The Effects of Li/Nb Ratio on the Preparation and Photocatalytic Performance of Li-Nb-O Compounds

Haifa Zhai 1,2*, Hairui Liu 1, Hongjing Li 1, Liuyang Zheng 1, Chunjie Hu 1, Zhao Wang 1, Jingjing Qi 1 and Jien Yang 1

Abstract

The effects of Li/Nb ratio on the preparation of Li-Nb-O compounds by a hydrothermal method were studied deeply. Li/Nb ratio has a great impact on the formation of LiNbO_3; the ratio smaller than 3:1 is beneficial to the formation of LiNbO_3, while larger than 3:1, forms no LiNbO_3 at all and the morphology and chemical bond of Nb_2O_5 raw material are totally modified by Li ions. The reason can be attributed to the large content of LiOH, which is beneficial to form Li_3NbO_4 not LiNbO_3, and also, even if LiNbO_3 particle locally forms, it is easily dissolved in LiOH solution with strong alkalinity. Pure LiNb_3O_8 powders are obtained with two absolutely opposite Li/Nb ratios: 8:1 and 1:3; the former shows a unique porous and hollow structure, quite different from the particle aggregation (the latter shows). Compared with Li/Nb = 1:3, the 4.2 times higher photocatalytic performance of LiNb_3O_8 (Li/Nb = 8:1) are observed and it can be attributed to the unique porous and hollow structure, which provides a high density of active sites for the degradation of MB. Compared to LiNbO_3, the improved photocatalytic performance of LiNb_3O_8 can be attributed to its layered structure type with the reduced symmetry enhancing the separation of electrons and holes.

Keywords: Lithium Niobate, Hydrothermal, Porous Materials, Photocatalysis

Background

Niobium compounds, a very versatile group of materials, including niobium oxides, alkali niobates, and columbite niobates, exhibit many interesting physical properties and have been widely studied in many fields, such as catalysis [1–3], memristors [4], dye-sensitized solar cells [5], optical devices, and others [6, 7]. LiNbO_3, as one of the most famous alkali niobates, presents prominent properties such as electro-optical and nonlinear optical behaviors, pyroelectricity, and piezoelectricity, and it is mainly used as optical modulators, waveguides, acoustic wave transducers, et al. in optical devices.

For environmental remediation and clean energy applications, niobates, such as (Na, K)NbO_3 [8], BiNbO_4 [9], LiNbO_3 [10], and LiNb_2O_6 [11], have been deeply investigated, owing to their special distorted [NbO_6] octahedral structures which favor a possible delocalization of charge carriers [12]. Secondly, the conduction bands consisting of Nb 4d orbitals located at a more negative state of redox potential of H+/H_2 promote the separation and transfer of photo-induced charge carriers and result in high photocatalytic activities [13]. Among these materials, LiNb_2O_6 displays unique performances. As a novel lithium-ion battery (LIB) anode material, the theoretical capacity of LiNb_2O_6 is 389 mAh/g assuming two-electron transfers (Nb^{5+} → Nb^{3+}), larger than many other anode materials, such as Li_4Ti_5O_12 [14, 15]. Used for supercapacitor devices, LiNb_2O_6 nanoflakes show excellent cycle stability with negligible specific capacitance decrease even after 15,000 cycles [16]. Also, it is used as an efficient photocatalyst in the applications of hydrogen generation and degradation of organic pollutants. Pure LiNb_2O_6 is a highly active UV-photocatalyst for water reduction producing 83.87 μmol of hydrogen in 1 h, and it does not produce hydrogen under visible-light irradiation due to its large band gap (i.e., 3.9 eV) and inability to absorb visible light [17, 18]. LiNb_2O_6 nanoflakes show fast decolorization of...
toluidine blue O (TBO) dye under UV light compared to commercial TiO2 powders [13]. At most time, the appearance of LiNb3O8 is recognized as an impurity phase during the preparation of LiNbO3, especially in film samples, owing to high annealing temperature or inhomogeneous distribution of Li element in precursors [19, 20]. Due to the difficulty to prepare a pure phase, LiNbO3 has been rarely studied, while for LiNbO3 powders, the preparation technologies are various, such as sol-gel [19], hydrothermal [21], and laser irradiation methods [22]. Hydrothermal method is widely used to synthesize nanomaterials with advantages such as low temperature, environmental friendliness, and homogenous particle-size distribution, which can efficiently avoid the variation of Li/Nb molar ratio without going through high temperatures. As for hydrothermal method, the parameters of reaction temperature, raw material ratio, and holding time play important roles in determining the as-obtained materials, while the research of Li/Nb ratio much larger than 1:1 in the preparation of Li-Nb-O compounds has not been reported before.

