Contributed paper

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Sources of ultraviolet light and systems for its shaping for photoelectrical investigation of semiconductor structures

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Photoelectric method is one of the most precise methods for measuring parameters of semiconductor structures, e.g., contact potential difference or potential barrier high for internal photoemission. Those parameters determine such important MOS transistor parameter like the threshold voltage V_T or the flatband voltage V_{FB}. Application of the photoemission phenomenon requires effective utilisation of the light source's energy and focusing it on the surface of a small structure. This paper discusses the issues related to the construction of an illumination system for photoelectric tests of semiconductor structures for ultraviolet light range. Light sources as well as systems for radiation shaping were described. Additionally, advantages and disadvantages of mirror and lenses systems, possibility of correcting certain aberrations and obtaining appropriate frontal distance required for introducing micromanipulators with measurement needles were discussed.

Information included in this paper had a major impact on the construction of the multitask system for photoelectric tests of semiconductor structures, the authors of which received the title Technology Master – Warsaw 2001 (Mistrz Techniki – Warszawa 2001) and the first level award of the of Polish Federation of Engineering Association (Naczelna Organizacja Techniczna) for great technology achievements.

Keywords: UV light sources, semiconductor structures, illuminating systems, optical beam shaping, monochromator.

1. Introduction

Photoelectric method is an important tool for defining physical characteristics of semiconductor structures. This method is based on internal photoemission occurring in the metal oxide semiconductor (MOS) structure. Illumination of the MOS structure with a semitransparent metallic gate ensuring electric polarisation and ultraviolet radiation (UV) transmission causes that in result of quantum absorption an electron close to the semiconductor-oxide or metal-oxide surface and with sufficiently high energy can pass to conduction energy band in dielectric. Because the probability of occurrence of a similar process for holes is significantly lower, one can assume that only electron current flows and application of positive or negative potential to the gate allows testing the selected semiconductor or metal photoemission. Several physical parameters of the MOS structures, including the level of potential barrier for internal photoemission or effective contact potential difference (ECPD), can be determined based on current-voltage (I-V) and current-spectral characteristics (I-λ). Changes of these characteristics can indicate the changes of electric charges in oxide. Figure 1 presents a diagram of the measuring system.

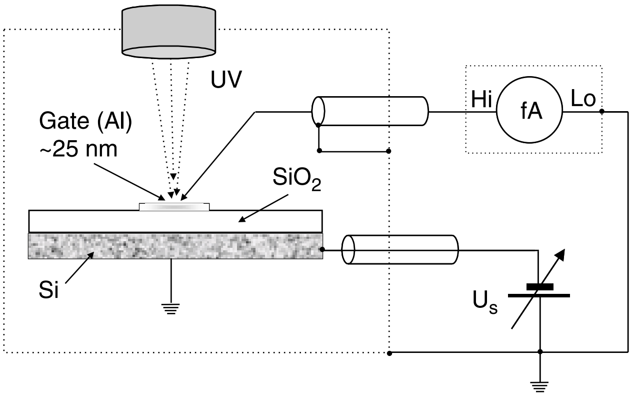

Fig. 1. MOS capacitor with translucent gate illuminated UV light.

A number of photoelectric methods for testing the distribution of charges and measuring ECPD were developed in the eighties [1–2], and subsequently improved at the Institute of Electronic Technology [3–6]. The method for ECPD measurement, after its recent improvements, is the most precise method and of a particular importance [7–8].

Monochromatic UV radiation within the wave range 200–400 nm is used in photoelectric measurement methods applied for the MOS structures of Si-SiO_2-Al type. The requirement to obtain sufficiently high radiation absorption in the emitting material constitutes a serious limitation of these methods. Therefore ensuring adequately high inten-

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sity of radiation incident on the sample is the most important prerequisite in the construction of the illuminating system for the photoelectric tests of the MOS structures.

