

knowledge the shortest so far reported directional coupler switch, perfectly suited for application to OEICs for high-frequency data processing and transmission.

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References

- 1 CADA, M., GAUTHIER, R.C., PATON, B.E., and CHROSTOWSKI, J.: 'Nonlinear guided waves coupled nonlinearly in a planar GaAs/GaAlAs multiple quantum well structure', *Appl. Phys. Lett.*, 1986, **49**, (13), pp. 755-777
- 2 BAUER, R.: 'Optimierung kurzer steuerbarer Doppelhetero-Richtkoppler in GaAlAs-Technologie für Integrierte Optik'. PhD Thesis, Technische Universität München, 1990, (in German)
- 3 ZUCKER, J.E., HENDRICKSON, T.L., and BURRUS, C.A.: 'Electro-optic phase modulation in GaAs/GaAlAs quantum well waveguides', *Appl. Phys. Lett.*, 1988, **52**, (12), pp. 945-947
- 4 DOLLINGER, F.: Technische Universität München, to be published

Wavelength detector using a pair of metal-semiconductor-metal photodetectors with subwavelength finger spacings

E. Chen and S.Y. Chou

Indexing terms: Metal-semiconductor-metal structures, Photodetectors

A wavelength detector that employs two metal-semiconductor-metal photodetectors with different subwavelength finger spacings is proposed and demonstrated. The resonance effect of the subwavelength-spaced fingers results in a photocurrent ratio that has one-to-one correspondence with the wavelengths of the monochromatic incident light. The device has a spectral range of 450 – 800nm with a resolution of 5nm. This device makes automatic wavelength calibration in optical instrumentation feasible.

Introduction: In the applications of many optical instruments, such as optical power meters, wavelength calibration is required to give accurate results. However, at present, the wavelength of the incident light needs to be entered into the instruments manually by an operator [1]. To make instruments capable of automatic wavelength calibration, a wavelength detector that can determine the wavelength of a monochromatic light is needed. Nabiev *et al.* reported a wavelength detector using two photodetectors separated by a distributed Bragg reflector [2]. Spectrometer-type wavelength sensitive detectors for wavelength-division multiplexing have also been extensively investigated for many years [3 – 8]. However, the typical spectral ranges of previous devices are only several tens of nanometres. For automatic wavelength calibration, a wavelength detector with large wide spectral range is required.

In this Letter we propose and demonstrate a wavelength detector that has a spectral range of 450 – 800nm with a resolution of 5nm. The device is realised by integrating two metal-semiconductor-metal (MSM) photodetectors. The finger spacings of these detectors are different and are less than the wavelength of the incident light. The resonance effect of the subwavelength spaced fingers results in a photocurrent ratio of the photodetectors that has an one-to-one correspondence value with the wavelength of mono-

chromatic light. The current ratio is then used to determine the wavelength of the light. As it has a good resolution in the entire visible spectrum range, this device can be used for automatic wavelength calibration in optical instrumentation.

Design and fabrication: It has been known for decades that the transmittance of a thin metal grating varies sharply as the wavelength of the incident light varies close to the grating's period [9]. This so-called resonance effect is the result of the resonance excitation of surface modes by the incident light [10, 11]. This phenomenon, wavelength dependence, also emerges in the photocurrent of an MSM photodetector, because its fingers basically form a metal grating [12]. If the photocurrent of an MSM photodetector is a monotonic function of the incident wavelength, it then can be used to determine the wavelength. However, the photocurrent of a photodetector is also proportional to the incident optical power. Therefore, the photocurrent alone cannot completely determine the wavelength. This problem can be solved by using the photocurrent ratio of two closely integrated MSM photodetectors. If these MSM photodetectors are integrated so closely that they will encounter the same optical power under light illumination, their photocurrent ratio will be independent of the optical power because the photocurrents of both detectors are proportional to the same power. The photocurrent ratio will still be wavelength-dependent if the finger spacings of the detectors are different. We need to find a photocurrent ratio which is a monotonic function of the light wavelength over a wide spectral range. The key factor to achieving such a photocurrent ratio is correctly choosing the finger spacings of the two detectors. We have found that two MSM photodetectors with 400 and 600nm finger spacings gave good spectral range and sensitivity.

