Data Article

Effect of methyl terminal and ethylene bridging groups on porous organosilicate glass films: FTIR, ellipsometric porosimetry, luminescence dataset

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\textbf{A B S T R A C T}

A dataset in this report is regarding an article, “A detailed ellipsometric porosimetry and positron annihilation spectroscopy study of porous organosilicate glass films with various ratios of methyl terminal and ethylene bridging groups” [1]. The data of porous organosilicate glass (OSG) low-k films was obtained by Fourier-Transform Infrared spectroscopy (FTIR), Ellipsometric Porosimetry (EP), Photoluminescence (PL) Spectroscopy. The data shows that the mechanical properties of OSG low-k films are principally controlled by introducing both terminal methyl and bridging organic groups, and porosity with proper pore size. The dataset presented here gives additional details regarding properties of carbon bridged OSGs presented in the paper [1]. Also, the data may give the impact of both terminal methyl and bridging ethylene groups on as deposited and thermally cured OSG films. Particularly, we added some details about FTIR, EP (especially related to calculation of the internal surface area)

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and UV induced luminescence. The data allow to test experimental and theoretical investigations of OSG low-k materials that might use in microelectronic fabrication industry and also might be used to extend beyond the analysis reported in the accompanying manuscript, and may aid for other applications of OSG materials.

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### Specifications Table

| Subject | Materials Science |
| --- | --- |
| Specific subject area | Chemical composition and porous structure of carbon bridged organosilicate glass (OSG) low-k films |
| Type of data | Table, Graph, Figure |
| How data were acquired | Absorbance spectra were acquired with Fourier-transform infrared (FTIR) spectrometer (JASCO FT/IR-6300). The thickness, refraction index, Young’s modulus, porosity, and pore size, distribution, specific surface area of the films data were analysis using SENpro spectroscopic ellipsometer with SpectraRay/4 software for data analysis (SENTECH, Germany). Dielectric constants are estimated from capacitance-voltage measurement with Agilent B1500A LCR meter. The UV induced luminescence spectra were recorded with JASCO FP-8300 spectrofluorometer (excitation source: Xenon arc lamp). |
| Data format | Raw, Analyzed |
| Parameters for data collection | OSG low-k films, –Si–CH₂ and –CH₂–CH₂– bridging groups, porogen concentration (0–50 wt%), films were cured in air and N₂ (soft baked and hard baked) for absorbance spectra, changes of thickness, refractive index, pore radius, porosity, Young's modulus, and dielectric constants on porogen concentrations or porosity and curing ambient, effect of porosity on specific surface area and UV induced luminescence. |
| Description of data collection | OSG low-k films with different concentration of –Si–CH₂ and –CH₂–CH₂– bridging groups with 0–50 wt% porogen loading were spin-on deposited on 100 mm Si wafers (1–10 Ω·cm). Then, the IR absorbance spectra of all films were collected after curing in air and in N₂ within wavenumber range from 4000 to 400 cm⁻¹. Atmospheric pressure ellipsometric porosimetry was used to evaluate porosity and pore size distribution. The specific surface area was calculated from the corresponding pore volume and pore radius of cylindrical pore. UV (6.2 eV) induced luminescence was analyzed in the photon energy range from 5.9 eV to 1.65 eV. The details of the data collection procedure are presented in experimental methods section. |
| Data source location | North China University of Technology, Beijing, China; Institute of Semiconductor Physics, Novosibirsk, Russia; MIREA – Russian Technological University (RTU MIREA), Moscow, Russia. |
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### Value of the Data

- The data are useful to understand properties of porous OSG low-k films with different ratio of terminal –CH₂ and bridging –CH₂–CH₂– groups.
- Micro- and nanofabrication industry can benefit from these data. Also, this work is beneficial for the modern integrated circuits (ICs) technology.
• The data could be utilized as references to improve the mechanical properties when a careful selection of bridging groups, the study of micropore structure and the curing optimization are needed.
• These data also represent the thermal stability of ethylene bridging groups in OSG films and how the pore structure is destructed for the fabricated films.
• The presented data could help researchers to select bridging groups for further improvements of mechanical properties of OSG films.

1. Data Description

The shared data are in support of the article [1] that represents the effects of methyl terminal and carbon bridging groups on critical properties of porous OSG films.

