The Astrophysical Journal, 610:635–641, 2004 August 1
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LYMAN BREAK GALAXIES AT $z \sim 5$: REST-FRAME ULTRAVIOLET SPECTRA[1]

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Received 2004 February 12; accepted 2004 April 11

ABSTRACT

We report initial results for spectroscopic observations of candidates of Lyman break galaxies (LBGs) at $z \sim 5$ in a region centered on the Hubble Deep Field–North by using the Faint Object Camera and Spectrograph attached to the Subaru Telescope. Eight objects with $I_C \leq 25.0$ mag, including one active galactic nucleus, are confirmed to be at $4.5 < z < 5.2$. The rest-frame UV spectra of seven LBGs commonly show no or weak Lyα emission lines (rest-frame equivalent width of 0–10 Å) and relatively strong low-ionization interstellar metal absorption lines of Si II λ1260, O I+Si II λ1303, and C II λ1334 (mean rest-frame equivalent widths of them are -1.2 to -5.1 Å). These properties are significantly different from those of the mean rest-frame UV spectrum of LBGs at $z \sim 3$ but are quite similar to those of subgroups of LBGs at $z \sim 3$ with no or weak Lyα emission. The weakness of Lyα emission and strong low-ionization interstellar metal absorption lines may indicate that these LBGs at $z \sim 5$ are chemically evolved to some degree and have a dusty environment. Since the fraction of such LBGs at $z \sim 5$ in our sample is larger than that at $z \sim 3$, we may witness some sign of evolution of LBGs from $z \sim 5$ to $z \sim 3$, although the present sample size is very small. It is also possible, however, that the brighter LBGs tend to show no or weak Lyα emission, because our spectroscopic sample is bright (brighter than L^*) among LBGs at $z \sim 5$. More observations are required to establish spectroscopic nature of LBGs at $z \sim 5$.

Subject headings: cosmology: observations — galaxies: active — galaxies: evolution — galaxies: formation — galaxies: high-redshift

1. INTRODUCTION

In order to understand formation and evolution of galaxies, systematic searches for galaxies in the early universe and detailed studies of the detected galaxies are necessary. In this decade, the number of galaxies detected at high redshift ($z > 2 \sim 3$) has been rapidly increasing. The use of photometric redshift selection from deep broadband images, especially so-called Lyman break method (e.g., Steidel & Hamilton (1992); Steidel et al. 1995) gives the largest sample of galaxies at $z \sim 3$ (Lyman break galaxies [LBGs]; e.g., Steidel et al. 2003). Extensive studies of them have been revealing individual and statistical nature of star-forming galaxies at $z \sim 3$ (e.g., Steidel et al. 1998, 1999; Pettini et al. 2001; Papovich et al. 2001).

At the same time, their optical follow-up spectroscopy has also been made extensively (e.g., Steidel et al. 1996a, 1996b, 1999) and has revealed rest-frame UV spectral features of LBGs in addition to their redshift information. Using about 800 spectra of LBGs at $z \sim 3$, Shapley et al. (2003) found that about three-fourths of them show significant Lyα emission line and the remainder show only Lyα absorption. The LBGs with weaker Lyα emission have stronger low-ionization interstellar metal absorption lines and redder UV continua. These trends suggest that the LBGs at $z \sim 3$ with weak Lyα emission are more metal enriched and dusty, i.e., more chemically evolved, than those with strong Lyα emission.