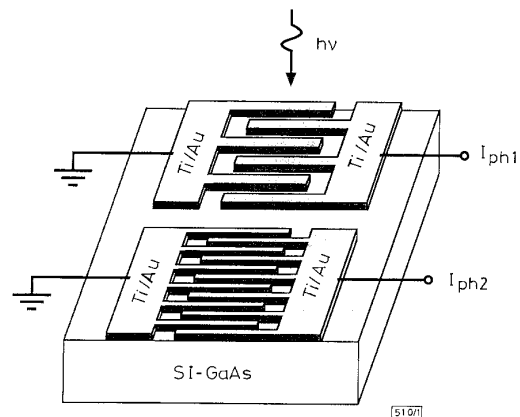


Fig. 1 Schematic diagram of a wavelength detector using a MSM photodetector pair

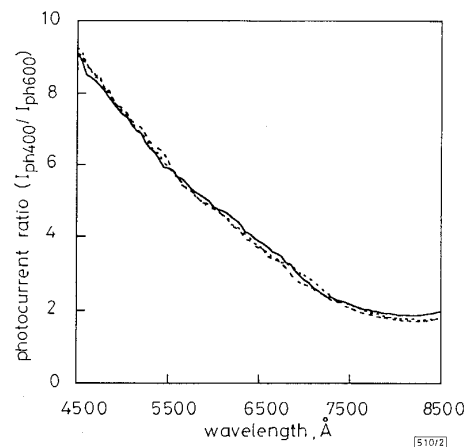


Fig. 2 Photocurrent ratio of two MSM photodetectors with 400 and 600nm finger spacings

..... 1.30 nW
 - - - - 1.80 nW
 ——— 2.30 nW

This MSM detector pair is integrated on a semi-insulating GaAs (SI-GaAs) substrate (Fig. 1). SI-GaAs is chosen to achieve low dark current and high sensitivity detectors. The trade-off of using GaAs is the sensitivity cut-off near the material's energy bandgap which is in the near infrared region. The two detectors are 0.35mm apart. The fingers of the detectors are made from 20/30nm thick Ti/Au metal fabricated using e-beam lithography. The finger's width-to-spacing ratio is 1:1 with a deviation of 10%. The active area of each photodetector is $20 \times 26\mu\text{m}^2$. The dark current of each detector is $\sim 15\text{nA}$ at 1.0V bias, mostly from the electrical contact pads.

Device performance: An Oriol QTH broadband light source and a SPEX 750M monochromator are used for the device characterisation. The output light from the setup has a power spectrum ranging from 440nm to infrared with a peak around 640nm, and is S-polarised (i.e. electrical field is perpendicular to the fingers). The photocurrents of the detectors are measured individually using a lock-in technique. Fig. 2 shows the photocurrent ratio of the two detectors at different incident optical powers (the power values labelled in the figure are those at 640nm wavelength). The photocurrent ratio is a monotonic function of the wavelength within the range 450–800nm, and it is also independent of input power. As the current ratio is in one-to-one correspondence with the light wavelength, it can be used for wavelength detection. The sensitivity drop at the infrared end (wavelength larger than 800nm) results from the low photosensitivity of the GaAs substrate near its bandgap. Our facilities also limit the measurements in the UV region. However, the curve maintains the same trend at 450 nm, implying a possible deep UV response.

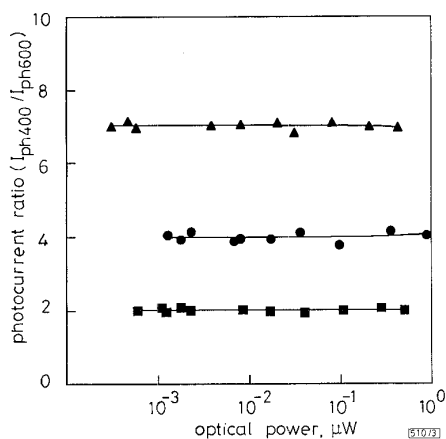


Fig. 3 Power response range of the wavelength detector
 ▲ 515nm, ● 1.80nm, ■ 760nm

The device's power response range is investigated at three wavelengths: 515nm of an Ar⁺ laser, 633nm of a HeNe laser and 760nm of a Ti:sapphire laser (Fig. 3). The current ratio remains constant at each wavelength in a power range that differs by several order of magnitude. The device's wavelength resolution, $\sim 5\text{nm}$, is determined by the noise level involved in the measurements of the current ratio, which mainly result from the fluctuations of the light source and dark current of the detectors. By integrating a divider circuit with the MSM pair, simultaneous photocurrent measurement and ratio-taking are possible, which will effectively suppress the common mode of the source noise. Dark current can be reduced by isolating the contact pads from the substrate.