2. Generation and shaping of light beams for testing semiconductor structures

2.1. Block diagram of the system illuminating a semiconductor structure

The illuminating system is responsible for providing possibly the largest light flux from the source through the monochromator to the surface of the tested structure. Figure 2 presents the block diagram of such a system.

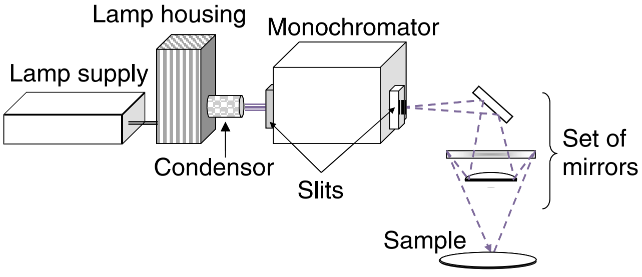

Fig. 2. Block diagram of illuminating system.

The system consists of three main blocks supplying radiation with the required wavelength and bandwidth to the surface of the tested semiconductor structure. They include: a set of the illuminator of the entrance slit of the monochromator consisting of the xenon lamp and the system focusing radiation on this slit, grating of monochromator and the optical system focusing radiation on the tested structure.

2.2. Sources of optical radiation used for testing semiconductor structures

Ultraviolet radiation (UV) 200–400 nm, first and foremost used for testing semiconductor structures, is supplied by high-pressure xenon or xenon-mercury lamps, deuterium, and excimer lamps, as well as by excimer and argon lasers. High brightness of light and limited size of discharge lamps' arc as well as their relatively low cost compared to laser light sources prefer them as the source of light for illuminating monochromators' slits. Light in these lamps is generated by electrical discharges in the atmosphere of heavy gas, mercury or deuterium vapours.

2.2.1. Xenon and xenon-mercury lamps

Spectrum of these sources of radiation is continuous from ultraviolet to infrared. Colour temperature of arc in these lamps remains within the range 5400–6000°C, depending on their power. Therefore, light of xenon discharge lamps approximates daylight. Distribution of the light brightness in the arc is non-uniform. More light is located close to the cathode. Figure 3 presents a typical distribution of the brightness of high-pressure xenon lamps.

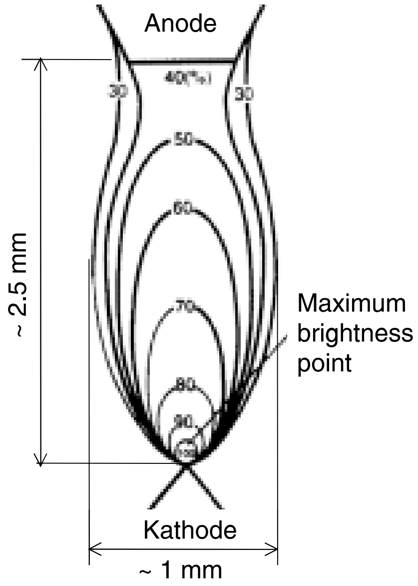

Fig. 3. Distribution of light intensity in xenon lamp arc.

In ozone-free lamps, the spectrum from the short-wave side is limited to about 230 nm. If shorter waves are required, a lamp with a quartz bulb, e.g., Suprasil glass, which ensures good transmission to 160 nm, should be used. Unfortunately, harmful ozone is produced for such wavelengths and application of these lamps requires utilisation of exhaust.

Figure 4 presents comparison of radiation spectrum of xenon, mercury, halogen, and deuterium lamp.

An analysis of spectrum characteristics presented in Fig. 4 indicates that the best results of the spectrum from ultraviolet are obtained when a xenon lamp with improved UV radiation is used. If the required spectrum is limited to ultraviolet, a deuterium lamp could be a better solution. An important parameter of the source is its power and size, because due to a need to introduce radiation through the monochromator's slit in a determined solid angle, application of discharge lamps with higher power does not result in increasing the power at the exit slit of the monochromator. Maximum radiation power that can be used depends on the monochromator's parameters and on the system for shaping the beam at the entrance slit of the monochromator.