What about the properties of LBGs at higher redshift? Are there any signs of evolution of LBGs? To answer these questions and obtain clues for understanding the formation and evolution of galaxies in the early universe, we made a systematic search for LBGs at $z \sim 5$ ($\sim$1 Gyr earlier to $z = 3$). We carried out wide (effectively $\sim$600 arcmin^2) and deep broadband (V, I_C, and z') imaging observations toward an area centered on the Hubble Deep Field–North (HDF-N; Williams et al. 1996) with Suprime-Cam (Miyazaki et al. 2002), which is attached to the Subaru Telescope. Thanks to plenty of redshift information about galaxies in and around the HDF-N, we could set suitable color criteria for a two-color ($V - I_C$ and $I_C - z'$) diagram to effectively select galaxies at $4.5 \lesssim z \lesssim 5.5$, avoiding foreground contamination, and obtained $\sim$300 LBG candidates at $z \sim 5$ with 23.5 mag less than $I_C \leq 26.0$ mag (Iwata et al. 2003). This is one of the largest LBG samples at $z \sim 5$ systematically surveyed. Using this sample, we statistically derived a rest-frame UV luminosity function (UVLF) of LBGs at $z \sim 5$, which shows only a slight change from $z \sim 5$ to $z \sim 3$. We also found that a spatial distribution of LBGs at $z \sim 5$ shows a large voidlike structure and a larger clustering amplitude than that at $z \sim 3$ (I. Iwata et al. 2004, in preparation). The presence of a similar voidlike structure is seen in Bremer et al. (2004), and a large clustering amplitude of LBGs at $z \sim 5$ may also suggest the presence of the larger bias in galaxy formation at $z \sim 5$ than at $z \sim 3$ (Ouchi et al. 2004b).

In order to confirm the redshifts of the LBG candidates and to study their spectral features and relations with their other properties, we started follow-up optical spectroscopy of our LBG candidates at $z \sim 5$. Although similar systematic searches for $z = 5$–6 galaxies have been carried out (e.g., Ouchi et al. 2004a; Bouwens et al. 2003; Yan et al. 2003; Stanway et al. 2003), the number of spectra of LBGs at $z \sim 5$ is still extremely small. Moreover, most of the spectra obtained so far show only Lyα emission, and the continuum spectral feature and relations with other properties observed in LBGs at $z \sim 3$ are still quite unknown. In this paper we

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present initial results of the optical spectroscopy of a part of our sample. Observations and data reduction are described in § 2, and the results are presented in § 3. In § 4 we compare the results with spectral features obtained for LBGs at $z \sim 3$ and discuss possible origins of the similarity and difference seen in spectral features. The magnitude system is based on AB magnitude unless otherwise noted.

2. OBSERVATIONS AND DATA REDUCTION

We made optical spectroscopy for a subset of our sample using multiobject-spectroscopy (MOS) mode of the Faint Object Camera and Spectrograph (FOCAS; Kashikawa et al. 2002) attached to the 8.2 m Subaru Telescope. The main spectroscopic targets are our LBG candidates brighter than $I_C = 25.0$ mag. Since a mask plate of FOCAS MOS covers a $6'$ aperture diameter field of view, we designed MOS masks to contain as many main targets as possible in each MOS field. The number of targets thus selected is 17. In addition to these, we selected seven objects with $I_C < 25.0$ mag that lie out of the color selection window but near the borderline of the window in order to examine our color selection criteria. We also included as many fainter LBG candidates ($I_C \geq 25.0$ mag) as possible in each mask.

Spectroscopic observations were made on 2003 February 24–26 under clear sky conditions. We used a grism of 300 lines mm^{-1} blazed at 7500 Å and the SO58 order cut filter. The wavelength coverage was from 5800 to 10,000 Å (depending on the slit position on the mask) with a pixel scale of 1.34 Å. The slit lengths were typically $10''$, and the slit widths were fixed to be $0''.8$, giving a spectral resolution of $R \sim 500$. One CCD pixel covered $0''.1$, and the spatial sampling was $0''.3$ $pixel^{-1}$ by on-chip 3 pixel binning. The exposure time of each frame was 0.5 hr, and the total exposure time was 5.5 hr for two masks (F01 and F02) and 5.0 hr for one mask (F08). We nodded the telescope with $\sim 1''$ along the slit length for each exposure. Spectrophotometric standard stars Feige 34 and Feige 66 were observed with long-slit mode (a slit width of $2''$) for sensitivity correction. Seeing during the observing runs was $0''.5$–$0''.8$.

