Simple apparatus for moderate wave length tuning by means of uniaxial stress

N Ya Minina, E V Bogdanov and S S Shirokov
Physics Department, Moscow State University, 119991 Moscow, Russia
E-mail: min@mig.phys.msu.ru

Abstract. We describe a simple cryostat combined with a device for uniaxial compression up to 4 kbar that permits optical measurements and a moderate electroluminescence wave length tuning at liquid nitrogen temperatures.

1. Introduction
It is well known that optical experiments under the pressure (for both hydrostatic and uniaxial ones) need rather complicated and expensive apparatus, especially at low temperatures. In the present paper we describe a simple optical cryostat with a uniaxial stress device inside for investigations of photoluminescence, electroluminescence and photoconductivity spectra at liquid nitrogen temperature that is cheap and easy in manufacturing. It will be shown that apparatus may be successfully used for electroluminescence investigation and the wavelength tuning by uniaxial compression.

2. Apparatus description
The optical cryostat depicted in figure 1 consists of a plastic foam cylindrical cup (1) with a window (2) made of a thin-walled steel tube covered with a 20 μm polythene film from both sides. Liquid nitrogen (3) is poured from a liquid nitrogen transport container to the bottom of plastic foam cup via a vinyl tube (4) and, in the case of excess, may pour out through the upper tube (5). The level of liquid nitrogen in the cryostat is checked with the help of differential thermocouple by zero electro-moving force (e.m.f.) between thermal junctions A and B. If e.m.f. value starts increase, the additional liquid nitrogen should be poured from the transport container by switching on a special heater inside it. The cryostat is firmly connected with the upper part (6) of the stretching device that has been described previously [1]. The lower part of this device depicted in figure 2 is inside the cryostat with the sample being just opposite the optical window in figure 1. The last one is better to be manufactured as a separate unit with thin glass instead of a polythene film and a pumped inner volume.

In the method used for uniaxial compression, a sample in the form of a parallelepiped is firmly fastened with epoxy in an elastic steel ring along the “Y” direction, and afterward a tensile stress is to be applied to the ring in the “X” direction (see figure 2a). The ring transforms a tensile stress into a compressive one, applied to the both ends of the sample in the plane of the ring. Axial distribution of the stress in the ring and a rigid fastening in the ring prevent the sample of a premature destruction. The tensile stress is applied with the help of two steel tubes in stretching device (see figures 1 and 2b): the outer one serves for a fixation of the lower part of the ring, and the inner one – for the tensile stress F transmission from the calibrated spring (figure 1) to the ring. Elongation of the spring may be performed in any convenient way. In our device we use a screw but with the special unit that prevents
the spring rotation. In the apparatus described above the sample is open for all optical measurements, and uniaxial compression can be performed step by step in liquid nitrogen during one experiment.

Figure 1. Schematic view of the optical cryostat with the stretching device inside as described in section 2.
1 - plastic foam cylindrical cup; 2 – optical window; 3 - liquid nitrogen source; 4, 5 - vinyl tubes; 6 - stretching device; 7 - elastic ring with the sample (see figure 2); 8, 9 - steel tubes; 10 - calibrated spring; A-B – thermocouple junctions.

Figure 2. (a) Sample (1), ring (2), “holder” for the fixation in the stretching device (3). (b) Ring fixation in the stretching device.

For photoluminescence measurements a proper optical fiber is to be inserted through the plastic foam wall of the cryostat for the sample illumination. Optical fiber may be used also in place of the window.

The uniaxial compression of samples is calibrated in dependence on $F$ by X-ray diffraction measurements. From calculations made on the base of X-Ray data, the useful empirical correlation (figure 3) was determined. It is used to find a compressive force $F_s$ applied directly to the sample from the tensile force $F = F_{ring}$, which is applied to the ring. The calibration curve depicted on figure 3 permits the evaluation of the direct compressive force for the samples of different cross sections $A$ and Young Modulus $E_s$ with about 10% accuracy, if only the ring dimensions and elastic properties are preserved.