FTIR spectra of the hybrid organosilicate films containing both the methyl terminal and ethylene bridging groups were studied. The films were deposited using precursors containing different ratio of 1,2-bis(trimethoxysilyl)ethane (BTMSE) and methyltrimethoxysilane (MTMS) via spin-on coating method. The BTMSE/MTMS ratio in the precursors was varied as 25/75, 33/67, and 47/53 (the BTMSE content was accordingly equal to 25; 33; 47 mol %) and labeled as 04, 08, and 12, respectively.

The chemical compositions of all the OSG films (samples of 04, 08, 12 series with different porosity) cured in the air and N₂, soft baked (SB) at 150 °C for 30 min and hard baked (HB) at 400 °C for 60 min, were deduced from the FTIR spectra (Figs. 1-9) (Raw data in Supplementary

![Fig. 1. Entire fingerprint region (a) and its local ranges (b, c, d) of FTIR spectra of ethylene-bridged OSG films soft baked (SB) at 150 °C in the air with different Brij30 content (0–50 wt%). The films were labeled as 04 correspond to the BTMSE/MTMS ratio of 25/75.](image)
Fig. 2. Entire fingerprint region (a) and its local ranges (b, c, d) of FTIR spectra of ethylene-bridged OSG films hard baked (HB) at 400 °C in the air with different Brij30 content (0–50 wt%). The films were labeled as 04 correspond to the BTMSE/MTMS ratio of 25/75.

material). Figs. 1, 4 and 7 show the FTIR spectra of 04, 08, and 12 samples respectively, after SB and Figs. 2, 3, 5, 6 and 8, 9 show the FTIR spectra of low-k samples after HB with different porogen concentrations (0–50 wt%).

The hydroxy and silanol groups (O–H, –Si–OH) in the films have specific absorption peaks at 3700–3100 cm⁻¹ and near 950 cm⁻¹, C=O group at 1750 cm⁻¹. The CH₈ groups are visible in the band range 3000–2800 cm⁻¹ and C–H groups at 1460 cm⁻¹. The presence of Si–CH₃ groups can be seen from the peaks at ~1275 cm⁻¹ and ~2970 cm⁻¹ [2]. The absorption band at 1250–1000 cm⁻¹ correspond to Si–O stretching modes.

Fig. 1 shows the SB samples series 04 with different template concentration. The concentration of the remaining Si–OCH₃ and Si–OH groups in soft baked films depends on the amount of introduced template (porogen) [3]. The sample 04 after HB in air shows C–H stretching vibrations near 2900 cm⁻¹ (Fig. 2b) [4].

Figs. 4 and 7 show the SB samples 08 and 12. The samples 04 with different porogen loading after HB in the air show Si–CH₃ groups in the regions 3000–2800, 1285–1265, and 950–650 cm⁻¹ (Fig. 2b, c (inset), and d). The HB samples 08 and 12 show C–H bonds of non-hydrolyzed methoxy groups (~2840 cm⁻¹), not condensed silanols (~950 cm⁻¹), Si–C bonds (~830 cm⁻¹) and C–C bonds (~720 cm⁻¹), (Figs. 5 and 7).

Table 1 shows the details of raw data for the dependence of film properties (thickness, refractive index, pore radius, porosity, Young’s modulus, and k-value) on the porogen and the carbon-bridge content (Brij30, 0–50 wt%) after HB in the air (400 °C, 30 min) and in N₂ (400 °C, 60 min).

Heptane adsorption/desorption isotherms of the films with 0–50 wt% porogen loading HB in the air and N₂ (Fig. 10) (Raw data in Supplementary material) show change of pore structure
versus template concentration and curing conditions. The films deposited with 75% and 67% MTMS (samples 04 and 08) without porogen cured in air and N\textsubscript{2} have intrinsic porosity about 9%.

A slow temperature ramp in the air curing comparable to that in N\textsubscript{2} curing was also performed for 50% porogen content samples (04, 08 and 12). These samples are labeled as Air(STR) and shown in Fig. 11 (Raw data in Supplementary material).

The values of specific surface areas for ethylene bridged OSG films calculated from EP data are demonstrated in the Fig. 12 (Raw data in Supplementary material). One can see that specific surface areas of all films were varied from 300 to 600 m\textsuperscript{2}/cm\textsuperscript{3} with calculated accuracy ±40 m\textsuperscript{2}/cm\textsuperscript{3} and depend on porosity and thickness.

