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To cite this version:
H. Wickramasinghe, Y. Martin, D. Spear, E. Ash. OPTICAL HETERODYNE TECHNIQUES FOR PHOTOACOUSTIC AND PHOTOTHERMAL DETECTION. Journal de Physique Colloques, 1983, 44 (C6), pp.C6-191-C6-196. <10.1051/jphyscol:1983629>. <jpa-00223188>

HAL Id: jpa-00223188
https://hal.archives-ouvertes.fr/jpa-00223188
Submitted on 1 Jan 1983
OPTICAL HETERODYNE TECHNIQUES FOR PHOTOACOUSTIC AND PHOTOTHERMAL DETECTION

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Abstract: We review the basic principles of optical heterodyne detection with particular reference to applications in photoacoustic and photothermal imaging. A novel scheme is described which utilises an optical heterodyne probe to detect current in thin film circuits in a non-contacting fashion. Recent experimental and theoretical results are presented.

1. INTRODUCTION

Since the publication of the first photoacoustic image showing microscopic (2 μm) resolution /1/, several novel schemes have been proposed for photacoustic or photothermal microscopy /2, 3, 4, 5, 6, 7/. The periodic absorption of energy by a surface gives rise to a number of different effects, such as the generation of acoustic waves, thermal waves, infra-red radiation and surface expansion. Using focussed heating beams and also possibly focussed detectors, each of these can be the basis of a microscopic instrument. In this paper, we deal with the use of a focussed detector for measuring the periodic surface expansion. The application of optical heterodyne detection methods - so successful in the field of surface acoustic wave device diagnostics /8, 9/ - to the detection of periodic expansion in thermal wave imaging has been published /7/. In the following section we shall outline the basic operating principle of the optical heterodyne detector.

Examples of the application of optical heterodyne detection to photoacoustic imaging and spectroscopy have already been published. /10,11/. In section 3, we present recent results on a novel scheme for recording current distribution in thin film circuits - it utilises a focussed optical heterodyne probe to detect the periodic surface expansion caused by Joule heating. Finally, in section 4, we present some concluding remarks.

2. OPTICAL HETERODYNE PROBE

The technique of optical heterodyne detection was first applied by Whitman and Korpel /12/ to measure surface acoustic wave field distributions. The basic scheme has since been refined to the point where it is now possible to detect complex surface wave field distributions below 10^{-3} Å at frequencies of several hundred MHz. /8, 9/. The operating principles of the probe can be understood with reference to Figure 1. It can be regarded as a modified Michelson interferometer in which the beam splitter is replaced by a Bragg cell - thereby providing a carrier frequency for the signal. The introduction of such a carrier frequency brings about some major advantages in subsequent signal processing; above all it ensures that spurious optical path length variations are not
detrimental provided that their spectrum does not fall into the signal processing bandwidth. The system is therefore remarkably free from disturbance which would otherwise be occasioned by microphonics, small temperature variations etc. The photodiode current includes components at the carrier frequency \((2f_B)\) and its sidebands \((2f_B \pm f_s)\). The carrier and one sideband are filtered and then mixed to recover the signal at \(f\). Finally, we determine the amplitude and phase of this signal by comparing it with a reference \(f_s\) derived from the signal source in a vector voltmeter. (see Figure 2). Alternatively, one could use the intermediate frequency outputs (signal and reference) from the vector voltmeter to drive a lock-in amplifier, thereby giving the possibility of reducing the detection bandwidth down to 0.1 Hz. It can easily be shown that microphonics and thermal fluctuations alter the phase of the carrier \((2f_B)\) and sidebands \((2f_B \pm f_s)\) in precisely the same fashion and therefore cancel out in the mixing process.

![Figure 1: Laser Heterodyne Probe](image1)

Figure 1: Laser Heterodyne Probe

![Figure 2: Coherent Laser Probe Detection Scheme at Signal Frequencies Above 1 MHz.](image2)

Figure 2: Coherent Laser Probe Detection Scheme at Signal Frequencies Above 1 MHz.