In our calibration experiments the rings with inner diameter $D_{in} = 3$ mm, outer diameter $D_{out} = 4.5$ mm and thickness $d = 0.75$ mm were cut by the electro-erosion method from nonmagnetic steel. The
sample dimensions are determined by the ring. It is evident (see figure 3) that at the same tensile force \( F = F_{\text{ring}} \) the samples with the same \( E_s \) but smaller cross section \( A \) experience higher uniaxial compression \( P = F_s/A \).

**Figure 3.** Ratio between compressive force \( F_s \) applied to the sample and tensile force \( F = F_{\text{ring}} \) applied to the ring for samples with different cross sections \( A \) (squares) and samples with different Young Modulus \( E_s \) (circles). Calculations are made on the base of X-ray measurements.

At present we have performed experiments only in liquid nitrogen, but this kind of cryostat may be also used in gas-flow regime for experiments in intermediate region of temperatures over 77 K. In this case, a special back coupling between the sample temperature (thermocouple e.m.f.) and the level of nitrogen flow (heater in the liquid nitrogen transport container) should be adjusted according to the experimental needs. It should be noted that the described technique for uniaxial compression can not be used at temperatures higher than approximately 220 K, because the thin epoxy layer between the sample and the ring starts to be rather plastic and stops to transfer compression.

3. Electroluminescence experiments

Below, we present some results on the influence of uniaxial compression up to \( P = 4 \) kbar on the electroluminescence (EL) spectra of \( p-\text{Al}_{x}\text{Ga}_{1-x}\text{As}/\text{GaAs}_{1-y}\text{P}_{y}/n-\text{Al}_{x}\text{Ga}_{1-x}\text{As} \) heterostructures usually used in commercial TM emitting 800 nm high-power diode lasers, that were obtained using our uniaxial stress technique combined with optical cryostat described above. The samples were in size \( 3\times0.55\times0.45 \) mm. The current was normal to the structure, and the external compressive stress was applied along \([110]\) direction. In such a case, the light emission was studied in the direction perpendicular to the compressive stress.

In figure 4 electroluminescence spectra taken at 300 K and 77 K without any external stress are represented. Figure 4 well illustrates that only cooling up to liquid nitrogen temperature shifts the spectral maximum on about 45 nm to the blue region of spectrum and makes it much sharper.

**Figure 4.** Normalized electroluminescence spectra measured without any external stress at temperatures: 1 – 300 K, 2 – 77 K.
The dependence of EL spectra on the stress along the [110] direction at 77 K is shown in figure 5. EL spectra at the red edge of the visible region taken without any stress applied have peaks at a wavelength of $\lambda \sim 753$ nm (i.e. at a photon energy of $E_{\text{ph}} \sim 1.646$ eV). The spectral maxima show a blue shift towards higher photon energies and demonstrate an increase of the EL intensity by a factor of 2 and more with increasing uniaxial compression up to $3 \div 4$ kbar. The peak photon energy changes slightly in a sublinear manner under an applied uniaxial stress with initial slope of $\frac{dE_{\text{ph}}}{dP} \approx 7.2$ meV/kbar. The shift of the spectral maximum with the applied stress is absolutely reversible in the investigated pressure area and reaches maximum values of $\Delta E_{\text{ph}} \approx 25$ meV. The presented shift of the transition photon energy under uniaxial compression shown in figure 5 is connected with increase of the energy gap in the quantum well material GaAs$_{1-y}$P$_y$.

![EL spectra measured at a temperature of 77 K under uniaxial compression along [110] direction P: 1 – 0, 2 – 1.3 kbar, 3 – 2.6 kbar, 4 – 3.9 kbar.](image)

Figures 4 and 5 are represented in this paper for illustration of the experimental set up. More complete information about these experiments and discussion is available in [2] and will be also published elsewhere in the near future.

**4. Conclusion**

We have described the simple optical cryostat with uniaxial stress device that operates at liquid nitrogen temperature and may be manufactured in Institution or University workshops. The apparatus is suitable for photoluminescence, electroluminescence and photoconductivity measurements, if an expensive set up is not available and for testing or temporary experiments. It permits a moderate diode wavelength tuning (spectral shift about 25meV) by uniaxial stress and may be useful, for example, in the course of impurity levels investigation in semiconductor structures.

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**References**

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