The UV induced luminescence of different OSG films studied in this work are shown in the Fig. 13 (Raw data in Supplementary material). Three major luminescent peaks were observed in these experiments. These peaks are typical for all studied samples but their intensities depend on precursor composition and curing.

2. Experimental Design, Materials and Methods

Organosilicate glass low-k films were prepared by acid-catalyzed condensation of 1,2-bis(trimethoxysilyl)ethane (BTMSE, 97%, Aladdin, LLC. China) with methyltrimethoxysilane (MTMS, 98%, Sigma-Aldrich, LLC. China) in tetrahydrofuran (THF, 99.5%, Energy-Chemical Shanghai Co., Ltd., China) using a sol-gel spin-on methods. The schematics of MTMS and BTMSE precursors are shown in Fig. 14.
Fig. 4. Entire fingerprint region (a) and its local ranges (b, c, d) of FTIR spectra of ethylene-bridged OSG films soft baked (SB) at 150 °C in the air with different Brij30 content (0–50 wt%). The films were labeled as 08 correspond to the BTMSE/MTMS ratio of 33/67.

The formation of hybrid OSG films was based on hydrolysis and condensation of MTMS and BTMSE precursors:

\[ Si - OCH_3 + H_2O \rightarrow Si - OH + CH_3 - OH \] (hydrolysis)

\[ Si - OH + HO - Si \xrightarrow{\text{condensation}} Si - O - Si + H_2O \]

The BTMSE precursor containing ethylene bridges is co-condensing with hydrolyzed MTMS precursors and forms the final hybrid structure (copolymer) (Fig. 15).

The spin-on coating solutions were a mixture of BTMSE, MTMS, THF, H_2O and HCl, and heated at 60 °C under stirring for 16 h and stored for 24 h at room temperature. Films were deposited by using BTMSE/MTMS ratio from 25/75, 33/67, and 47/53 (the BTMSE content was accordingly equal to 25; 33; 47 mol%). The molar ratio of H_2O/THF with BTMSE/MTMS was 2.25/6. Then, the different amount of Brij30 template (C_{12}H_{25}(OCH_2OCH_2)_4OH with MW = 362 g/mol) was added and stirred. The template content was varied in the range of 0–50 wt%. The films were spin-on deposited onto 100 mm Si wafers (1–10 Ω•cm) at the rotation speed of 2500 and/or 8000 rpm and soft baked (SB) in an oven at 150 °C for 30 min in the air. Then, the wafer was cleaved into two pieces, and each piece was hard baked (HB) in a different oven, one was baked at 400 °C for 30 min in the air while the other was baked at 400 °C for 60 min in N_2. Finally, the data were obtained from as-deposited and thermally cured OSG low-k films.

To study the chemical composition of the deposited films, infrared (IR) absorbance spectra was obtained by using FT/IR-6300 Fourier-transform infrared (FTIR) spectrometer (JASCO, Tokyo, Japan). The absorbance spectra of the deposited films were obtained in transmission mode with a resolution of 4 cm\(^{-1}\) (at least 64 scans) in the range 4000 to 400 cm\(^{-1}\). The wavenumber accu-
Fig. 5. Entire fingerprint region (a) and its local ranges (b, c, d) of FTIR spectra of ethylene-bridged OSG films hard baked (HB) at 400 °C in the air with different Brij30 content (0–50 wt%). The films were labeled as 08 correspond to the BTMSE/MTMS ratio of 33/67.

racy and maximum resolution were within ±0.01 cm⁻¹ and 0.07 cm⁻¹, respectively. The signal-to-noise ratio was 50,000:1. The high-intensity ceramic source light source, gold 28° Michelson interferometer with auto-alignment mechanism and a Ge/KBr beam splitter were used for measurement. The background spectra were obtained using a pure silicon sample cut from the same wafer that was used for the film deposition. All spectra are normalized to the highest Si–O–Si peak.