The above detection scheme works well at signal frequencies above 1 MHz. At frequencies below 1 MHz it becomes difficult to separate directly the carrier (which in our case is at 160 MHz and primarily determined by the availability of commercial Bragg cells) from its sidebands. In this case, one can beat the signals down to an intermediate frequency around 10 MHz and resort to crystal filters /13/. The phase and amplitude signals are stored in a computer together with XY positional information about the sample (which is mechanically scanned in a raster fashion). The image is displayed as a 3-D plot using a graphics recorder. In Figure 1, the vibration of the sample is produced by surface acoustic waves. In photodisplacement microscopy, this vibration is produced by a second (pump) laser beam which is chopped at \(f_s\) and focused at the same point on the sample as the probe beam. Similarly in the case of Joule microscopy, the surface vibration is produced by Joule heating in a thin film caused by AC current flow.
The minimum detectable vibration amplitude can be calculated using simple expressions for the expected noise levels and relating these to the signal corresponding to a given vibration amplitude /8, 14/. For a shot noise limited system with laser power \( P = 50 \mu W \), a diode with quantum efficiency \( \eta = 0.8 \) and an amplifier noise factor \( F = 2 \), the minimum theoretical detectable amplitude is \( 2.5 \times 10^{-4} \mu \text{m} \) in a bandwidth of 1 Hz.

3. JOULE MICROSCOPY

In this section we present recent results on a thermal wave imaging system for measuring current in thin film circuits /15/. The basic principle is illustrated in Figure 3. Periodic current flowing down the thin film track results in periodic expansion due to Joule heating; this expansion can then be detected using an optical heterodyne interferometer which is focussed and scanned across the surface. Either the phase or amplitude of the vibration can be recorded.

![Figure 3: Configuration for Detecting Current in Thin Film Circuits](image)

The form of the track used in our initial experiments is shown in Figure 3. The aluminium track was 0.4 \( \mu \text{m} \) thick and its width varied from 20 \( \mu \text{m} \) to 40 \( \mu \text{m} \) with a periodicity of 20 \( \mu \text{m} \); the peak current at 10 KHz was 60 mA. Figure 4 shows the amplitude and phase plots across the track. The asymmetrical pattern is consistent with current crowding at the edges of the track. Figure 5 shows the theoretical calculations for the vibration amplitude and phase - the agreement is reasonable. Calculations were performed by first solving for the current density distribution in the track and then calculating the power dissipated in each elementary area on the track. If the track is very thin, we can neglect the heat flow in the plane of the track as compared with its value normal to the surface; in this case, we can replace the track by a number of point sources on the surface of the substrate and proceed to calculate the vibration amplitude and phase. Although this is a simplistic model, the agreement is encouraging.

![Figure 4: Vibration Amplitude and Phase Plots Across Track Shown in Figure 3; Detection Frequency is 10 KHz.](image)
We have studied the effect of electromigration using this technique. A 160 mA uni-directional current was passed through a 100 μm wide aluminium track on glass for 70 hours. The vibration amplitude was measured in the usual way using an AC current with a peak current of 60 mA. Figure 6 shows amplitude scans along the track before and after the uni-directional current was applied for 70 hours, demonstrating clearly the effect of electromigration.

In Figure 7 we show the detection of a sub-surface hole. The sample was an 80 μm wide aluminium track on a glass substrate with a 0.3 mm diameter hole drilled across the track, beneath the surface. The hole was almost touching the surface at one edge of the track and 10 μm below the surface at the other edge. The phase and amplitude scans clearly show the effect of the tilted hole on the recorded distributions. There is a curious dip in the amplitude distribution before it reaches a peak value. This has been studied theoretically, and we believe it is caused by phase cancellation due to reflected thermal waves from the sub-surface hole.

**Figure 5**: Theoretical Amplitude and Phase Plots Across Track Shown in Figure 3: Chopping Frequency is 10 KHz.

**Figure 6**: Observation of Electromigration in a 100 μm Aluminium Track
Figure 7. Detection of a Sub-Surface Hole; Peak Current in the Track was 60 mA.

Figure 8: Observation of Defect in an Integrated Circuit; Peak Current was 60 mA.

Figure 8 shows the detection of a defect in an integrated circuit. A fault was found between one of the input pins and ground of a data conversion chip. A scan along the relevant current carrying track clearly showed a higher signal in the cross over region indicating a short circuit through the oxide. Finally, we have layed a 30 μm aluminium track across the structure sketched in Figure 9. The phase scan along the track clearly shows up the different features; in particular the signal phase increases over the oxide layer and there is an observable phase difference scanning through the P and N type materials. It is not yet established whether this contrast is due to variations in surface quality or doping density between the P and N type materials.

4. CONCLUSION

We have discussed the application of optical heterodyne methods to photoacoustic and photothermal detection. Several results on the application of this technique to Joule Microscopy were presented.
Figure 9: Phase Scan Along the Track Deposited Across the Structure Shown; Peak Current was 100 mA.

REFERENCES

11. Amer N., Presented at 1982 Ultrasonics Symposium, San Diego, CA.

Acknowledgements

We would like to thank British Telecom for providing the defective IC and Mr. F. Stride for fabricating the thin film circuits.