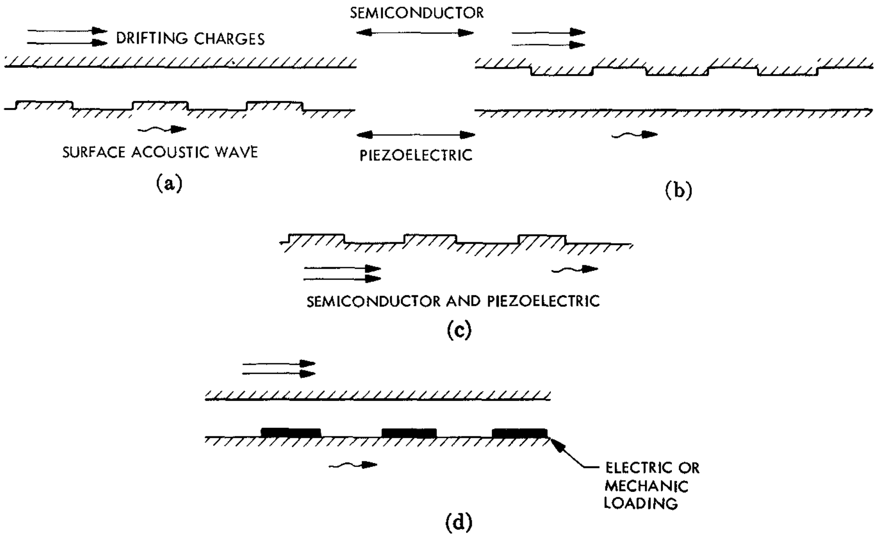

Fig. 1. Different schemes for a DFB surface acoustic wave oscillator.

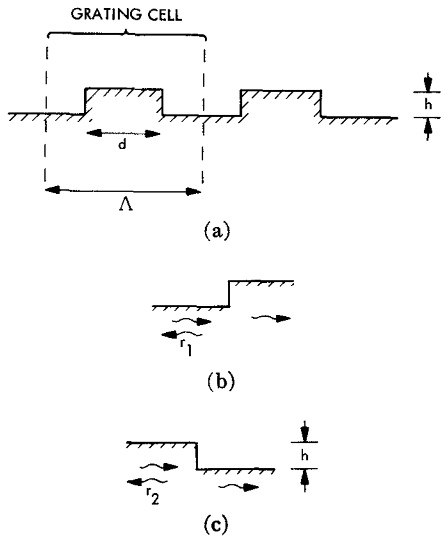

Fig. 2. Grating cell. r_1 is the reflection from a vertical surface elevation and r_2 is the reflection from the vertical surface depression.

Distributed Feedback Acoustic Surface Wave Oscillator

CHARLES ELACHI

***Abstract*—The application of the distributed feedback concept to generate acoustic surface waves is discussed. It is shown that surface corrugation of the piezoelectric boundary in a semiconductor-piezoelectric surface acoustic wave amplifier could lead to self-sustained oscillations.**

I. INTRODUCTION

The distributed feedback (DFB) concept has been recently used in the development of thin-film lasers [1]–[3], and its characteristics were the subject of many publications [4]–[7]. The basic idea is to replace the reflecting mirrors at the end of an amplifying medium by a Bragg grating throughout the medium which would generate a distributed feedback. In Fig. 1 we show a number of possible configurations which can be used for acoustic surface wave generation by having distributed feedback in a piezoelectric-semiconductor or acoustic surface wave amplifier. The distributed Bragg grating could consist of surface corrugation or periodic perturbation of any parameter which would affect the acoustic wave, electrostatic wave, or drifting charges. In this letter, we will use a simple model to evaluate the feasibility of a DFB surface acoustic wave oscillator using the scheme in Fig. 1(a).

Manuscript received March 11, 1974; revised June 6, 1974. This paper represents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Calif., under Contract No. NAS7-100 sponsored by the National Aeronautics and Space Administration and in part by the U. S. Air Force under Grant AFOSR-68-1400.

The author is with the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Calif. 91103.