The thickness, refraction index (RI), porosity, and pore size distribution of the films were estimated by using ellipsometric porosimetry (EP). The system uses a SENpro spectroscopic ellipsometer with SpectraRay/4 software for the data analysis (SENTECH, Germany). Evaluation of porosity and pore size distribution was carried out by using atmospheric pressure ellipsometric porosimetry. The idea of this method is generally similar to traditional nitrogen adsorption porosimetry and it uses phenomena of progressive filling and emptying of the pores during the increasing and reducing pressure of a selected adsorptive. Atmospheric pressure ellipsometric porosimetry uses the controlled isothermal mixing of solvent-free and vapor-saturated carrier gases. Dry nitrogen was used as a carrier gas and heptane vapor as an active adsorptive. First, the initial nitrogen flow splitted into 2 ones and one of them passes through the thermostat bubbler filled by liquid heptane. This flow is fully saturated by heptane vapor and then it is mixed with flow of pure nitrogen. The bubbler temperature and ratio between these 2 nitrogen flows defines the heptane partial pressure, which can be varied from P/P₀= 0 to P/P₀=1 (P and P₀ are current and saturated vapor pressures, respectively). The heptane partial pressure slowly changed by changing the nitrogen flows ratio during the adsorption and desorption.
Simultaneously, ellipsometry spectra are collected in an automatic regime at different pressure and totally up to 50–100 spectra are measured during the complete adsorption-desorption cycle.

The condensed heptane vapor changes low-k index of refraction because the liquid heptane \((n = 1.33)\) replaces air \((n = 1)\) in the pores. The change of refractive index is reflected by phase (Delta) and amplitude (Psi) characteristics of elliptically polarized light, which are measured by spectroscopic ellipsometry. The ellipsometry spectra of low-k film in the range 350–850 nm is measured and fitted by using the well-known Cauchy relationship (Eq. (1)):

\[
n(\lambda) = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4}
\]  

(1)

where, the three terms are adjusted to match the refractive index \((n)\) for the transparent material. The low-k index of refraction is changing during the adsorption but heptane is also transparent at 350–850 nm wavelength region. Therefore, Cauchy relationship can be used for the films with condensed heptane. When all ellipsometry spectra corresponding to different heptane pressure are available, the indices of refraction can be extracted for any wavelength located in the range between 350 and 850 nm.

The further calculation procedure was based on a custom developed software Porelli. Ellipsometry transfers to Porelli the measured values of Delta and Psi. Then these values are recalculated to the indices of refraction that are used for obtaining the adsorption-desorption isotherms.
Fig. 7. Entire fingerprint region (a) and its local ranges (b, c, d) of FTIR spectra of ethylene-bridged OSG films soft baked (SB) at 150°C in the air with different Brij30 content (0–50 wt%). The films were labeled as 12 correspond to the BTMSE/MTMS ratio of 47/53.

(adsorptive volume V versus P/P₀) via Lorenz-Lorentz Eq. (2).

\[
V = \frac{\left(\frac{n_{ef}^2 - 1}{n_{ef}^2 + 2} - \frac{n_{ads}^2 - 1}{n_{ads}^2 + 2}\right)}{\left(\frac{n_{ad}^2 - 1}{n_{ad}^2 + 2} - \frac{n_{ads}^2 - 1}{n_{ads}^2 + 2}\right)},
\]

where, \(n_{ef}\) is the measured RI of porous film filled by adsorptive molecules, \(n_{ads}\) is the RI of liquid adsorptive (Heptane in our case), \(n_{s}\) is the RI of the film skeleton (the dense part of the film).

Then, these isotherms are used for calculation of porosity and pore size. Fig. 16 presents experimental data (See in supplementary material) obtained for a 30% porous low-k film using the data at 632 nm. It is also possible to analyze full ellipsometry spectra for each P/P₀ point or to use the change of Delta/Psi at several different wavelengths but this approach is more time consuming and, to according to our experience, doesn’t give any advantages if the film is transparent. The progressive change of condensed adsorbate amount during the adsorption and desorption allows to calculate the pore size distribution with the help of Kelvin equation [1]. The Porelli software calculates and reports the fitting curves during the adsorption and desorption, refractive indices of the materials with empty and completely filled pores, skeleton refractive index, porosity and pore size distribution, internal surface area, and Table 2 with Delta/Psi changes versus partial pressure.

The Young’s moduli (E) data of porous OSG low-k films were determined from adsorption-induced deformation by using experimental strain isotherms measured by EP. Change of the film thickness due to the capillary forces is just about few percent and it is not visible in the
Fig. 8. Entire fingerprint region (a) and its local ranges (b, c, d) of FTIR spectra of ethylene-bridged OSG films hard baked (HB) at 400 °C in the air with different Brij30 content (0–50 wt%). The films were labeled as 12 corresponding to the BTMSE/MTMS ratio of 47/53.