2.2.2. Optical systems for shaping optical radiation before the monochromator's entrance slit

Lamps being the source of radiation used in the diagnosis of semiconductor structures can operate in vertical or horizontal position that has a significant impact on the con-

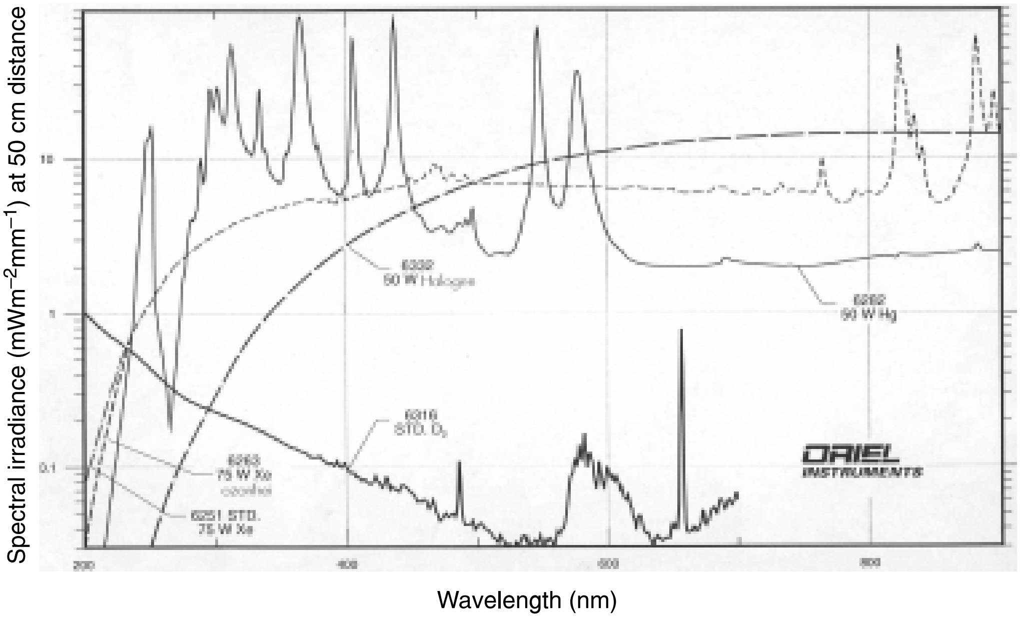

Fig. 4. Radiation spectrum for various types of lamps.

struction of optical systems focusing radiation on the exit slit of the monochromator. Figure 5 presents a system for focusing light for a lamp operating in vertical position.

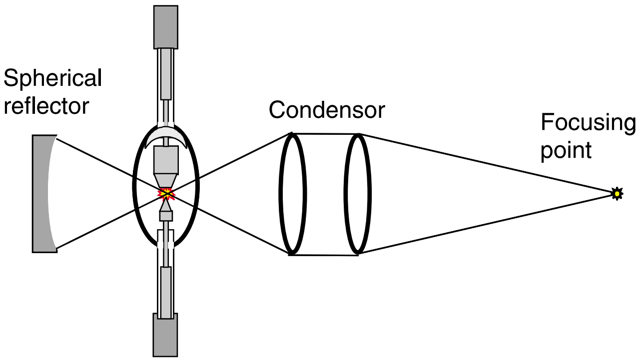

Fig. 5. System of lenses focusing light for a lamp operating in vertical position.

This system consists of a spherical mirror and lens condenser. The lens condenser consists of lenses creating an image of the lamp arc on the entrance slit of the monochromator. The main disadvantage of this solution is low light focusing effectiveness, because only a part of emitted energy incident on the mirror and lens system is used. An ability to increase solid angle of the illuminator of the monochromator's entrance slit is limited by a focal ratio of the monochromator itself. Light focusing effectiveness of such systems does not exceed 30%, and in UV range usually equals about 15%. However, the described illuminator's structure has a number of important advantages: good selection of component optical elements, easy positioning of the arc to the mirror and condenser, good focusing of the lamp's radiation beam, in particular in multilens condensers.