In this paper, the effects of Li/Nb ratio on the preparation of Li-Nb-O compounds by a hydrothermal method were studied deeply. A series of analytical techniques were used to characterize the crystallinity, morphology, and chemical composition of the Li-Nb-O samples, especially the changes before and after the hydrothermal reaction. Pure LiNbO3 and LiNbO3 photocatalysts were prepared, and the photocatalytic performance was studied with the effect of Li/Nb ratio in raw materials.

**Methods**

The preparation of Li-Nb-O compounds was carried out by the hydrothermal method using lithium hydroxide monohydrate (LiOH·H2O; Aladdin, ACS, ≥ 98.0%) and niobium pentaoxide (Nb2O5; Aladdin, AR, 99.9%) as starting materials. Firstly, 3.5 mmol of Nb2O5 was dispersed into 35 ml deionized water with a certain amount of LiOH·H2O under magnetic stirring. The mole ratios of Li:Nb are 1:3, 1:1, 2:1, 3:1, 4:1, 5:1, 6:1, 7:1, and 8:1; as the results of the samples prepared with ratios of 4:1, 5:1, 6:1, and 7:1 are similar, only the ratios of Li:Nb = 4:1 and 7:1 are shown below. The suspension solutions were put into 50-mL Teflon-lined hydrothermal synthesis autoclave reactors and maintained at 260 °C for 24 h, then cooled down naturally to room temperature. The as-obtained powders were then washed with deionized water and ethanol for several times and dried at 60 °C. Finally, the products were calcined at various temperatures from 500 to 800 °C for 2 h with a ramp rate of 5 °C/min.

The X-ray diffraction (XRD) patterns were recorded using a Bruker D8 Discover diffractometer with Cu Kα radiation (40 kV, 40 mA). The morphologies of the samples were characterized by field emission scanning electron microscope (FESEM; JSM-6700F). Chemical bonds were analyzed by Fourier-transformed infrared spectroscopy (FTIR) in the range of 2000–650 cm⁻¹. X-ray photoelectron spectroscopy (XPS) analysis was performed on a Thermo-Fisher Escalab 250Xi instrument to characterize the chemical component of Li-Nb-O compounds. The specific surface area was measured on a surface area apparatus (Micromeritics ASAP 2460) at 77 K by N2 adsorption/desorption method (BET method). The photoluminescence (PL) spectra were detected using an F-280 fluorescence spectrophotometer with an excitation wavelength of 320 nm.

To evaluate the photocatalytic performance of Li-Nb-O compounds, the degradation of methylene blue (MB) aqueous solution (5 mg/L) was carried out under irradiation of a 500 W Hg lamp at a natural pH value. Fifty milligrams of powders were dispersed into 50 mL of MB aqueous solution. Before the irradiation, the suspension was stirred in dark for 1 h to achieve adsorption equilibrium. Then, the suspension was irradiated by the Hg lamp. The concentration of residual MB was analyzed with an interval of 30 min using an ultraviolet-visible near-infrared (UV-vis-NIR) spectrophotometer at 665 nm.

**Results and Discussion**

The XRD patterns of the products obtained after hydrothermal reaction with different Li/Nb mole ratios are shown in Fig. 1. It is obvious that pure LiNbO3 phase (JCPDF, No. 20-0631) is obtained with Li:Nb = 2:1. For the ratio of Li/Nb smaller than 2:1, such as 1:1 or 1:3, the main phase is still LiNbO3, accompanied with the residual of Nb2O5 (JCPDF, No. 37-1468), which means that the Li content is not sufficient to fully react with Nb2O5 to form LiNbO3. When we increase the Li content largely, an amazing phenomenon occurs: there is no LiNbO3 formed at all after the hydrothermal reaction, as

![Fig. 1 XRD patterns of the Li-Nb-O powders obtained after hydrothermal reaction with different Li/Nb mole ratios](image-url)
clearly shown in Fig. 1. When the ratio of Li/Nb is 4:1 or larger, only Nb₂O₅ phase exists in XRD patterns, no other impurities detected. Is the Li ion washed away during the washing process? Just like the former literature reported [23].