However, these changes are resolved by ellipsometry measurements and the calculated Young’s modulus have good correlation with the results obtained with other instrumentation. The calculation of $E$ of thin porous films using EP data uses the following Eq. (3):

$$d = d_0 \left(1 - \frac{\pi}{E}\right) = d_0 - k \ln \frac{P}{P_0}$$  \hspace{1cm} (3)

where, $\pi$ is microscopic capillary pressure, $d$ and $d_0$ are the film thicknesses when pores are filled by adsorptive and empty, $P$ and $P_0$ are current and equilibrium vapor pressure, respectively, coefficient $k$ is equal to $d_0RT/V_LE$, where $V_L$ is molecular volume, $R$ is gas constant, and $T$ is absolute temperature. To calculate $E$, it is necessary to fit the experimental curve describing the change of the film thickness versus relative pressure, to find $k$, and to use the following formula (Eq. (4)):

$$E = \frac{d_0RT}{kV_L}$$  \hspace{1cm} (4)

The only molecular characteristic of the absorption needed for calculation of Young’s modulus from EP data is the molecular volume.

To measure the dielectric constant, $k$, capacitance-voltage (CV) measurements were carried out using wafer probing (Cascade Microtech Summit 12,000, CA, USA) and a precision Agilent B1500A inductance, capacitance and resistance meter (Santa Clara, CA, USA). A C-V test structure with top electrodes were formed by Al dots (thickness = 110 nm) deposition sputtered through a metal shadow mask on the OSG low-k/Si films. The final C-V test vehicles is then Al/low-k films/Si. The measured capacitance per unit area was almost stable with frequency until 100 kHz. The $k$-value was then extracted from the measured capacitance by using the well-known formula.
Fig. 9. Entire fingerprint region (a) and its local ranges (b, c, d) of FTIR spectra of ethylene-bridged OSG films hard baked (HB) at 400 °C in N₂ with different Brij30 content (0–50 wt%). The films were labeled as 12 correspond to the BTMSE/MTMS ratio of 47/53.

Fig. 10. Heptane adsorption/desorption isotherms of the films with 0–50 wt% porogen loading hard baked in the air and N₂ with BTMSE/MTMS ratio (a) 25/75 (b) 33/67, and (c) 47/53. The samples labeled 04, 08 and 12 correspond to the BTMSE/MTMS ratios of 25/75, 33/67 and 47/53, respectively.

of the parallel plate capacitor, C,

\[ C = \varepsilon_0 \frac{A}{d} \]  

where, \( \varepsilon_0 \) is the permittivity of free space \( (8.85 \times 10^{-12} \text{ F/m}) \), A is the area of Al dot and d is the thickness of low-k film.

Specific surface area is accessible for the adsorbent molecules area of a solid surface per unit mass of material. EP calculates the cumulative surface area. The specific surface area of each small group of pores \( \delta A_i \) are calculated from the corresponding pore volume and pore radius as
Table 1
Properties of studied films after hard baked in the air and N₂. The BTMSE/MTMS molar ratios were 25/75 (04), 33/67 (08) and 47/53 (12).

