



Regular article

Adhesive As-S-Se-I immersion lenses for enhancing radiation characteristics of mid-IR LEDs operating in wide temperature range



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HIGHLIGHTS

- LED integral power as a function of refractive index for two lens shapes has been simulated.
- Chalcogenide melt adhesion force towards electronic engineering materials has been determined.
- LED stability against cracking in wide temperature range has been calculated and experimentally justified.

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ABSTRACT

The influence of As-S-Se-I chalcogenide glass lenses on the integral and spectral power and pattern of LED radiation has been shown. Simulation of the influence of the refractive index on the integral power for two lens shapes has been performed. The wettability and adhesion force of As-S-Se-I melt has been determined for several electronic engineering materials. Mechanical stresses between chalcogenide glass and adjacent diode body materials have been calculated for -100 to 53 °C temperature range. Stability of the immersion lenses against cracking has been experimentally investigated for -150 to 53 °C temperature range.

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1. Introduction

Near and middle infrared devices are widely used for various applications in the $1\text{--}5\text{ }\mu\text{m}$ working range, such as chemical gas sensors, biophotonics and biomedicine [1]. Latest research in the field is dedicated to the development [2,3] and application [4,5] of IR semiconducting sources and detectors operating in wide temperature range [6,7]. However, their wide application is hindered by the low radiation output from the crystal due to the total internal reflection at the interface between the high-refractive crystal and air, significant radiation scattering and the expensiveness of suitable optical materials.

Shaping the radiant crystal into a lens shape is an unreasonably expensive solution, therefore, there is a need in a material that

would transmit in the working range, possess a high index of refraction (in order to decrease the critical angle) and provide a full optical contact with the LED's crystal. Polymeric materials are unsuitable due to the low index of refraction (usually less than 1.7). The production of lenses from monocrystalline materials is expensive, furthermore, their application demands the use of optical adhesives.

The most efficient solution is to cover the LED with an immersion lens made of glass which is transmitting in the working range and possesses both low glass softening point ($T_s < 100$ °C) and a high refraction index ($n > 2$). We have chosen the As-S-Se-I chalcogenide glasses as satisfying the abovementioned requirements. Chalcogenide glass immersion lenses multiply the radiation output coefficient several times (depending on their index of refraction and shape) and alter the radiation pattern by giving the lens a different shape. Low T_s is determined by the application temperature of the lens not exceeding 200 °C to avoid the $p\text{--}n$ transition degradation.

Abbreviations: CG, chalcogenide glass; CM, chalcogenide melt.

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2. Materials and methods

2.1. Chalcogenide glass characteristics

Chalcogenide glass $\text{As}_{12.8}\text{S}_{24.2}\text{Se}_{53}\text{I}_{10}$, has been used for immersion. The glass characteristics are the following: $T_s = 53^\circ\text{C}$, for refractive index dispersion see Fig. 1.

Glass softening point was measured with the use of BÄHR DIL802 difference-dilatometer.

Refractive index has been measured by interference fringes method [8] using an FSM-1201 FTIR spectrometer.

2.2. Lens application

The lenses were applied on LMS34 LEDs (with kovar bodies) by method of dispensing chalcogenide melt (CM), $T = 150\text{--}180^\circ\text{C}$, lens shape was adjusted by varying the mass of the drop.

2.3. Radiation patterns, radiation spectra and integral power

Radiation patterns have been plotted based on the data obtained with the use of an Lms36PD-05 photodiode and a rotating table.

Monochromator MDR-41 with a Judson J10D-M204-R01M-60 detector have been used for the recording of radiation spectra.

THORLABS IS200 series integration sphere and a Judson J10D-M204-R01M-60 detector have been used to measure integral power.

2.4. Wetting angle and surface tension

Wetting angle has been determined by means of Drop Shape Analysis method [9]. The drop mass did not exceed 0.05 g. The height and radius of the drop have been measured with the use of Leica EZ4 HD microscope.

