Conference materials
UDC 539.23+539.25+539.26+537.32+537.9
DOI: https://doi.org/10.18721/JPM.183.109

Si-based photodetector with an Mg_2Si contact layer for SWIR range

I. M. Chernev [1] ✉, E.Yu. Subbotin [1], A.G. Kozlov [2], S.A. Sinotova [2],
A.V. Prikhodchenko [2], A.O. Lembikov [2], G.A. Prokopeva [2],
D.L. Goroshko [1], N.G. Galkin [1]

[1] Institute of Automation and Control Processes FEB RAS, Vladivostok, Russia;
[2] Far Eastern Federal University, Vladivostok, Russia
✉ chernev@iacp.dvo.ru, igor_chernev7@mail.ru

Abstract. Mg_2Si film ~2.3 μm was synthesized by reactive deposition Mg on Si(111) at 340 °C in UHV. The photoresponse of backlighted Al/Si/Mg_2Si Schottky structure represents the bell-shaped curve with the peak at 1045 nm and intensity 29 mA/W, 105 mA/W and 195 mA/W under the 0 V, 1 V and 5 V bias respectively with FWHM ~130 nm.

Keywords: magnesium silicide, silicon, films, epitaxy, reactive epitaxy, crystal structure, microscopy, photoresponse

Funding: The research was carried out within the state assignment of IACP FEB RAS (Theme FWFW-2021-0002). A.G.K. and A.V.P acknowledges support from the Russian Ministry of Science and Higher Education (State Assignment No. FZNS2023–0012) as part of the SEM and XRD investigation.

Citation: Chernev I.M., Subbotin E.Yu., Kozlov A.G., Sinotova S.A., Prikhodchenko A.V., Lembikov A.O., Prokopeva G.A., Goroshko D.L., Galkin N.G., Si-based photodetector with an Mg_2Si contact layer for SWIR range, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 18 (3.1) (2025) 53–58. DOI: https://doi.org/10.18721/JPM.183.109

Материалы конференции
УДК 539.23+539.25+539.26+537.32+537.9
DOI: https:// doi.org/10.18721/JPM.183.109

Фотодетектор на основе кремния с контактным слоем Mg_2Si для коротковолнового ИК диапазона

И.М. Чернев [1] ✉, Е.Ю. Субботин [1], А.Г. Козлов [2], С.А. Синотова [2],
А.В. Приходченко [2], А.О. Лембиков [2], Г.А. Прокопьева [2],
Д.Л. Горошко [1], Н.Г. Галкин [1]

[1] Институт автоматики и процессов управления ДВО РАН, г. Владивосток, Россия;
[2] Дальневосточный федеральный университет, г. Владивосток, Россия;
✉ chernev@iacp.dvo.ru, igor_chernev7@mail.ru

Аннотация: Пленка Mg_2Si толщиной ~2.3 мкм была синтезирована методом реактивного осаждения Mg на Si(111) при температуре 340 °C в сверхвысоком вакууме. Фотоотклик структуры Шоттки Al/Si/Mg_2Si представляет собой колоколообразную кривую с пиком при 1047 нм и интенсивностью 29 мА/Вт, 105 мА/Вт и 195 мА/Вт при смещении 0В, 1 В и 5 В, соответственно, с шириной пика ~130 нм.

Ключевые слова: силицид магния, кремний, пленки, эпитаксия, реактивная эпитаксия, кристаллическая структура, микроскопия, фотоотклик

Финансирование: Работа выполнена за счет средств государственного бюджета ИАПУ ДВО РАН FWFW-2021-0002. А.Г. Козлов и А.О. Лембиков благодарят Министерство науки и высшего образования Российской Федерации за государственную поддержку научных исследований (госзадание № ФЗНС2023-0012).

Ссылка при цитировании: Чернев И.М., Субботин Е.Ю., Козлов А.Г., Синотова С.А., Приходченко А.В., Лембиков А.О., Прокопьева Г.А., Горошко Д.Л., Галкин Н.Г. Фотодетектор на основе кремния с контактным слоем Mg_2Si для коротковолнового ИК диапазона // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2025. Т. 18. № 3.1. С. 53–58. DOI: https://doi.org/10.18721/JPM.183.109

Introduction

Photodetectors for the 1000–1600 nm range find applications in fields such as medical imaging, health and environmental monitoring, optical communication systems, as well as sorting/identification systems [1, 2] and brain imaging [3]. The narrowband spectral photoresponse with a FWHM of ~100 nm not only reduces the impact of noise-induced illumination but also enables the development of wavelength-division multiplexing devices.