Conclusion: A monolithic wavelength detector with a spectral range of 450–800nm and a resolution of 5nm is proposed and demonstrated. The device employs two MSM photodetectors with finger spacings less than the wavelength of the incident light. The wavelength of an incident light is determined by the photocurrent ratio of the detectors. The direct usage of this device is for automatic wavelength calibrations, for example, as a power meter capable of automatic wavelength compensation. Other features of MSM photodetectors, such as their small dimensions, planar

structure and fabrication compatible with IC processing, make this device commercially viable and also attractive for optical IC and communications.

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References

- Newport 800, 1800 and 2800 series power meters; coherent FieldMaster power meters
- NABIEV, R.F., CHANG-HASNAIN, C.J., ENG, L.E., and LAU, K.Y.: 'Spectrodetector: novel monolithic wavelength reader and photodetector', *Electron. Lett.*, 1995, **31**, pp. 1373–1374
- SOOLE, J.B.D., SCHERER, A., LEBLANC, H.P., ANDREADAKIS, N.C., BHAT, R., and KOZA, M.A.: 'Monolithic InP-based grating spectrometer for wavelength-division multiplexed systems at 1.5 μm ', *Electron. Lett.*, 1991, **27**, pp. 132–134
- PRANK, U., MIKULLA, M., and KOWALSKY, W.: 'Metal-semiconductor-metal photodetector with integrated Fabry-Perot resonator for wavelength demultiplexing high bandwidth receivers', *Appl. Phys. Lett.*, 1993, **62**, (2), pp. 129–130
- PEZESHKI, B., TONG, F.K., KASH, J.A., KISKER, D.W., and POTEMSKI, R.M.: 'Vertical cavity waveguide spectrometer for WDM communication'. LEOS'93, San Jose, CA, USA, 1993, pp. 198–199
- GOOSSEN, K.W., CUNNINGHAM, J.E., SANTOS, M.B., and JAN, W.Y.: 'Voltage-tunable multiple quantum well photodetector vertically integrated with voltage-tunable multiple quantum well filter', *Appl. Phys. Lett.*, 1993, **62**, (25), pp. 3229–3231
- CARRARESI, L., DE SOUZA, E.A., MILLER, D.A.B., JAN, W.Y., and CUNNINGHAM, J.E.: 'Wavelength-selective detector based on a quantum well in a standing wave', *Appl. Phys. Lett.*, 1994, **64**, (2), pp. 134–136
- MILLER, D.A.B.: 'Laser tuners and wavelength-sensitive detectors based on absorbers in standing waves', *IEEE J. Quantum Electron.*, 1994, **30**, (2), pp. 732–749
- WOOD, R.W.: 'On a remarkable case of uneven distribution of light in diffraction grating problems', *Phil. Mag.*, 1902, **4**, pp. 396–402
- HELSEL, A., and OLINER, A.A.: 'A new theory of Wood's anomalies on optical gratings', *Appl. Opt.*, 1965, **4**, (10), pp. 1275–1297
- UTAGAWA, K.: 'Theory of diffraction efficiency and anomalies of shallow metal gratings of finite conductivity', *J. Opt. Soc. Am.*, 1979, **69**, (2), pp. 333–343
- KUTA, J.J., VAN DRIEL, H.M., LANDHEER, D., and ADAMS, J.A.: 'Polarization and wavelength dependence of metal-semiconductor-metal photodetector response', *Appl. Phys. Lett.*, 1994, **64**, (2), pp. 140–142

Dielectric relaxation as a limit on transistor switching speed

P.H. Ladbrooke and J.E. Carroll

Indexing terms: Semiconductor devices, Dielectric relaxation

Charge re-arrangement in a semiconductor device by the process of dielectric relaxation is re-examined accounting for carrier inertia. Where the length of the control region in contemporary transistors is of the order of $0.1\mu\text{m}$, dielectric relaxation, not transit time, is likely to be the frequency-limiting mechanism.

Introduction: An often quoted limit to the speed of operation of transistors is the transit time of charge carriers through the control region, i.e. the gate of a field effect transistor (FET) [1] or the base of a bipolar junction transistor (BJT) [2]. Another limitation, which is often assumed to operate on shorter time scales, is dielectric relaxation [3, 4]. In this Letter, dielectric relaxation is re-examined accounting for carrier inertia, with the conclusion that it may impose a limit comparable to the transit time in contemporary devices.