The data were reduced with standard procedure using IRAF.[5] Bias was subtracted by using the overscan region and bias frames, and flat-fielding was made by normalizing averaged dome flat images. The spectra for each target were then carefully aligned and combined for each night. Wavelength calibration was made using night-sky emission lines exposed in the object frame with rms errors of 0.4–0.9 Å. Sky emission was subtracted by using the IRAF task *background*. Five pixels were binned for a wavelength direction to improve the signal-to-noise ratio (S/N). A one-dimensional spectrum of each object was extracted by using the IRAF task *apall*. Since our targets are faint, an aperture for the extraction was determined for each object by eye to trace the object well. After sensitivity correction (including correction for atmospheric *A* and *B* bands by tracing the absorption features in the spectra of the standard stars) was applied to combined spectra for each night, we obtained final spectra by combining them.

3. RESULTS

Figure 1 shows spectra of eight objects identified to be at $z \sim 5$. Object 3 (F01-03) has already been identified with an active galactic nucleus (AGN) at $z = 5.186$ by Barger et al. (2002) in follow-up spectroscopy of 1 Ms *Chandra* observations of the HDF-N. A significant continuum break at the redshifted Lyα is seen in all the spectra. The average of the depression factor D_A (Oke & Korycansky 1982) for these objects is $\sim$0.6, which is very close to those for QSOs at $z \sim 5$ (e.g., Songaila & Cowie 2002) and the estimation by Madau (1995). The spectra of seven LBGs (excluding object 3) also show low-ionization interstellar (LIS) metal absorption lines such as Si II λ1260, O I +Si II λ1303, and C II λ1334, which are prominent features in UV spectra of nearby starburst galaxies (e.g., Heckman et al. 1998) and in spectra of LBGs at $z \sim 3$ (e.g., Steidel et al. 1996a; Shapley et al. 2003). Thus they are securely identified to be at $z \sim 5$. We determined their redshifts as an average of these two or three LIS absorption lines and listed the results in Table 1, as well as their coordinates and photometric data. The obtained redshift range from 4.5 to 5.2 is consistent with that expected from the color selection (Iwata et al. 2003, Fig. 7). We also constructed a composite rest-frame spectrum of the seven LBGs by scaling the continuum level of each spectrum and show the result in Figure 2, together with the composite spectrum of 811 LBGs at $z \sim 3$ (Shapley et al. 2003).

Intriguingly, spectra of the seven LBGs in Figure 1 show no or weak Lyα emission.[6] Four objects show no significant Lyα emission line, and the other three objects (1, 6, and 7) show a Lyα emission line, but their rest-frame equivalent widths are rather weak: $EW_{rest} \sim 1$, $\sim$6, and $\sim$10 Å, respectively, with an error of 20%–30%. The average rest-frame equivalent width of Lyα of the seven LBGs is 2.5 Å, and that derived from the composite spectrum is 4.5 Å.[7] The positions of Lyα for some of them are located in the wavelength region of the atmospheric *B*-band absorption. We estimate that the uncertainty in the correction for the absorption is at most $\sim$10%.

A mean rest-frame equivalent width of three LIS absorption lines (Si II λ1260, O I+Si II λ1303, and C II λ1334) for each of the seven LBGs is measured to be -1.2 to -5.1 Å and is listed in Table 1. The average rest-frame equivalent widths of Si II λ1260, O I+Si II λ1303, and C II λ1334 of the seven LBGs are -3.2, -2.3, and -2.4 Å, respectively, which agree with those measured in the composite spectrum; -2.8, -2.0, and -2.4 Å, respectively.[8] Some of the LBGs show a high-ionization absorption feature of Si IV $\lambda\lambda$1393, 1402 that is also detected in local starburst galaxies and LBGs at $z \sim 3$. Most of them lie in the wavelength region where the sky emission is strong or an atmospheric absorption is severe, and we did not measure an equivalent width for each object. The Si IV $\lambda\lambda$1393, 1402 feature can be seen in the composite spectrum, thanks to the improvement of the S/N.

Peaks of the Lyα emission lines are redshifted with respect to the LIS lines by 650 ± 300, 530 ± 300, and 700 ± 300 km s^{-1} for objects 1, 6, and 7, respectively. In the composite spectrum, the offset is 620 ± 250 km s^{-1}. The value is almost the same as that of the LBGs at $z \sim 3$ with weak or no Lyα emission lines (630 km s^{-1} for group 2 by Shapley et al. [2003]) and also fits a relation between the outflow velocity

[5] Image Reduction and Analysis Facility, distributed by National Optical Astronomical Observatoriy, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

[6] Object 3 (F01-03) is an AGN and shows a broad ($\sim$1000 km^{-1}) and strong ($EW_{rest} \sim 44$ Å) Lyα emission.

