDG inserting a Gunn diode.

After the geometric parameters and the permittivities of dielectric layers of ISDG are selected by means of general criterions, the following calculation will be carried out:

1. To draw the k-β curves of m=0 and m=-1 based on the computation discussed detail in the reference[4], and to determine the cross point A as accurate as possible.
2. To find the β_0 from k-β curves according to given operating frequency f or wave number k, then the grating period $\Lambda=\pi/\beta_0$ is obtained for the case of p=1.
3. To calculate the coupling coefficient K from formula (7) for p=1 and s=1, which means the operating mode of E_{11}^x. Then the design parameters $(\Delta\omega)_{stop}$, R_0, and T_L are calculated from (12),(10) in sequence.
4. To determine the lengths of grating section, let $KL_1\leq1.0$ for the power output side, and let $KL_2\geq2.5$ for the other side of equivalent mirror.
5. To estimate the maximal output power P_{out} from the oscillting power P_{osc} by the relation of

$$P_{out}=P_{osc}T_L^2=P_{osc}/ch^2(KL_1) \quad (13)$$

6. To draw the equivalent circuit as shown in Fig.3b, where Y_d is the diode admittance with typical data as Fig.3c; Y_{in1} and Y_{in2} are the input admittances looking into the uniform section #1 and #2 from diode, which depend the input admittances at the reference planes T_1 and T_2,

and lengths of l_1 and l_2 in Fig.3a , and the transmission parameters Y_0, β_0 of an uniform ISDG. Fig.3d shows the typical data of $Y_r=Y_{in1}+Y_{in2}$ for $l_1=l_2=\lambda_g/4$ and the geometric sizes and materials that are used in a practical oscillator.

7. The design criteria for the equivalent circuit is that the oscillation conditions must be satisfied,

$$Y_d+Y_r=0 \ , \ \begin{cases} G_d=-G_r \\ B_d=-B_r \end{cases} \quad (14)$$

EXPERIMENTAL RESULTS

A practical oscillator had been fabricated and tested. Fig.4 describes both the tested and computed k-β curves. In Fig.5, the characteristics of oscillation frequency and output power vary with the diode biasing. The oscillation frequency is insensitive relatively to the bias voltage , but the power and the spectral purity are sensitive to the bias.

The comparison with the experimental data discovered that the increasing in the grating length results in the increase of sensitivity of power and decrease that of frequency, these fact are due to the increase of Q .

A oscillator sample has been assembled with other components and devices of ISDG in a millimeter wave mini-system, which is operating well and stable.

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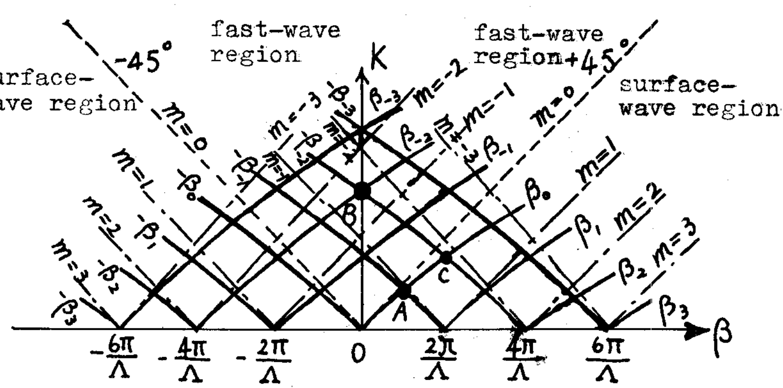