CM surface tension has been determined by means of pendant drop tensiometry method [10]. Surface tension of sulfur at 150°C

has been determined in order to calibrate the method. The deviation did not exceed 7% [11].

Liquid/solid work of adhesion has been derived from Young–Dupre equation:

$$W_{LS} = \sigma_{\text{glass}}(1 + \cos \theta),$$

where $\sigma_{\text{glass}} = 111 \text{ mJ/m}^2$ – the surface tension of the used CM, $\cos \theta$ – the wetting angle cosine. The determined surface tension is in good agreement with that of an analogous CM given in [12].

2.5. Thermal and mechanical properties

CG thermal expansion coefficient has been measured with the use of BÄHR DIL802 difference-dilatometer (temperature range –100 to 53°C , fused silica inert sample, liquid nitrogen cooling).

Mechanical properties have been determined through measurements of the longitudinal ultrasonic wave velocities (V_L) and transverse ultrasonic wave velocities (V_T) analogous to those described in [13].

2.6. Temperature testing

Experimental testing of LED stability against cracking has been performed with the use of BÄHR DIL802 difference-dilatometer (temperature range –150 to 53°C , LED as the experimental sample, liquid nitrogen cooling). On course of the experiment, the LED was periodically switched on in order to examine its workability. After low-temperature testing visual inspection was performed with the use of a Leica EZ4 HD microscope.

2.7. Simulation

The increment of the integral power (ΔP) has been calculated with the use of the following formula:

$$\Delta P = \frac{P_{CG}}{P_0} \cdot 100\%,$$

where P_0 is the integral power of the LED without a lens, P_{CG} – the integral power of the LED with a lens.

Type A lens possesses the minimal size sufficient to completely immerse the radiant crystal and LED's upper electric contact (Fig. 4, left). Type B lens is the one that has shown maximum experimental increase of integral power (Fig. 5, left).

LEDs with two lens shapes have been simulated in Zemax software. Numerical simulation of the radiation output from the crystal and radiation patterns has been performed in the “non-sequential mode”. A rectangular radiation source, simulating a radiative p - n junction, was put inside of the LED crystal (InAs) of the size $350 \times 350 \times 250 \text{ mm}$. The wavelength of the radiation source matched the wavelength for the LED's radiation peak intensity ($3.4 \mu\text{m}$). The influence of the diode body material absorption has been omitted (“mirror” type material option).

3. Results and discussion

3.1. LED radiation patterns, radiation spectra and current-voltage characteristic before and after immersion

LED images with and without a lens are given in Fig. 2. LED radiation patterns, radiation spectra and current-voltage characteristic before and after immersion are given in Fig. 3.

LEDs with immersion lenses possess enhanced spectral power and narrowed radiation patterns, current-voltage characteristic do not change.

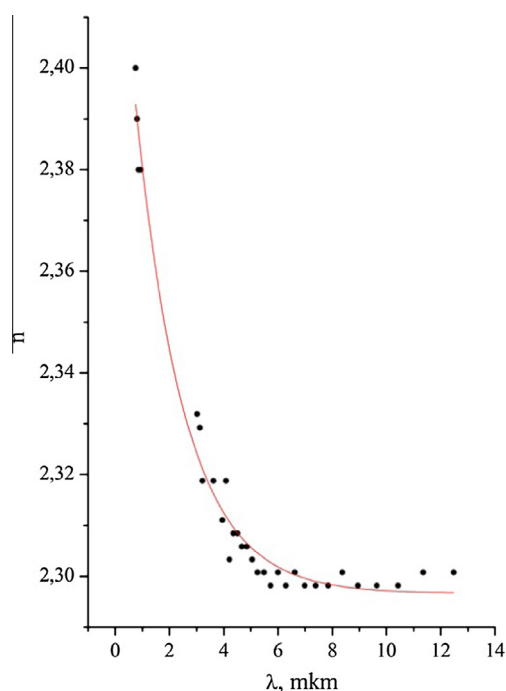


Fig. 1. Refractive index dispersion.

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