To illustrate the phase evolution when the Li/Nb ratio is large enough, the products obtained by the hydrothermal method, using Li/Nb = 8:1 as an example, are calcined at different temperatures and the XRD patterns are shown in Fig. 2. When the products are calcined at 500 and 600 °C, a new phase LiNbO₃ appears which proves that a Li element truly exists in the products obtained just after the hydrothermal reaction, though not detected by XRD. Also, a diffraction peak at 30.26° appears at 600 °C, which can be indexed as (410) plane of monoclinic LiNb₃O₈. The reaction can be described by the following Eq. (1) [24]:

\[
\text{LiNbO}_3 + \text{Nb}_2\text{O}_5 \rightarrow \text{LiNb}_3\text{O}_8
\]

At 700 °C, the monoclinic LiNb₃O₈ is the predominant phase with almost negligible impurity. The pure phase of LiNb₃O₈ is obtained at 800 °C with all the diffraction peaks indexed to the monoclinic phase (ICPDF, No. 36-0307), a space group of P21/a, which provides a new way to prepare LiNb₃O₈ compounds.

FTIR test is also performed to study the phase evolution of the products with Li:Nb = 8:1, as shown in Fig. 3. The raw material Nb₂O₅ is tested as a reference. In Fig. 3, the band at 962 cm⁻¹ due to the stretching vibrations of Nb = O in Nb₂O₅ is existent until 700 °C [25]. After hydrothermal reaction, no other bands detected at this range means the only niobate is still Nb₂O₅. When the calcination temperature is 500 and 600 °C, a new band at 891 cm⁻¹ appears, while disappears at 700 °C, consistent with the XRD results of the formation and reaction of LiNbO₃. At 700 and 800 °C, the bands at 908 and 828 cm⁻¹ correspond to the formation of LiNb₃O₈ compounds [26, 27]. The FTIR results are well consistent with the XRD results of Fig. 2.

Based on the results, we can conclude that Li/Nb ratio has a great impact on the formation of LiNbO₃; the ratio smaller than 3:1 is beneficial to the formation of LiNbO₃, while larger than 3:1, no LiNbO₃ forms at all. Based on the diagram, the congruent Li content is 97.2 mol% of the Nb content for the preparation of perfect single-phase LiNbO₃, and the excess or deficiency of the Li content is compensated by the formation of Li₃NbO₄ or LiNb₃O₈ phase [28]. The large excess of LiOH is beneficial to form Li₃NbO₄ not LiNbO₃, while no Li₃NbO₄ phase is observed after hydrothermal reaction due to the insufficient reaction condition; even if the LiNbO₃ particle locally formed, it is easily dissolved in LiOH solution with strong alkalinity [29].

As discussed above, the Li element is not detected after the hydrothermal reaction without further calcination, while it truly exists in the products with Li:Nb = 8:1. For Nb₂O₅, is it still the same as the raw material after the hydrothermal reaction? The XPS test is carried out to characterize the chemical component of Nb₂O₅ raw material and the products obtained after hydrothermal reaction, as shown in Fig. 4. The difference of Nb 3d₃/₂ and 3d₅/₂ is the 2.7 eV for both samples, indicating the Nb⁵⁺ state in both samples without other reduced Nb oxides species [3]. The binding energies of Nb 3d shift towards the low binding-energy state after the hydrothermal reaction, about 0.5 eV difference. It means that the chemical environment of Nb changes, while no other compounds are formed. The change may
be due to the existence of Li ions in the product; though no obvious Li-Nb-O compound is formed, the existence of Li ions with larger ionicity has strong attraction of O ions around Nb, resulting in the chemical shift of Nb 3d binding energy.

The influence of Li ions on Nb$_2$O$_5$ is also observed in SEM images, as shown in Fig. 5. Figure 5a is the image of Nb$_2$O$_5$ raw material, with irregular shape, dense structure, and length of several micrometers. After the hydrothermal reaction, the large crystal particle is divided into small particles with the maximum size of about 200 nm, though the small particles still aggregate together. From the XRD and XPS results, we know that the small particles are still Nb$_2$O$_5$. The change of the morphology of Nb$_2$O$_5$ can be attributed to the hydrothermal condition and large content of LiOH·H$_2$O in raw materials.