II. COUPLING COEFFICIENT

The feedback efficiency is expressed by the coupling coefficient between a forward and a backward wave. Let us consider a surface wave, of wavelength λ, propagating on a corrugated surface [Fig. 2(a)] where $h \ll \lambda$ and $\Lambda = \lambda/2$ (i.e., Bragg condition). Let r_1 be the reflection coefficient when the wave encounters a vertical surface elevation [Fig. 2(b)] and r_2 the reflection coefficient at a vertical surface depression [Fig. 2(c)]. The reflection coefficient of one grating cell is then:

$$R = r_1 \exp[i(2\pi d/\lambda)] + r_2 \exp[-i(2\pi d/\lambda)] = i(r_1 - r_2) \quad (1)$$

where we assumed $d = \Lambda/2 = \lambda/4$, and that $|r_1|$ and $|r_2|$ are small so that multiple reflections can be ignored. RR^* represents the energy transferred from the forward wave to the backward wave over a length Λ. Thus the coupling coefficient is:

$$X = R/\Lambda = i(r_1 - r_2)/\Lambda = 2i(r_1 - r_2)/\lambda. \quad (2)$$

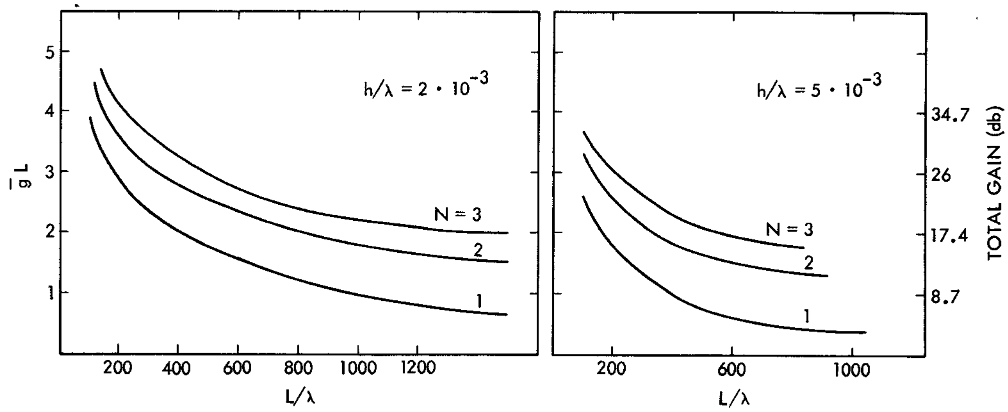

Fig. 3. Oscillation threshold average gain coefficient as a function of L/λ. N corresponds to the longitudinal modes.

For the purpose of this letter, we are only interested in evaluating the order of magnitude of X. McGarr and Alsop [8] have determined analytically and experimentally the reflection from vertical boundaries, and they have shown that both r_1 and r_2 are of the same order of magnitude as h/λ, and that r_2 is many times larger than r_1 (and both are negative for $h \ll \lambda$). Thus we can say that:

$$X \sim ih/\lambda^2 \tag{3}$$

or in a normalized form:

$$XL \sim ihL/\lambda^2 \tag{4}$$

where L is the length of the grating.

III. THRESHOLD OSCILLATION GAIN

Kogelnik and Shank [4] have derived the relation between the coupling coefficient XL, the threshold gain coefficient g, and the wave vector mismatch $\delta(\delta = \beta - \beta_0 =$ difference between the operating wave vector and the Bragg wave vector $2\pi/\Lambda$). Elachi *et al.* [6] generalized their results to the case where there is gain g_1 in the forward direction, and a different gain or loss g_2 in the backward direction. This relation is

$$XL = \pm\psi/\sinh(\psi L) \tag{5}$$

$$\psi = [(\bar{g} - j\delta)^2 - X^2]^{1/2}$$

where

$$\bar{g} = (g_1 + g_2)/2.$$

Equation (5) has many solutions which correspond to the longitudinal spectrum of distributed oscillators [4]. In Fig. 3, we plotted the average gain $\bar{g}$ required for oscillation as a function of L/λ for two values of h/Λ and for different longitudinal modes N. $N = 1$ is the mode nearest to the Bragg frequency. The normalized coupling coefficient was taken as equal to ihL/λ^2.