Narrow-band semiconducting Mg_2Si is known as a material for near-infrared *p-n* photodetectors and thermoelectric generators [4–6]. However, beyond these applications, there is evidence that Mg_2Si is perspective as a contact material for silicon as well. It was demonstrated [7, 8] that metal silicides (Yb, Y, Ca, Ba, Sr, Fe) are of particular interest as contact materials for *n*-type silicon because selectively open for the electronic part of the photogenerated carriers. This effect occurs due to the reduction of energy barriers at the silicide/silicon interface caused by Fermi-level pinning, leading to more efficient extraction of photogenerated charge carriers from silicon. This approach avoids overdoping of under-contact regions, thereby further reducing recombination losses.

In this work, we tested an Al/*n*-Si/Mg_2Si Schottky photodetector based on 500 μm thick Si with a Mg_2Si back contact.

Materials and Methods

Growth experiments were conducted in an ultra-high vacuum (UHV) chamber "Varian" with a base pressure of ~10^{-9} Torr. A 500 μm thick Si(111) substrate (ρ > 1000 Ω·cm) was first cleaned in a piranha solution and then degassed under UHV conditions at 650 °C for 6 hours. Subsequently, a high-temperature annealing at 850 °C for 10 minutes was performed to remove the native silicon oxide. A high-purity Mg (5N) source was degassed under UHV conditions for several hours as well. The Si substrate temperature of 340 °C was monitored using a PhotriX optical pyrometer. A magnesium portion ≈1.7 μm was deposited onto the preheated up to 340 °C substrate over ≈200 msec. Details of the Mg_2Si film synthesis procedure can be found in our previous works [9–11]. Finally, the Mg_2Si film ≈ 2.3 μm was synthesized.

The X-ray diffraction (XRD) technique was performed on a Kolibri (Burevestnik) X-ray diffractometer equipped with a Cu(29) anode operating at an excitation voltage of U = 8.86 kV, emitting radiation with an average Kα wavelength of λ = 1.54 Å. The thickness of the grown Mg_2Si film was studied with the ThermoFisher Scios 2 DualBeam scanning electron microscope (SEM). For preparing a hole with a smooth flat surface a focused Ga^+ ion beam (FIB) was used. Raman spectroscopy measurements were performed using an NTEGRA Spectra II system (NT-MDT) at room temperature with 473 nm laser excitation.

The spectral photosensitivity was measured in 420–1400 nm spectral range with a setup consisting of: a W halogen lamp, monochromator with a set of optical filters and diffraction gratings, mechanical light modulator (f = 533 Hz) and Lock-In Amplifier for signal enhancement. The current-voltage characteristics were acquired employing high-accuracy multimeters AKIP B7-78/1 and a Keithley instrument.

Results and Discussion

The procedure of sample growth and preparation for photoresponse measurements is schematically illustrated in Fig. 1, *a*. For spectral photosensitivity measurements, the sample was cut to a size of about 2×2 mm and then stacked by Ag glue (to Mg_2Si film side) in a chip with a copper pad – contact "2". The top contact "1" was fabricated with ultrasonic Al wiring to another copper pad (see Fig. 1, *b*).

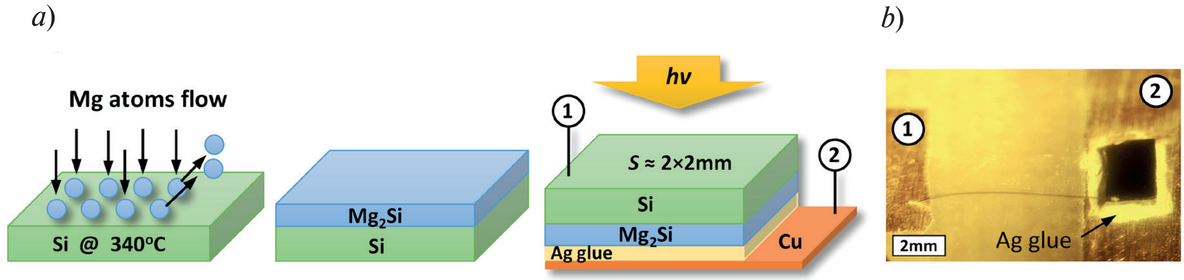

Fig. 1. Schematic growth procedure and sample preparation for photoresponse measurements (*a*), real photo of photodetector prototype. "1" and "2" are copper contact pads (*b*)

The thickness of the fabricated Mg_2Si film is ~2.3 μm, as determined by cross-sectional SEM analysis (see Fig. 2, *a*). The XRD results are presented in Fig. 2, *b*. The spectrum shows peaks associated with diffraction from the Si(111) substrate, as well as Mg_2Si peaks corresponding to diffraction from the (111) and (222) planes at 2θ angles of 24.31° and 49.81°, respectively. The calculated lattice parameter was 6.339 Å, which is 0.2% smaller than the reference value 6.351 Å [13], indicating the compressive strain.