[7] The S/N of the continuum is improved much in the composite spectrum. This leads to lower the continuum level in a longer wavelength region adjacent to the Lyα line, which seems to result in a slightly larger Lyα equivalent width for the composite spectrum.

[8] For some objects, the LIS line falls in the wavelength region of the atmospheric *A* band, and uncertainty of the correction is estimated to be $\sim$20%.

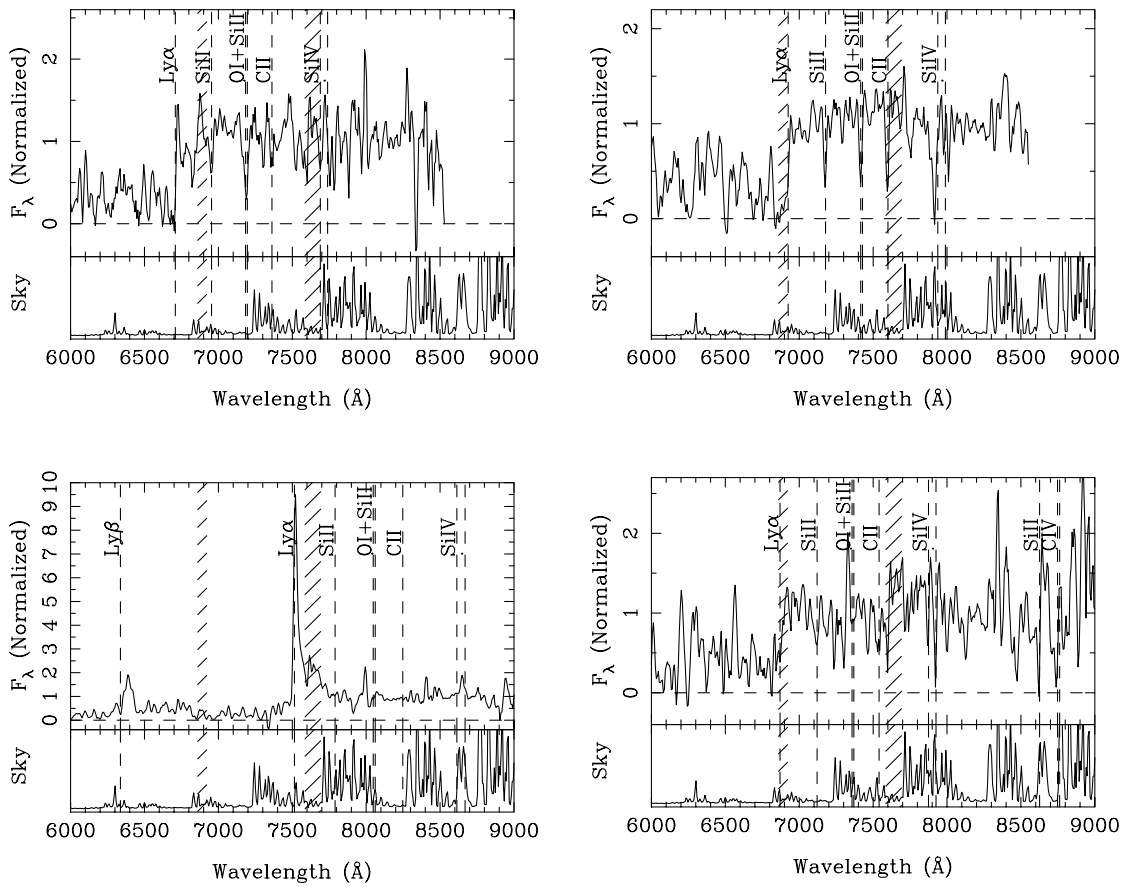


FIG. 1.—Spectra of objects at $z \sim 5$ with the positions of their rest-frame UV lines. *Top:* Objects 1 (*left*) and 2 (*right*). *Bottom:* Objects 3 (*left*; the AGN of Barger et al. [2002]) and 4 (*right*). The flux scale is F_λ and normalized with the continuum level averaged over the region longer than Lyα excluding sky emission and the LBG absorption lines. These spectra are smoothed with a boxcar over 3 pixels. The sky spectrum is shown in the lower panel of each figure, and atmospheric absorptions are shown as vertical hatched regions. *Top:* Objects 5 (*left*) and 6 (*right*). *Bottom:* Objects 7 (*left*) and 8 (*right*).