| Label | BTMSE/MTMS ratio | Thickness (±5 nm) | RI (±0.005) | Radius (nm) | Open Porosity (±1%) | YM (±0.02 GPa) | kvalue (±0.02) |
|-------|------------------|-------------------|-------------|-------------|---------------------|----------------|---------------|
| 04- 0%-Air | 25/75 | 617.3 | 1.381 | 0.81 | 0.81 | 8.7 | 3.10 |
| 04- 10%-Air | 262.0 | 1.370 | 0.81 | 0.81 | 12.4 | – | 2.19 |
| 04- 30%-Air | 629.2 | 1.308 | 1.42 | 1.61 | 27.7 | 7.4 | 2.66 |
| 04- 50%-Air | 585.1 | 1.200 | 4.65 | 3.00 | 50.6 | – | 1.95 |
| 08- 0%-Air | 33/67 | 585.7 | 1.390 | 0.81 | 0.81 | 9.1 | – | 3.20 |
| 08- 10%-Air | 602.5 | 1.380 | 0.81 | 0.81 | 12.8 | – | 3.09 |
| 08- 30%-Air | 582.3 | 1.295 | 1.25 | 1.61 | 32.2 | 7.6 | 2.52 |
| 08- 50%-Air | 500.0 | 1.218 | 3.20 | 2.65 | 46.6 | – | 1.95 |
| 12- 0%-Air | 47/53 | 637.4 | 1.399 | 0.81 | 0.81 | 1.2 | – | 3.30 |
| 12- 10%-Air | 565.5 | 1.393 | 0.81 | 0.81 | 12.2 | – | 3.15 |
| 12- 30%-Air | 575.4 | 1.299 | 1.18 | 1.18 | 32.4 | 7.2 | 2.37 |
| 12- 50%-Air | 476.8 | 1.225 | 2.34 | 1.94 | 45.5 | – | 1.95 |
| 04- 0%-N₂ | 25/75 | 647.4 | 1.385 | 0.81 | 0.81 | 8.7 | 9 | 3.00 |
| 04- 10%-N₂ | 702.7 | 1.362 | 0.81 | 0.81 | 14.3 | 8.3 | 2.87 |
| 04- 30%-N₂ | 688.8 | 1.290 | 1.25 | 1.25 | 26.9 | 5.4 | 2.51 |
| 04- 50%-N₂ | 502.5 | 1.233 | 2.00 | 1.94 | 45.0 | 4.4 | 2.15 |
| 08- 0%-N₂ | 33/67 | 626.4 | 1.390 | 0.81 | 0.81 | 9.2 | – | 3.11 |
| 08- 10%-N₂ | 616.9 | 1.359 | 0.81 | 0.81 | 16.1 | – | 2.98 |
| 08- 30%-N₂ | 617.4 | 1.269 | 1.42 | 1.61 | 35.7 | 5.2 | 2.50 |
| 08- 50%-N₂ | 473.1 | 1.227 | 2.00 | 1.94 | 44.9 | – | 2.16 |
| 12- 0%-N₂ | 47/53 | 630.5 | 1.401 | 0.81 | 0.81 | 6.2 | 9.6 | 3.22 |
| 12- 10%-N₂ | 664.6 | 1.379 | 0.81 | 0.81 | 14.2 | 9.8 | 3.17 |
| 12- 30%-N₂ | 671.3 | 1.271 | 1.25 | 1.25 | 28.4 | 4.3 | 2.46 |
| 12- 50%-N₂ | 547.6 | 1.220 | 1.94 | 1.94 | 48.0 | 4.3 | 2.21 |

RI = Refractive Index, Ads = Adsorption, Des = Desorption, YM = Young’s Modulus, k = Dielectric constants.

Fig. 11. Heptane adsorption/desorption isotherms showing the effect of porosity with varying the BTMSE/MTMS ratio for films obtained from 50% porogen loading after soft baked and hard baked in the air with the slow temperature increase. The BTMSE/MTMS ratio is 25/75, 33/67 and 47/53 in samples 04, 08 and 12, respectively.

$$\delta A_i = \delta V_i/r_i \text{ (for cylindrical pores)}.$$ By assuming the values of $\delta A_i$ over the whole pore system a value of the cumulative surface area were obtained.

The UV induced luminescence spectra of the OSG films were measured by JASCO FP-8300 spectrofluorometer by using a continuous output Xe arc lamp with shielded lamp housing (150W) and holographic concave grating in modified Rowland mount monochromator. The
Fig. 12. Specific surface area of ethylene bridged OSG films calculated from EP data. The films were deposited with 10%, 30% and 50% Brij30 template concentration and cured in N₂ and air at 400 °C. The samples labeled (a) 04, (b) 08 and (c) 12 correspond to the BTMSE/MTMS ratios of 25/75, 33/67 and 47/53, respectively.

Fig. 13. Photoluminescence of OSG films obtained from 04 to 12 samples with different porogen concentrations (10–50%), (a) as-deposited (AD) (b) after soft baked (SB) at 150 °C in the air and (c) after hard baked (HB) at 400 °C in the air, upon excitation with light of 6.2 eV.

Radio-photometer system using monochromatic light was used to monitor the intensity output of the Xe lamp. The samples were mounted in a standard cell holder (10 mm rectangular cell holder) SCE-846/D061161450 provided by JASCO. The wavelength accuracy and maximum resolution is 1 nm. The excitation was used from 200 nm (6.2 eV). The emission spectra range were in
Fig. 14. Schematics of MTMS and BTMSE precursors.

Fig. 15. Schematics of MTMS–BTMSE copolymer.