Disadvantages of this structure include low effectiveness, reduction of the spectrum range by the condenser's material or a need to use expensive materials, such as certain types of quartz glass, losses of power due to several reflections on the surfaces of lenses, chromatic and spherical aberration (in particular in case of simple condenser structure, sometimes including one lens) of the system shaping the beam.

Figure 6 presents the system for focusing light with ellipsoidal mirror frequently used for a lamp operating in a horizontal position.

The lamp is located in the ellipsoidal reflector which is the entire focusing element. The main advantage of this system is high effectiveness of light focusing up to 60% obtained through a significant solid angle in which the source radiation is collected, and lack of lens condenser system. Disadvantages of the system include shading of the

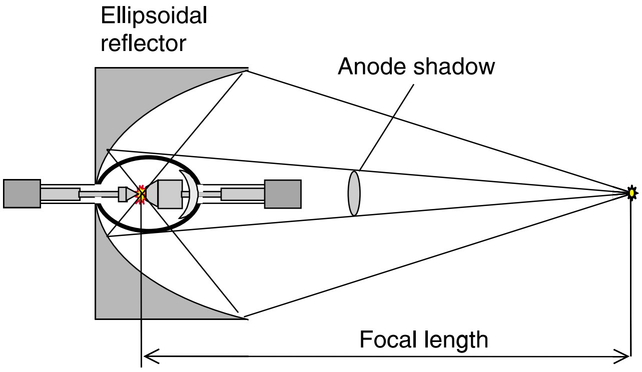

Fig. 6. System for focusing light for a lamp operating in horizontal position.

central part of the radiation beam by the electrode, significant increase in the arc image. For co-operation with the monochromator it needs to reduce solid angle of entrance beam.

3. Monochromator

Triax 180 grating monochromator, manufactured by Jobin Yvon-Spex aperture number equals 1:3.9 and focal of about 180 mm was used in the described testing stand. This monochromator is provided with two diffraction gratings (1200 gr/mm and 2400 gr/mm). Out of wide spectrum, which can be obtained from this device, mainly the range 200–400 nm, and most often the range 200–250 nm is used in tests of semiconductor structures. Utilisation of the monochromators allows continuously changing the wavelength. It makes possible precise utilisation of interference occurring in thin layers of the MOS condenser for the measurement purposes. This is controversial, whether selection of the monochromator as a unit for filtering radiation of lamps, which was mentioned before, is an optimal solution taking into consideration utilisation of this radiation and relatively high price. Potentially, it could be replaced with a set of a few interference filters for UV range.

4. Optical systems for focusing radiation from the monochromator on the tested structure

A possibility to use lens systems for illuminating semiconductor structures was analysed and verified based on calculations. The analysis included sets of two, three, and four lenses fulfilling Rayleigh's condition. It can be proved that the sets of two lenses fulfilling this condition should be produced from a material with refractive index of 2.5 [9]. Unfortunately, none of the materials ensuring good transmission of UV radiation has such refractive index. Similar situation occurs for the sets of three lenses, however, the lenses material should have refractive index of 1.75. It is a set of four lenses that can be made of the material with refractive index of 1.5. The only material with a close refractive index, transmitting UV radiation is quartz glass, e.g. Suprasil I glass manufactured by Hereaus. However, chromatic aberration cannot be corrected in such systems what causes the changes in size of resulting pictures and at the same time modifies a power density on the surface of the tested structure.