The products obtained after hydrothermal reaction are calcined at 800 °C with different Li/Nb ratios. Hereafter, we choose three typical Li/Nb ratios as examples: 1:3, 2:1, and 8:1. The XRD patterns of the three samples are shown in Fig. 6. From the XRD results, pure LiNbO$_3$ are prepared with Li/Nb = 2:1 and has shown no change even when calcined at 800 °C. For the preparation of another Li-Nb-O compound LiNb$_3$O$_8$, it can be obtained with two absolutely opposite Li/Nb ratios: 8:1 and 1:3 (designated as LiNb$_3$O$_8$-8:1 and LiNb$_3$O$_8$-1:3). For other Li/Nb ratios not shown in Fig. 6, the products calcined at 800 °C result in the formation of two mixed phases: LiNb$_2$O$_6$ and LiNbO$_3$. Based on the XRD results, pure LiNb$_3$O$_8$ powders are prepared with two different Li/Nb ratios, while is there any differences between the two products?

The SEM images of the two products are displayed as Fig. 7b, c, respectively. As shown in Fig. 7, the morphology of LiNb$_3$O$_8$-1:3 are quite different with that of LiNb$_3$O$_8$-8:1. LiNb$_3$O$_8$-8:1 has a porous and hollow structure formed by LiNb$_3$O$_8$ nanoparticles with the length of several micrometers, similar as that of a honeycomb. It is quite different with the particle aggregation of solid-state reaction, as LiNb$_3$O$_8$-1:3 shown. The BET areas of LiNb$_3$O$_8$-8:1 and LiNb$_3$O$_8$-1:3 are 4.46 and 0.96 m$^2$/g, respectively, the larger surface area of the
former results from the porous and hollow structure. The morphology difference can be attributed to the different morphologies of the reactants: for LiNb$_3$O$_8$-8:1, the reactant of LiNbO$_3$ is formed based on the calcinations of the products after hydrothermal reaction, the morphology of the products is shown in Fig. 5b, while for LiNb$_3$O$_8$-1:3, the morphology of LiNbO$_3$ obtained directly after the hydrothermal reaction is hexahedron-like, as shown in Fig. 7a [21]. The formation of the porous and hollow structure for LiNb$_3$O$_8$-8:1 can be attributed to the lithium volatilization during the calcinations process, which is beneficial to the formation of new LiNb$_3$O$_8$ particles and networks between the particles [11]. For LiNbO$_3$ calcined at 800 °C (i.e., Li/Nb = 2:1), its grain size is about 200 nm and the shape seems irregular, as shown in Fig. 7d; the BET area is about 3.91 m$^2$/g.

The photocatalytic performances of LiNb$_3$O$_8$ and LiNbO$_3$ are shown in Fig. 8. From the UV-vis absorption spectra of MB at the varied irradiation time (Fig. 8a–d), it is observed that the maximum absorption band (665 nm) becomes weak with the increase of the irradiation time. The degradation rate of MB is largely improved with the catalysts of LiNb$_3$O$_8$ and LiNbO$_3$ under UV light, especially for LiNb$_3$O$_8$-8:1, about 85% of MB degraded after 30 min irradiation, as shown in Fig. 8e. As the photo-degradation of MB using Li-Nb-O catalysts obeys the pseudo-first-order kinetics, described by the modified Langmuir-Hinshelwood kinetics mode [30], the constants of the pseudo-first-order rate ($k$) are calculated, displayed in Fig. 8f. The obtained first-order rate constants of MB without catalysts, LiNb$_3$O$_8$-1:3, LiNbO$_3$, and LiNb$_3$O$_8$-8:1 are $0.71 \times 10^{-2}$, $1.61 \times 10^{-2}$, $4.18 \times 10^{-2}$, and $6.73 \times 10^{-2}$ min$^{-1}$, respectively. The higher the first-order rate constant is, the more
outstanding the photocatalytic performance is. The \( k \) of LiNb\(_3\)O\(_8\)8:1 is 9.5 times of MB without catalysts, 4.2 times of LiNb\(_3\)O\(_8\)-1:3, and 1.6 times of LiNbO\(_3\). Compared with LiNb\(_3\)O\(_8\)-8:1, the higher photocatalytic performance of LiNb\(_3\)O\(_8\)-8:1 can be attributed to the unique porous and hollow structure, which provides a high density of active sites for the degradation of MB [31].