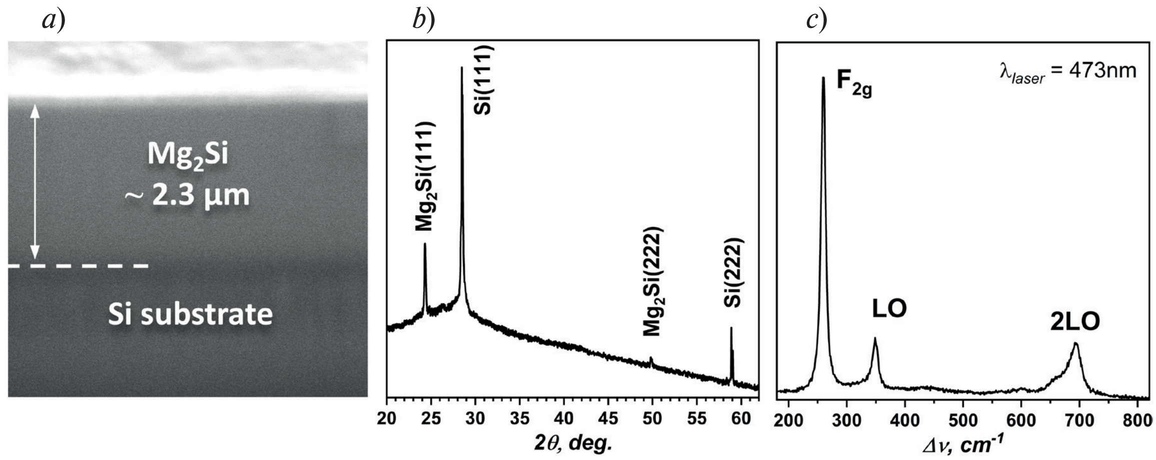

Fig. 2. Mg_2Si film on Si(111) substrate. Cross-sectional SEM image (*a*), XRD pattern (*b*), Raman scattering spectrum (*c*)

Fig. 2, *c* demonstrates Raman spectroscopy data for the grown Mg_2Si film. The intense peak at 259 cm^{-1}, along with peaks at 349 cm^{-1} and 693 cm^{-1}, are characteristic of Mg_2Si [13, 14]. The absence of the 520 cm^{-1} peak, which is typical for crystalline silicon, results from the substantial thickness of the Mg_2Si film that completely absorbs the 473 nm excitation laser radiation.

Fig. 3, *a* shows the spectral photoresponse measurements in the diode mode. The curves exhibit a pronounced peak at a wavelength of 1045 nm. The response behavior is uncommon of conventional Si *p-n* and Schottky photodiodes. For comparison, Fig. 3, *a* presents the spectral photoresponse of a commercially available Hamamatsu Si photodiode (red curve). As the external bias is applied, the signal intensity increases; however, the overall spectral behavior remains the same.

The photoresponse intensity at the peak is 105 mA/W and 195 mA/W under 1 V and 5 V bias, respectively (see Fig. 3, *a*). The Al/Si/Mg_2Si structure also exhibits a photoresponse at zero bias 29 mA/W, indicating the presence of a built-in field at the Si/Mg_2Si junction (see Fig. 3, *b*). The