Consequently, condensers with several mirrors were developed, based on the assumption that maximum dimensions of the monochromator's entrance slit are 66 mm. This proves that the system with lateral magnification lower than one should be used. In the construction process, the Zemax v.10.0 software by Focus Software was used. Among others, the following versions of optical system's configuration were developed:

- mirror lens with focal length of about 13 mm and diameter of entrance pupil of about 16 mm. The size of the diameter of the entrance pupil arises from the value of the monochromator's aperture number of 3.9 and from the distance between the convex mirror and the monochromator's entrance slit equal about 62 mm. Required lateral magnification equalled about –0.2,
- mirror lens with focal length of about 85 mm and diameter of entrance pupil of about 52 mm. Required lateral magnification equalled about –0.41.

This paper presents the results of correcting the second of the aforementioned systems for shaping the beam illuminating the tested structure. Taking into consideration a good correction of spherical and field aberrations, the possibility of constructing a system consisting of two mirrors with axial centres displaced of curvature was verified. Such systems are usually built as concentric systems, i.e., the systems with a common centre of the elements' curvature [10]. However, in this case we have dropped this verified model in order to avoid a huge increase in the diameter of the concave mirror. Figure 7 presents the diagram of the system.

The mirror system operates correctly in a very wide range of wavelengths (from 200 nm even to tens of micrometers with a limited selection of coverings coatings for reflecting surfaces), which is opposite to systems including refraction elements, e.g. lenses. Figure 8 presents a sequence of interferograms for this system for a number of different field co-ordinates.

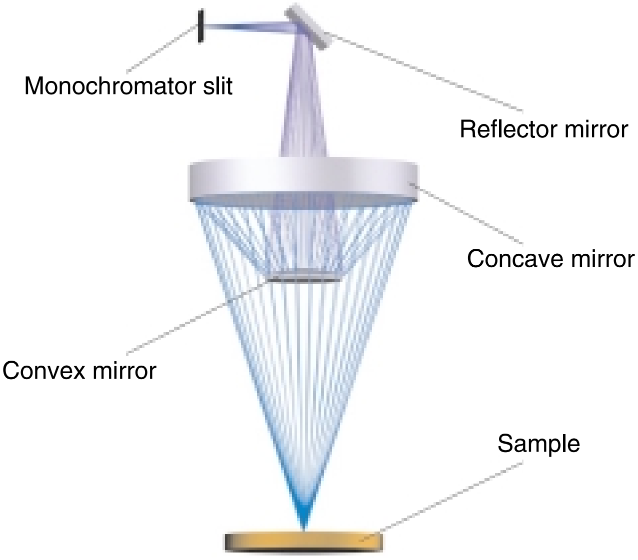

Fig. 7. Diagram of the optical system of mirror lens with axial centres displaced of curvature.

5. Mechanical structure of the system focusing optical radiation on the surface of tested structures

Except for fastening, the mirror holders should allow for angle and linear orientation of the mirrors. Angle orientation is controlled with a pair of supporting and contracting screws lo-