To illustrate let us consider the case where $\lambda = 3\ \mu$, $\Lambda = 1.5\ \mu$, and $L = 2$ mm. For $h/\Lambda = 4 \times 10^{-3}$, the average gain coefficient needed for the first mode is $\bar{g} = 15$ cm^{-1}. For $h/\Lambda = 10^{-2}$, then $\bar{g} = 6$ cm^{-1}. These correspond to an average relative imaginary wave vector β_i/β_r equal to 0.75×10^{-3} and 0.3×10^{-3}, respectively. The forward gain g should be well above these values (at least by a factor of 2) to account for the losses due to bulk wave radiations [9], [10] which usually are small, and for the fact that the backward wave is attenuated.

Bers and Burke [11], and Bers [12] have studied in detail the resonant amplification of surface acoustic waves with electrons drifting across a magnetic field with and without diffusion. Referring to their analysis and results it is clear that relative imaginary wave vectors well above 1.5×10^{-3} can be achieved. To minimize the attenuation of the backward wave, the electron drift velocity v_0 should not exceed by far the acoustic wave velocity v_a because otherwise backward resonant attenuation would occur at about the same frequency as forward resonant amplification.

Taking $v_0/v_a = 5$, β_i/β_r is larger than 1.5×10^{-3} over a very wide frequency band from about $\simeq 10^{-3}\omega_\sigma$–$\sim 0.1\omega_\sigma$ depending on the magnetic field and the diffusion coefficient. ω_σ is the effective carrier relaxation frequency [11], [12].

IV. CONCLUSION

Even though the preceding study is approximate, it is clear that DFB oscillation can be achieved in surface acoustic wave amplifiers. Surface corrugations with periods as short as 0.1 μ have recently developed using holographic techniques [13]. Thus ultrahigh frequency oscillators could be developed if semiconductors with high enough relaxation frequency, and low-diffusion coeficients are available.

REFERENCES

[1] H. Kogelnik and C. V. Shank, *Appl. Phys. Lett.*, vol. 18, p. 153, 1971.
[2] K. O. Hill and A. Watanabe, *Opt. Commun.*, vol. 5, p. 389, 1972.
[3] D. P. Schnike, R. G Smith, E. G. Spencer, and M. F. Gavin, *Appl. Phys. Lett*., vol. 21, p. 494, 1972.
[4] H. Kogelnik and C. V. Shank, *J. Appl. Phys.*, vol. 43, p. 2327, 1972.
[5] C. Elachi and C. Yeh, *J. Appl. Phys.*, vol. 7, p. 3146, 1973.
[6] C. Elachi, G. Evans, and C. Yeh, presented at the Integrated Optics Conf. (New Orleans, La.), Jan. 1974.
[7] W. S. C. Chang, "Periodic structures and their application in integrated optics," *IEEE Trans. Microwave Theory Tech.* (*1973 Symposium Issue*), vol. MTT-21, pp. 775–785, Nov. 1973.
[8] A. McGarr and L. E. Alsop, *J. Geophys. Res.*, vol. 72, p. 2169, 1967.
[9] H. S. Tuan and C. P. Chang, "Tapping of Love waves in an isotropic surface waveguide by surface-to-bulk wave transduction," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-20, pp. 472–477, July 1972.
[10] H. L. Bertoni, "Piezoelectric Rayleigh wave excitation by bulk wave scattering," *IEEE Trans. Microwave Theory Tech.* (*Special Issue on Microwave Acoustics*), vol. MTT-17, pp. 873–882, Nov. 1969.
[11] A. Bers and B. E. Burke, *Appl. Phys. Lett.*, vol. 16, p. 300, 1970.
[12] A. Bers, in *Proc. IEEE 1970 Ultrasonics Symposium*, Oct. 1970.
[13] C. V. Shank and R. V. Schmidt, *Appl. Phys. Lett.*, vol. 23, p. 156, 1973.

Surface Acoustic Wave UHF Interferometer

GENE CHAO AND LOUIS BREETZ

Abstract—**A 330-MHz surface acoustic wave (SAW) interferometer is described. The delay for the interferometer is provided by a 6.67-μs ST quartz SAW delay line. The interferometer is capable of 50-dB nulls of 150-kHz periodicity over a 10-MHz instantaneous bandwidth.**

Manuscript received March 11, 1974; revised June 10, 1974.
The authors are with the Naval Research Laboratory, Washington, D. C. 20375.