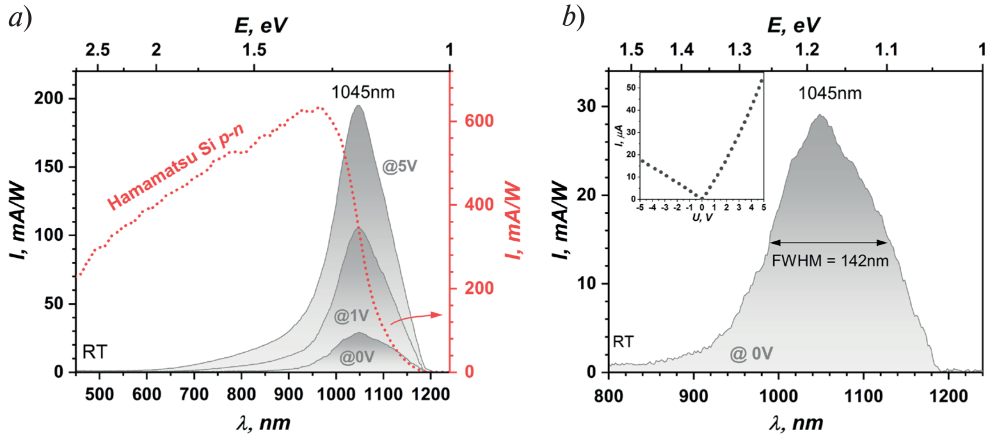

Fig. 3. Spectral photoresponse measured in diode mode, commercially available Hamamatsu Si *p-n* photodiode photoresponse curve is red (*a*), at zero-bias. I-V is in insert (*b*)

rectifying junction is further confirmed by the current-voltage characteristic, which exhibits diode-like behavior (see Fig. 3, *b*, inset). The peak photoresponse wavelength of 1045 nm corresponds to the energy of a number of indirect interband transitions in Si, while the substrate thickness filters out the short-wavelength range of the incident light.

The photoresponse measurements were performed in a configuration where the positive terminal of the external bias source was connected to the top contact "1"(see Fig. 1). The Al/Si/Mg_2Si structure forms a double Schottky junction, and the "positive-1" & "negative-2" connection geometry is forward-biasing for the upper Al/Si junction while reverse-biasing the lower Si/Mg_2Si junction.

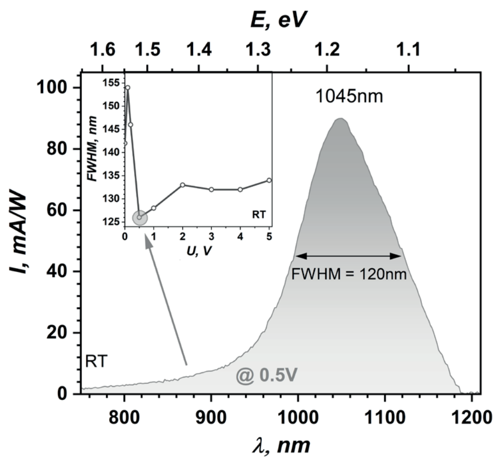

Fig. 4. Spectral photoresponse at 0.5 V bias. FWHM *vs.* bias dependence is in insert

The FWHM exhibited slight variations under different bias, measuring 128 nm and 134 nm at 1 V and 5 V, respectively (see Fig. 4, inset). The minimum FWHM of 120 nm was observed at a bias of 0.5 V (see Fig. 4), with a corresponding photoresponse intensity of 90 mA/W.

Conclusions

High crystal quality ~2.3 µm thick Mg_2Si film was fabricated on Si(111). The photosensitive structure Al/Si/Mg_2Si was prepared and spectral photoresponse was tested in diode and zero-bias mode. It was demonstrated the narrowband photoresponse with peak at 1045 nm and intensity of 29 mA/W, 105 mA/W and 195 mA/W under the 0 V, 1 V and 5 V respectively. The FWHM varies from 140nm at zero-bias to ~130 nm at 1–5 V. The lowest FWHM = 120 nm observed at 0.5 V bias and 90 mA/W intensity.

Acknowledgments

The research was carried out within the state assignment of IACP FEB RAS (Theme FWFW-2021-0002). A.G.K. and A.V.P acknowledges support from the Russian Ministry of Science and Higher Education (State Assignment No. FZNS2023–0012) as part of the SEM and XRD investigation.

REFERENCES

1. **Rathnamalala C.S.L., Hernandez S., Lucero M.Y., Swartchick C.B., Shaik A.K., Hammer N.I., East A.K., Gwaltney S.R., Chan J., Scott C.N.,** Xanthene-Based Nitric Oxide-Responsive Nanosensor for Photoacoustic Imaging in the SWIR Window, Angew.Chem. 135 (2023) e202214855.

2. **Wu Z., Zhai Y., Kim H., Azoulay J.D., Nga Ng T.,** Emerging Design and Characterization Guidelines for Polymer-Based Infrared Photodetectors, Acc. Chem. Res. 51(12) (2018) 3144–3153.

3. **Shi L., Sordillo L.A., Rodrнguez-Contreras A., Alfano R.,** Transmission in near-infrared optical windows for deep brain imaging, J. Biophotonics. 9 (1-2) (2016) 38–43.