Compared to LiNbO\(_3\), the improved photocatalytic performance of LiNb\(_3\)O\(_8\)-8:1, which has almost the same absorption ability of MB as that of LiNbO\(_3\), can be attributed to its layered structure type with the reduce symmetry. The layered structure can enhance the separation of electrons and holes [32], consistent with the PL spectra, as shown in Fig. 9. At the same time, the LiNb\(_3\)O\(_8\) framework is constructed by three different niobate octahedrons and Li atoms share partial octahedral sites; the higher niobate octahedral site is expected to provide more active sites for photocatalysis. Finally, the smaller energy band gap of LiNbO\(_3\) (about 3.9 eV) than that of LiNbO\(_3\) (4.14 eV) means that it can utilize more incident light to participate in the photocatalytic process [33].

The separation efficiency of photogenerated carriers of Li-Nb-O catalyst are investigated by PL spectra, as shown in Fig. 9. As we know, PL emission spectra mainly result from the recombination of free carriers. As seen in Fig. 9, LiNb\(_3\)O\(_8\) shows smaller emitting peaks around 470 nm than LiNbO\(_3\). It means that LiNb\(_3\)O\(_8\) has longer charge carrier lifetime and improved efficiency of interfacial charge transfer, which can be attributed to its layered structure with the reduced symmetry enhancing the separation of electrons and holes.

**Conclusions**

From the results above, we can conclude that Li/Nb ratio has a great impact on the formation of LiNbO\(_3\); the ratio smaller than 3:1 is beneficial to the formation of LiNbO\(_3\), while larger than 3:1, forms no LiNbO\(_3\) at all and the morphology and chemical bond of Nb\(_2\)O\(_5\) raw material are totally modified by Li ions. The reason can be attributed to the large content of LiOH, which is beneficial to form Li\(_2\)NbO\(_4\) not LiNbO\(_3\), and also, even if the LiNbO\(_3\) particle locally forms, it is easily dissolved in LiOH solution with strong alkalinity. Pure LiNb\(_3\)O\(_8\) powders are obtained with two absolutely opposite Li/Nb ratios: 8:1 and 1:3; the former shows a unique porous and hollow structure, quite different with the particle aggregation (the latter shows). Compared with Li/Nb = 1:3, higher photocatalytic performance of LiNb\(_3\)O\(_8\) (Li/Nb = 8:1) are observed and it can be attributed to the unique porous and hollow structure, which provides a high density of active sites for the degradation of MB.

Compared to LiNbO\(_3\), the improved photocatalytic performance of LiNb\(_3\)O\(_8\) can be attributed to its layered structure type with the reduced symmetry enhancing the separation of electrons and holes.

**Acknowledgements**

This work was financially supported by the National Natural Science Foundation of China (No. 51202107) and the Foundation of Henan Educational Committee (No. 16A140028).

**Authors’ contributions**

HZ and HL conceived and designed the experiments; HL and LZ prepared the samples; CH and ZW performed the XRD and SEM measurements; JQ performed the XPS; JY participated in the photocatalytic test; HZ wrote the paper. All of the authors read and approved the final manuscript.

**Competing interests**

The authors declare that they have no competing interests.