Fig.1 Dispersion curves of the grating of ISDG

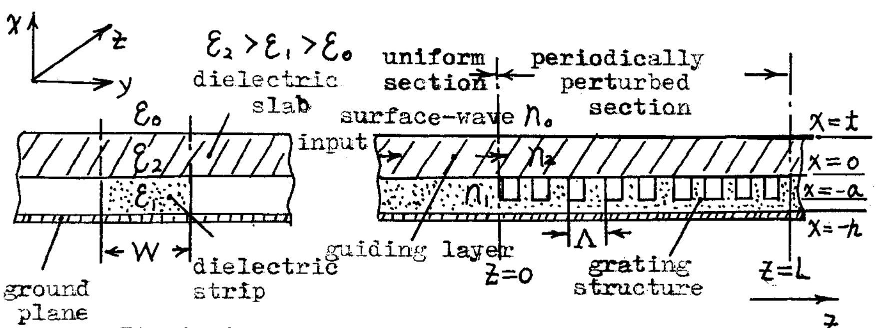
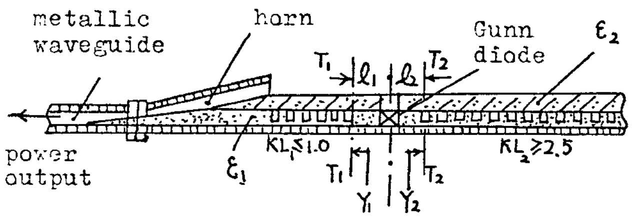
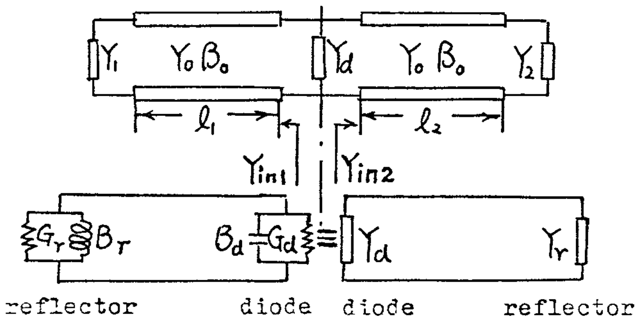


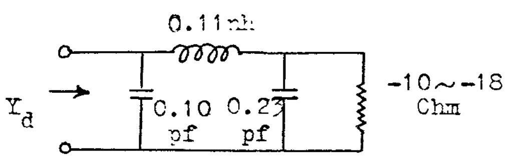
Fig.2 Cross-section of ISDG



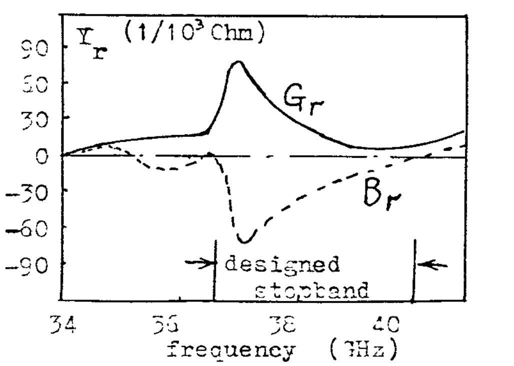
(a) Structure



(b) Equivalent circuits

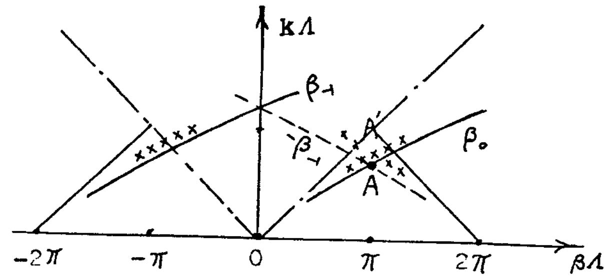


(c) Typical data of diode admittance

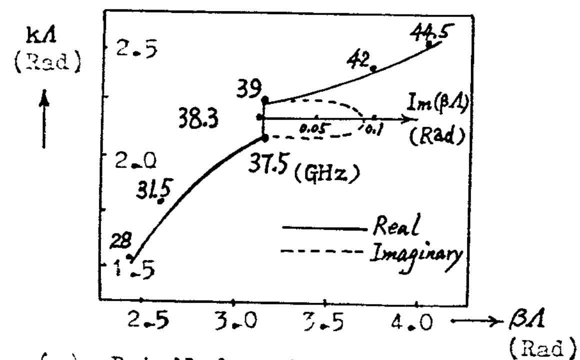


(d) Typical data of $Y_r = Y_{in1} + Y_{in2}$

Fig.3 DBR oscillator and its equivalent circuits



(b) Tested and computed results



(a) Detailed part around the operating point A

Fig.4 Dispersion curves for grating of ISDG

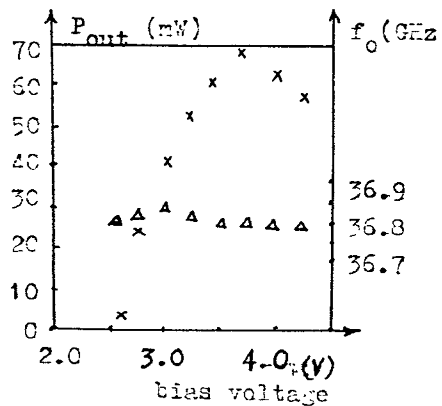


Fig.5 Measured data of DBR oscillator

(x ....P_{out}, Δ ....f_o)