4. **El-Amir A.A.M., Ohsawa T., Nabatame T., Ohi A., Wada Y., Nakamura M., Fu X., Shimamura K., Ohashi N.,** Ecofriendly Mg_2Si-based photodiode for short-wavelength IR sensing, Mater. Sci. Semicond. Process. 91 (2019) 222–229.

5. **Udono H., Tajima H., Uchikoshi M., Itakura M.,** Crystal growth and characterization of Mg_2Si for IR-detectors and thermoelectric applications, Jpn. J. Appl. Phys. 54 (2015) 07JB06.

6. **Zaitsev V.K., Fedorov M.I., Gurieva E.A., Eremin I.S., Konstantinov P.P., Samunin A.Yu., Vedernikov M.V.,** Highly effective $Mg_2Si_{1-x}Sn_x$ thermoelectrics, Phys. Rev. B 74 (2006) 045207.

7. **Lin L., Guo Y., Robertson J.,** Metal silicide Schottky barriers on Si and Ge show weaker Fermi level pinning, Appl Phys Lett. 101(5) (2012) 052110.

8. **Cho J., Sivaramakrishnan Radhakrishnan H., Recaman Payo M., Debucquoy M., Van Der Heide A., Gordon I., Szlufcik J., Poortmans J.,** Low Work Function Ytterbium Silicide Contact for Doping-Free Silicon Solar Cells, ACS Appl Energy Mater. 3 (4) (2020) 3826–3834.

9. **Chernev I.M., Subbotin E.Yu., Kozlov A.G., Gerasimenko A.V., Ustinov A.Yu., Galkin N.G., Poliakov M.V., Volkova L.S., Dudin A.A., and Gouralnik A.S.,** Thick *p*-type Mg_2Si film on Si: Growth, structure and transport properties, J. Alloys Compd. 964 (2023) 171301.

10. **Gouralnik A.S., Shevlyagin A.V., Chernev I.M., Ustinov A.Yu., Gerasimenko A.V., Gutakovskii A.K.,** Synthesis of crystalline Mg_2Si films by ultrafast deposition of Mg on Si(111) and Si(001) at high temperatures. Mg/Si intermixing and reaction mechanisms, Mater. Chem. Phys. 258 (2021) 123903–123910.

11. **Gouralnik A.S., Maslov A.M., Ustinov A.Yu., Dotsenko S.A., Shevlyagin A.V., Chernev I.M., Il'yashenko V.M., Kitan S.A., Koblova E.A., Galkin K.N., Galkin N.G., Gerasimenko A.V.,** Formation of Mg_2Si at high temperatures by fast deposition of Mg on Si(111) with wedge-shaped temperature distribution, Appl. Surf. Sci. 439 (2018) 282–284.

12. Powder Diffraction File Card No. 30–0080 ($CaSb_2$) and Mg_2Si (65–2988) (CD ROM), International Center for Diffraction Data (ICDD), Newtown Square, PA.

13. **Onari S., Cardona M.,** Resonant Raman scattering in the II-IV semiconductors Mg_2Si, Mg_2Ge, and Mg_2Sn, Phys. Rev. B 14 (1976) 3520–3531.

14. **Buchenauer C.J., Cardona M.,** Raman Scattering in Mg_2Si, Mg_2Ge, and Mg_2Sn, Phys. Rev. B. 3 (1971) 2504–2507.

THE AUTHORS

CHERNEV Igor M.
igor_chernev7@mail.ru
ORCID: 0000-0002-8726-9832

SUBBOTIN Evgeniy Y.
jons712@mail.ru
ORCID: 0000-0001-9531-3867

KOZLOV Aleksei G.
kozlov.ag@dvfu.ru
ORCID: 0000-0001-8774-0631

SINOTOVA Sofia A.
sinotova.sa@dvfu.ru
ORCID: 0009-0002-7285-3224

PRIKHODCHENKO Alena V.
prikhodchenko.av@dvfu.ru
ORCID: 0009-0006-2778-8143

LEMBIKOV Aleksei O.
lembikov.ao@dvfu.ru
ORCID: 0000-0003-0436-0612

PROKOPEVA Glikeriya A.
glikeriya61@gmail.com
ORCID: 0009-0008-0181-8994

GOROSHKO Dmitrii L.
goroshko@iacp.dvo.ru
ORCID: 0000-0002-1250-3372

GALKIN Nikolay G.
ngalk@dvo.ru
ORCID: 0000-0003-4127-2988

Received 31.08.2025. Approved after reviewing 25.09.2025. Accepted 30.09.2025.