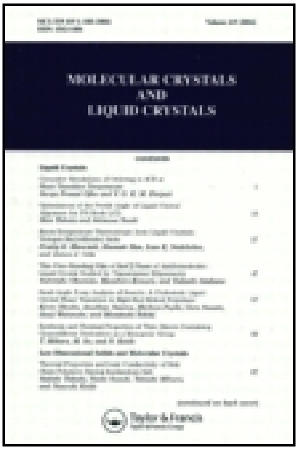

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Diarylethenes in Astrophysics: From Materials to Devices

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Diarylethenes in Astrophysics: From Materials to Devices

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The photochromic properties of transparent/opaque transition and the change of the refractive index (Δn) have been exploited to develop devices for astronomical spectrographs, both as focal plane masks and as dispersive elements (volume phase holographic gratings, VPHGs), respectively. In both cases the possibility to write and erase with suitable irradiation has revealed a new perspective for non-disposable and fully customisable items for spectroscopy. High contrast focal plane masks based on the photochromism of poly-1,2-bis(2-methyl-3-thienyl)perfluorocyclopentene have been obtained. Concerning the use of photochromic molecules as dispersing elements, low molecular weight diarylethenes and diarylethenes polymers have been considered and ellipsometric measurements were carried out to determine the refractive index change which accompanies the photochromic process.

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Keywords: diarylethenes; focal plane masks; photochromism; volume phase holographic gratings

INTRODUCTION

A modern telescope is usually equipped with a spectrograph whose function is to resolve light, which is collected by the telescope, into its components to be analysed. A spectrograph for astronomical observations is composed of a mask with slits, a collimator, filters, dispersing element, camera and detector. We have investigated the possibility of exploiting the reversible changes of physico-chemical properties that accompany photochromic reaction using selected diarylethenes [1] for the development of novel focal plane masks and volume phase holographic gratings. These applications are based on the change in transmittance and in refractive index between two isomeric forms, respectively.

PHOTOCHROMIC FOCAL PLANE MASKS

Spectrographs for astronomical observations are equipped with devices which allow to select the light of sky objects of interest in the field of view of the instrument, namely focal plane masks. Focal plane mask (FPM) is a flat sheet, usually metallic, located at the focal plane of the telescope and perpendicular to the light beam axis having well-defined custom slits. Aside from the commonly used single long slit, FPMs with custom slits makes multi object spectroscopy (MOS) possible: the slits are opened in correspondence of the position of several objects, thus making possible to take numerous spectra in a single exposure. MOS masks are custom fabricated with a few extremely precise methods, such as punching machines and laser cutters. Well-established production technology and maximum contrast at every wavelength are the most important characteristics of the traditional focal plane masks. The main drawback of these devices is that any time an observation has to be made, a new mask is needed; using “disposable” masks becomes a trouble if the spectrograph is not easily reachable, such as in spaceborne telescopes.

Our idea was to obtain rewritable FPM exploiting the basic concept of photochromism: [2,3] the transmission spectra of the two possible forms of diarylethenes show very different values in the UV-vis region, namely very high transparency in the visible range for the open form and absorption for closed form. This effect mimics, at the molecular level, the opaque (metal) – transparent (slit) elements in FPMs; by

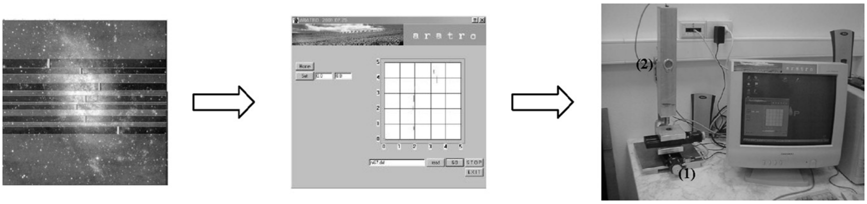

FIGURE 1 Reading and writing procedure for ARATRO.

UV irradiation the photochromic FPM can be made "opaque" while the "slits" pattern can be easily written with a suitable laser. Because of the reversibility of the process, the observation pattern can be written and erased many times, thus obtaining a rewritable FPM.

ARATRO was built as setup for the writing of photochromic focal plane masks [2]. As shown in Figure 1, it consists of two PC controlled perpendicular stages (1), a column which holds a diode laser (660 nm, 40 mW) mounted on a focus system (2). Since the laser focus can be custom changed, it is possible to vary in a continuous range the width of the slit written on the photochromic layer; this certainly represents one of the advantages with respect to the traditional focal plane masks.

Poly-1,2-bis(2-methyl-3-thienyl)perfluorocyclopentene (compound **1**, Fig. 2) has been chosen as diarylethene chromophore for developing photochromic MOS masks: it shows absorption spectrum well-tuned with the spectral range of astronomical interest, the closed form being characterised by a broad band covering a wide spectral range of the

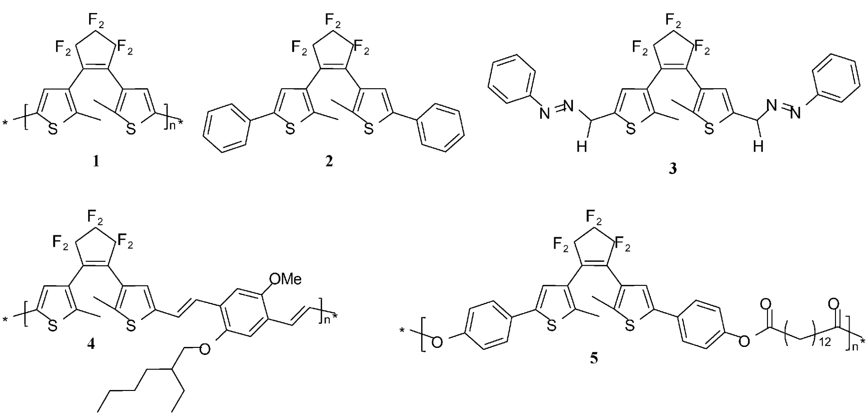

FIGURE 2 Molecular structures of the diarylethene derivatives used in this study.