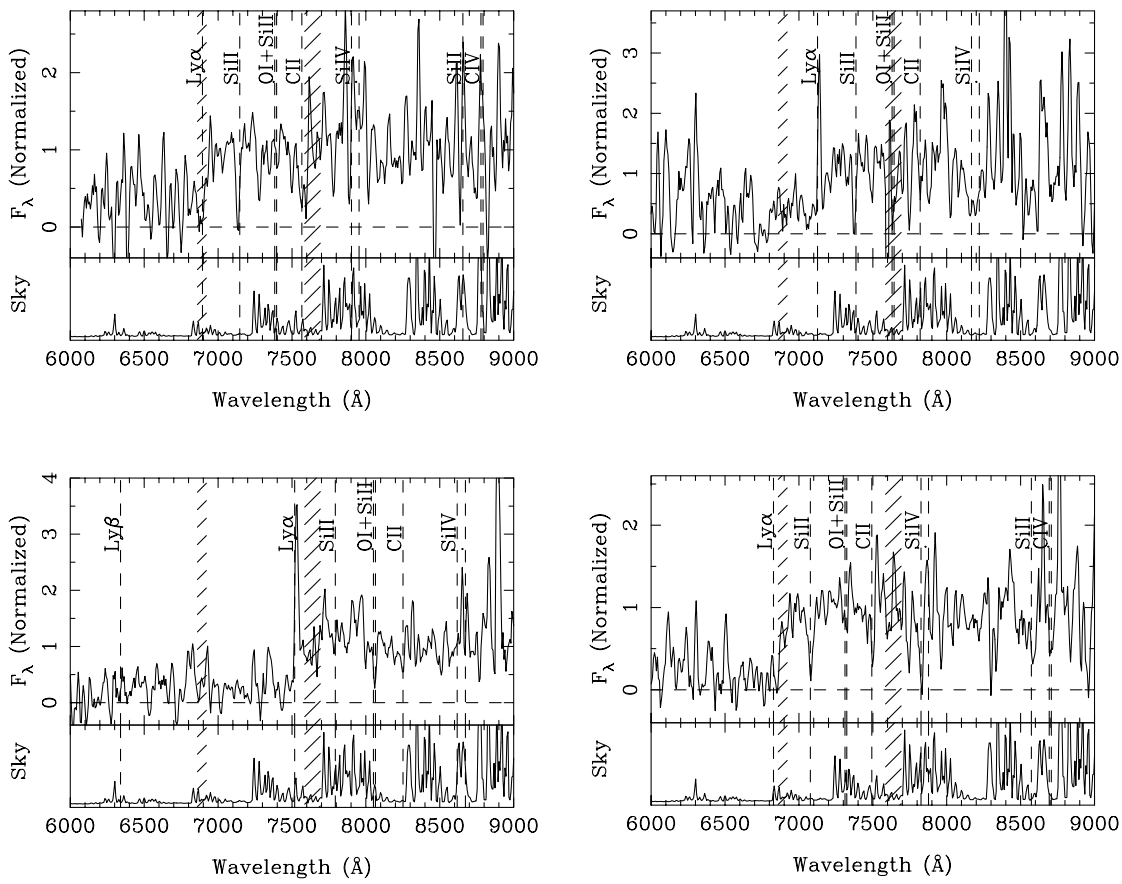


FIG. 1.—*Continued*

TABLE 1
SPECTROSCOPIC SAMPLE IDENTIFIED TO BE AT $z \sim 5$

IDENTIFICATION	R.A. (J2000.0)	DECL. (J2000.0)	I_C[a]	$V - I_C$[b]	$I_C - z'$[b]	REDSHIFT[c]	EW Lyα[d,e]	EW LIS[e,f]
1 (F8-2).....	12 38 11.2	+62 09 19.3	24.03	2.22	0.11	4.517	1.4	−2.2
2 (F2-2).....	12 37 57.5	+62 17 19.2	24.16	2.40	0.07	4.695	0	−2.2
3[g] (F1-3).....	12 36 47.9	+62 09 41.3	24.17	3.31	−0.10	5.186	44.4	−0.7
4 (F1-1).....	12 37 05.7	+62 07 43.1	24.62	2.26	0.15	4.650	0	−1.2
5 (F2-6).....	12 38 29.0	+62 16 18.8	24.63	1.96	0.20	4.667	0	−5.1
6 (F2-3).....	12 38 25.5	+62 18 19.7	24.74	3.02	0.14	4.857	6.3	−2.7
7 (F2-8).....	12 38 04.4	+62 14 19.8	24.80	3.28	0.21	5.183	9.8	−2.0
8 (F2-7).....	12 38 16.7	+62 18 05.5	24.83	>3.19	0.42	4.615	0	−3.9

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

[a] I_C magnitude. MAG_AUTO from SExtractor (Bertin and Arnouts 1996) is adopted. Photometric errors are estimated to be 0.16 and 0.19 mag for 24.0 mag $< I_C \leq$ 24.5 mag and 24.5 mag $< I_C \leq$ 25.0 mag, respectively.

[b] These values are measured with a 1.″6 aperture. The errors in $V - I_C$ and $I_C - z'$ colors are 0.05–0.2 and 0.05–0.1 mag, respectively, depending on the I_C magnitude and color.

[c] Redshifts determined as an average of the two or three low-ionized interstellar metal absorption lines (Si II λ1260, O I+Si II λ1303, and C II λ1334) except for object 3; we adopted the redshift measured with Lyα emission for this object. The error of redshift is $\sim$0.006 (comparable to the spectral resolution).