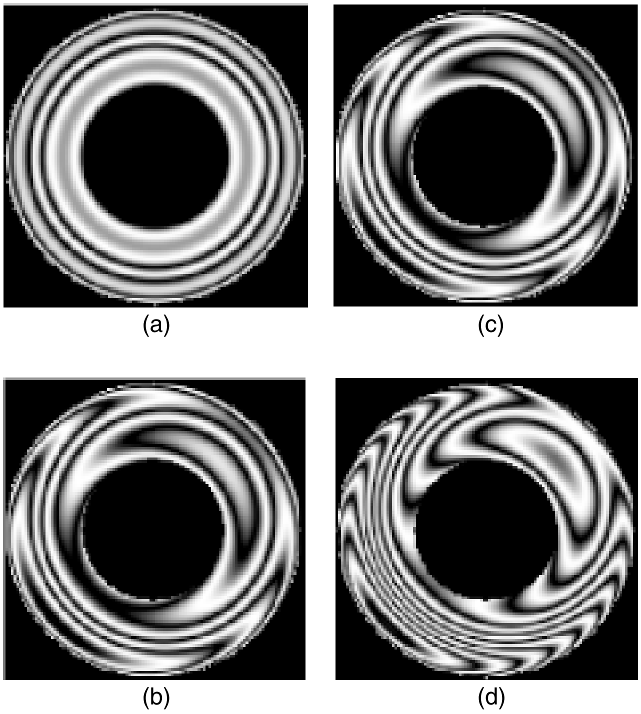

Fig. 8. Interferograms for the illuminating mirror system (a) zero-value of the analysed area, (b) linear analysed area equal 1.41 mm, (c) analysed area equal 2.83 mm, (d) analysed area equal 4.24 mm. The maximum value of the deformation of the wave front, that does not exceed 10 for the wavelength of 550 nm in the extreme point of the area [see (d)].

cated every 120° on the edge of rings fastening the mirror. The convex mirror can be aligned to the concave mirror using a hub structure used in mirror telescope systems.

Figures 9 and 10 show how the optical elements (presented in Fig. 8) are fixed. A part of the monochromator is visible at the right of the picture and a part of the stage on which the tested structures are fixed can be seen at the bottom.

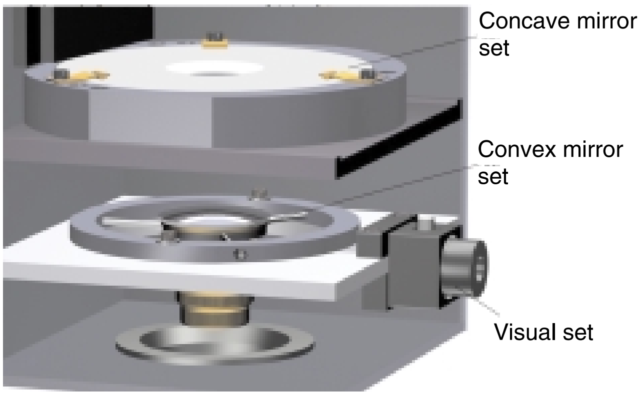

Fig. 9. Mirrors holders responsible for regulating angle and linear orientation.

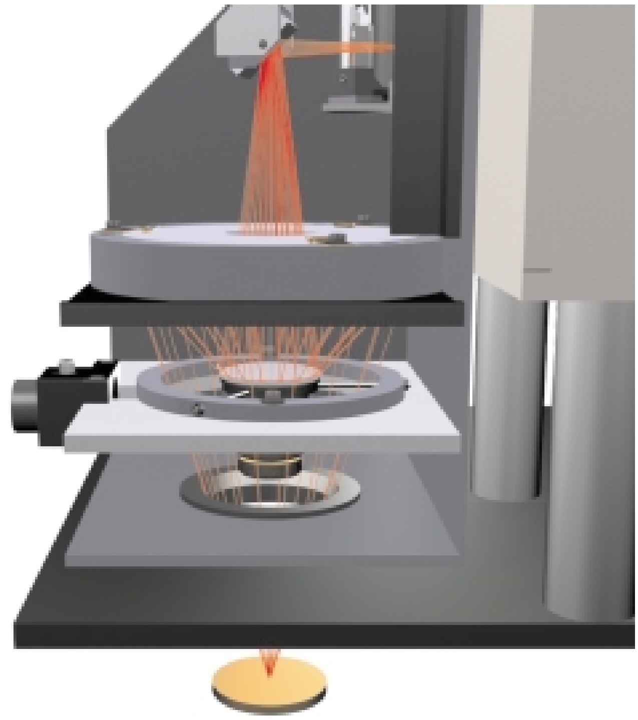

Fig. 10. View of fixed elements of the optical system shaping beam of radiation from the exit slit of the monochromator.

6. Conclusions

The paper presents a solution regarding the system illuminating semiconductor structures in photoelectric measurements. Advantages of these solutions include achromatism, limited distortion of the wave surface of the light beam and large working space. Achieved parameters are unattainable in lens systems.

Acknowledgements

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