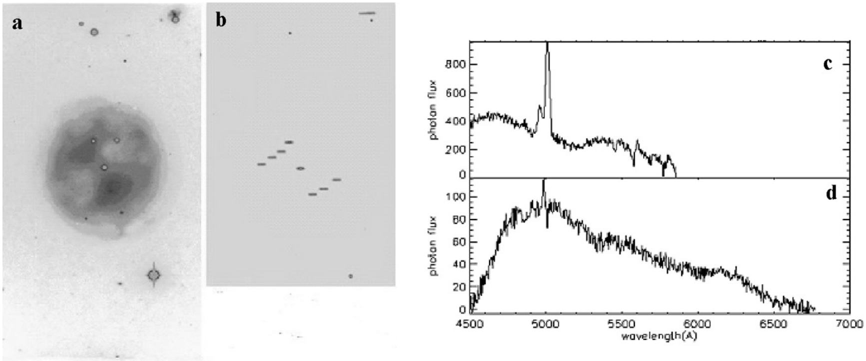

FIGURE 3 Sky test of photochromic FPM.

visible. Moreover, the absence of thermochromism, verified at 80°C over 3 months, guarantees the stability of the written pattern. Characterisation and photochromic properties of **1** have been reported elsewhere [4,5].

For sky tests, 50 by 50 mm photochromic masks consisting of films of polymethylmethacrylate (PMMA) with a content of 6% of **1** have been prepared. It was not possible to use the photochromic molecule as it is in the bulk, but a polymer matrix was needed to obtain good mechanical properties of the device and user-friendly manipulation.

As an example of a result obtained using photochromic masks, data of the Owl nebula (M97) are reported. Figure 3 shows the observation field (a) and the photochromic mask with the pattern written in real time during the observation night (b). In spite of the limited spectral working range and the non complete opaqueness of the photochromic mask in the closed form, data collected were actually reduced following the standard procedure used for traditional masks. We were able to extract the spectra of the emission of the nebula (Fig. 3c) and of the central nebula star (Fig. 3d).

PHOTOCHROMIC VOLUME PHASE HOLOGRAPHIC GRATINGS

Diffraction grating is a fundamental part of spectrograph whose function is to disperse the collected light into its monochromatic components to be analyzed. Surface relief gratings are usually produced, where light is diffracted into discrete directions by a number of grooves ruled on the grating surface by a diamond tool. Replacement of classical grooves by a regular change of the refractive index of the

TABLE 1 Molecular Weights and Δn (Measured by Ellipsometry at 1500 nm) of the Investigated Diarylethenes

Sample	2	3	4	5
Molecular weight [g/mol]	520.5	604.6	12000*	6200*
Δn (1.5 μm)	10^{-4}	$5.0 \cdot 10^{-3}$	$3.1 \cdot 10^{-2}$	$1.1 \cdot 10^{-2}$

*For polymers, molecular weight corresponds to M_w.

material has been proposed as an alternative, and volume phase holographic gratings (VPHGs) have been obtained. Compared with surface relief gratings, volume phase holographic gratings exhibit larger efficiencies and great flexibility, high density lines being possible even on curved and large surfaces.

Due to the variation of refractive index between the two states, photochromic materials may be useful for the construction of volume phase holographic gratings.

To this aim, a series of both low molecular weight diarylethenes (compounds **2** and **3**, Fig. 2), embedded in PMMA with a content of 5.8% wt., and backbone diarylethene polymers (polymers **4** and **5**, Fig. 2) have been prepared and Δn of each sample was measured by ellipsometry [5]. The results at 1500 nm are reported in Table 1. This wavelength was chosen since it is well above the absorption of the closed form and for its relevance in technology.

Considering the low molecular weight diarylethenes (compounds **2** and **3**), it is apparent that there is a structure-property relationship strongly dependent on the presence of electroactive substituents (compound **3**) [6]. Moreover, a further increase of Δn (of one order of magnitude) has been achieved using proper diarylethene polymers (polymers **4** and **5**) whose average molecular weights are large enough to allow the preparation of amorphous films even without any polymer matrix of support. It is worth noting that Δn obtained with backbone diarylethene polymers is comparable with that of dichromated gelatin, presently used as materials for VPHGs.

CONCLUSIONS

We demonstrated the usefulness of photochromic molecules for the realization of devices for non-disposable and fully customisable items for astronomical spectroscopy. Rewritable photochromic FPMs have been actually obtained and a real sky observation was carried out and reported. Concerning the dispersing elements, novel backbone diarylethenes polymers have been proposed as material for the realisation of VPHGs, the Δn obtained being as large as that typical of dichromated gelatin.

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