Fig. 16. Change of ellipsometric characteristics Delta and Psi during the adsorption (a) and desorption (b) of heptane vapors in 30% porous low-k films. The solid line is the result of theoretical calculation of Delta/Psi trajectory when index of refraction is changing from 1.147 to 1.600. The refractive indices of low-k film were equal to 1.301 (when pores are empty) and 1.416 when pores filled by heptane. The film thickness was fixed at 430.9 nm, wavelength is 632 nm and incident angle are equal to 69.60°.
the wavelength from 210 to 750 nm. The measurements were fully controlled by using a Spectra Manager. The excitation and emission bandwidth were 5 nm with scan speed 1000 nm/min.

**CRediT Author Statement**

**Md Rasadujjaman:** Data curation, Formal analysis, Methodology, Writing - original draft, Writing - review & editing; **Jinming Zhang:** Formal analysis; **Konstantin P. Mogilnikov:** Formal analysis; **Alexey S. Vishnevskiy:** Formal analysis; **Jing Zang:** Formal analysis, Methodology, Resources, Supervision; **Mikhail R. Baklanov:** Conceptualization, Supervision, Writing - review & editing.

**Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships which have, or could be perceived to have, influenced the work reported in this article.

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### Table 2

Raw data of Delta (Δ)/Psi (Ψ) changes versus partial pressure (P/P₀) during adsorption and desorption.

| No. of exp. | Adsorption | Desorption |
|-------------|------------|------------|
| P/P₀ | Δ (deg.) (±0.05) | Ψ (deg.) (±0.02) | P/P₀ | Δ (deg.) (±0.05) | Ψ (deg.) (±0.02) |
| 1 | 0 | 95.24 | 27.59 | 26 | 1.00 | 100.91 | 64.72 |
| 2 | 0.011 | 95.33 | 27.55 | 27 | 0.950 | 100.31 | 64.22 |
| 3 | 0.022 | 93.59 | 29.13 | 28 | 0.901 | 100.79 | 63.96 |
| 4 | 0.034 | 92.66 | 29.92 | 29 | 0.850 | 100.09 | 63.5 |
| 5 | 0.045 | 91.90 | 30.57 | 30 | 0.800 | 99.60 | 63.16 |
| 6 | 0.067 | 90.80 | 32.03 | 31 | 0.749 | 99.50 | 62.92 |
| 7 | 0.100 | 89.83 | 34.14 | 32 | 0.698 | 98.54 | 62.57 |
| 8 | 0.133 | 89.12 | 36.48 | 33 | 0.646 | 98.51 | 62.02 |
| 9 | 0.166 | 89.10 | 39.24 | 34 | 0.594 | 98.49 | 61.67 |
| 10 | 0.221 | 90.04 | 45.12 | 35 | 0.542 | 98.35 | 61.24 |
| 11 | 0.276 | 92.53 | 50.92 | 36 | 0.489 | 97.80 | 60.59 |
| 12 | 0.329 | 94.60 | 55.57 | 37 | 0.436 | 97.12 | 60.06 |
| 13 | 0.383 | 96.34 | 58.53 | 38 | 0.383 | 96.94 | 59.43 |
| 14 | 0.436 | 97.25 | 59.93 | 39 | 0.329 | 96.29 | 58.71 |
| 15 | 0.489 | 97.72 | 60.57 | 40 | 0.276 | 95.35 | 57.99 |
| 16 | 0.542 | 97.99 | 61.07 | 41 | 0.221 | 90.64 | 46.39 |
| 17 | 0.594 | 98.26 | 61.59 | 42 | 0.166 | 89.01 | 39.09 |
| 18 | 0.646 | 98.83 | 62.07 | 43 | 0.133 | 89.19 | 36.33 |
| 19 | 0.698 | 99.16 | 62.51 | 44 | 0.100 | 89.94 | 33.86 |
| 20 | 0.749 | 99.26 | 62.85 | 45 | 0.067 | 91.10 | 31.85 |
| 21 | 0.800 | 99.61 | 63.23 | 46 | 0.045 | 92.11 | 30.46 |
| 22 | 0.850 | 100.14 | 63.64 | 47 | 0.034 | 92.65 | 29.83 |
| 23 | 0.901 | 100.28 | 64.04 | 48 | 0.022 | 93.20 | 29.18 |
| 24 | 0.950 | 100.73 | 64.22 | 49 | 0.011 | 95.57 | 27.46 |
| 25 | 1.000 | 100.83 | 64.62 | 50 | 0 | 95.58 | 27.43 |
| - | - | - | - | 51 | 0 | 95.24 | 27.59 |
Supplementary Materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.dib.2021.106895.

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