[d] Rest-frame equivalent width of Lyα emission. A value zero refers to an object without a Lyα emission.

[e] Error of equivalent width for each line is estimated to be 20%–30%.

[f] Rest-frame equivalent width of the average of three LIS absorption lines (Si II λ1260, O I+Si II λ1303, and C II λ1334).

[g] X-ray–selected AGN (Barger et al. 2002).

and the equivalent widths of LIS for LBGs at $z = 4-5$ by Frye et al. (2002).

We also measured a continuum slope β ($f_\lambda \propto \lambda^\beta$) of the composite spectrum to be $\beta \sim -0.55$ with a fitting uncertainty of ± 0.3. However, since the value is determined in a short wavelength coverage ($\sim$250 Å) and depends on an applied binning scale and a clipping threshold in making the composite spectrum, the uncertainty of β would be much larger. Thus we do not discuss the result further.

Among the remainder of the spectroscopic sample in the color-selection window with $I_C < 25.0$ mag, two objects show hints of the presence of a continuum break at the wavelength corresponding to a redshifted Lyα at $z \sim 5$ and of one or two LIS absorption lines that could be identified to be at $z \sim 5$.

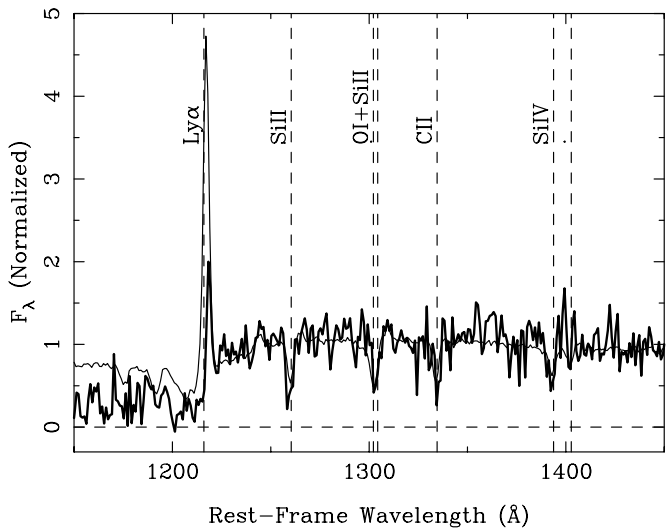


FIG. 2.—Composite spectrum of the seven LBGs at $z \sim 5$ (*thick line*). The composite spectrum of 811 LBGs at $z \sim 3$ by Shapley et al. (2003) is overplotted (*thin line*). Both of them are binned to a resolution of 1 Å pixel^{-1}.