**Publisher’s Note**

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

**Received: 3 June 2017 Accepted: 11 August 2017 Published online: 15 August 2017**

**References**

1. Nico C, Monteiro T, Graça MPF (2016) Niobium oxides and niobates physical properties: review and prospects. Prog Mater Sci 80:1–37
2. Zhai HF, Li AD, Kong JZ, Li XF, Zhao J, Guo BL, Yin J, Li ZS, Wu D (2013) Preparation and visible-light photocatalytic properties of BiNbO\(_3\) and BiTaO\(_4\) by a citrate method. J Solid State Chem 202:6–14
3. Zhai HF, Jiang SY, Zheng LY, Li PP, Li HQ, Luo HY, Kong JZ (2016) Efficient visible-light photocatalytic properties in low-temperature Bi-Nb-O system photocatalysts. Nanoscale Res Lett 11:383
4. Kumar S, Davila N, Wang ZW, Huang XP, Stachan JP, Vine D, Kilcoyne ALD, Nishi Y, Williams RS (2017) Spatially uniform resistance switching of low current, high endurance titanium-niobium-oxide memristors. Nano 9:1793–1798
5. Abe R, Shinmei K, Koumura N, Hara K, Ohtani B (2013) Visible-light-induced water splitting based on two-step photoexcitation between dye-sensitized layered niobate and tungsten oxide photocatalysts in the presence of a triiodide/iodide shuttle redox mediator. J Am Chem Soc 135:16872–16884
6. Pullar RC (2009) The synthesis, properties, and applications of columbite niobates (M\(_2\)Nb\(_2\)O\(_6\)); a critical review. J Am Ceram Soc 92:563–577
7. Janner D, Tulli D, Garcia-Granda M, Belmonte M, Pruneri V (2009) Microstructured integrated electro-optic LiNbO\(_3\) modulators. Laser Photonics Rev 3:301–313
8. Liu JW, Chen G, Li ZH, Zhang ZG (2007) Hydrothermal synthesis and photocatalytic properties of ATaO\(_3\) and ANbO\(_3\) (A = Na and K). Int J Hydrogen Energ 32:2269–2272
9. Zhai HF, Kong JZ, Wang AZ, Li HJ, Zhang TT, Li AD, Wu D (2015) The polymerization effect on synthesis and visible-light photocatalytic properties of low-temperature β-BiNbO₄ using Nb-citrate precursor. Nanoscale Res Lett 10:457

10. Wang X, Yan WB, Zhang LX, Shi LH, Chen HJ, Zhang YW, Wu M, Zhang PJ (2015) Tunable photocatalytic activity of photochromic Fe-Mn-codoped LiNbO₃ nanocrystals. Opt Mater Express 5:2240–2245

11. Zhai HF, Liu HR, Li HJ, Zheng LY, Hu CJ, Zhang X, Li QL, Yang JE (2017) Hydrothermal-assisted sintering strategy towards porous- and hollow-structured LiNbO₃ anode material. Nanoscale Res Lett 12:463

12. Wang X, Yan WB, Zhang LX, Shi LH, Chen HJ, Zhang YW, Wu M, Zhang PJ (2015) Tunable photocatalytic activity of photochromic Fe-Mn-codoped LiNbO₃ nanocrystals. Opt Mater Express 5:2240–2245

13. Zhai HF, Liu HR, Li HJ, Zheng LY, Hu CJ, Zhang X, Li QL, Yang JE (2017) Hydrothermal-assisted sintering strategy towards porous- and hollow-structured LiNbO₃ anode material. Nanoscale Res Lett 12:463

14. Yin J, Zou ZG, Ye JH (2003) Photophysical and photocatalytic properties of MIn₀.₅Nb₀.₅O₃ (M = Ca, Sr, and Ba). J Phys Chem B 107:61–65

15. Liu JL, Shakir I, Kang DJ (2014) Single crystalline LiNb₃O₈ nanoflakes for efficient photocatalytic degradation of organic pollutants. J Phys Chem C 118:21551–21556

16. Liu JL, Shakir I, Kang DJ (2014) Lithium niobate nanoflakes as electrodes for highly stable electrochemical supercapacitor devices. Mater Lett 119:84–87

17. Sahoo PP, Maggard PA (2013) Crystal chemistry, band engineering, and photocatalytic activity of the LiNbO₃–CuNb₃O₈ solid solution. Inorg Chem 52:4443–4450

18. Zielinski B, Borowiak-Palen E, Kalenzuk RJ (2008) Preparation and characterization of lithium niobate as a novel photocatalyst in hydrogen generation. J Phys Chem Solids 69:236–242

19. Deb Nath C, Kar S, Verma S, Barmwal KS (2015) Synthesis of LiNbO₃ nanoparticles by citrate gel method. J Nanosci Nanotechnol 15:3757–3763

20. Zlotnik S, Tobaldi DM, Seabra P, Labrincha JA, Vilarinho PM (2016) Alkali niobate and tantalate perovskites as alternative photocatalysts. ChemPhysChem 17:3570–3575

Submit your manuscript to a SpringerOpen journal and benefit from:

- Convenient online submission
- Rigorous peer review
- Open access: articles freely available online
- High visibility within the field
- Retaining the copyright to your article