However, the S/N of their spectra are poor, and we do not discuss these objects in this paper. For the remaining targets, we could not find any significant features due to the poor S/N. A roughly estimated upper limit on the rest-frame Lyα equivalent width for these objects is $\sim$20 Å. For the targets with $I_C \geq 25$ mag, we could not find any significant features due to the poor S/N. The S/N of the spectrum depends not only on the I_C magnitude, but also on its surface brightness. The objects identified to be at $z \sim 5$ tend to have the sizes (FWHM) comparable with the seeing size and thus have brighter peaks than those of the objects having larger sizes.

Figure 3 shows the positions of the objects identified to be at $z \sim 5$ (*filled circles*) in the two-color diagram ($V - I_C$ and $I_C - z'$), as well as the unidentified objects with $I_C <$ 25.0 mag (*open triangles*). One of the seven LBGs shown in Figure 1 is undetected in V band ($V > 28.5$ mag), while the remaining six are detected in V band in an aperture of 1.″6. Four among seven targets ($I_C < 25.0$ mag) outside of the selection window are identified to be Galactic M stars (filled pentagons). These results suggest that our selection criteria for objects at $z \sim 5$ are reasonable.

4. DISCUSSION

Shapley et al. (2003) divided spectroscopically confirmed $\sim$800 LBGs at $z \sim 3$ into four subgroups (each group consists of $\sim$200 LBGs) on the basis of rest-frame Lyα equivalent width and made composite spectra for each group. They found that about three-fourths of the $\sim$800 LBGs at $z \sim 3$ show Lyα emission lines, and about two-thirds show strong Lyα emission ($EW_{rest} > 10$ Å).[9] They also found that LBGs with

[9] Shapley et al. (2003) measured the equivalent width of Lyα line by summing up both emission and absorption. In our case, we measured the equivalent width of Lyα only for the emission part mainly because it is hard to distinguish intrinsic absorption and intergalactic absorption. Thus the value of rest-frame equivalent width of Lyα by Shapley et al. (2003) is the lower limit when it is compared with our equivalent width.

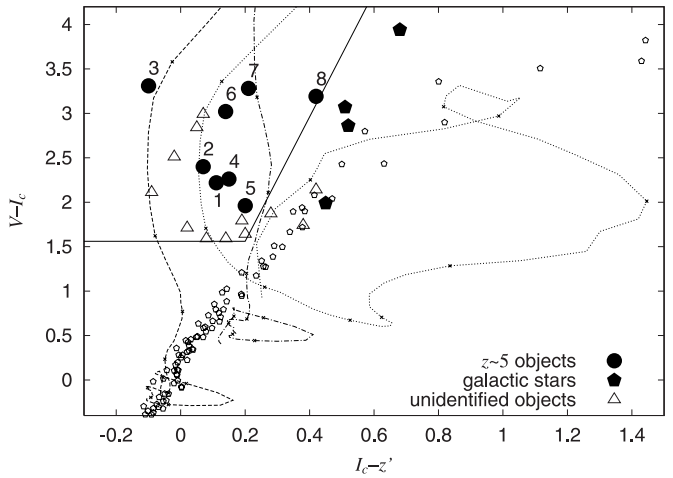


FIG. 3.—Positions of our spectroscopic targets ($I_C < 25.0$ mag) in a two-color diagram. Our color selection criteria for LBGs at $z \sim 5$, $V - I_C \geq 1.56$ and $V - I_C \geq 7(I_C - z') + 0.16$ mag (Iwata et al. 2003) are indicated by thick lines. Filled circles represent the objects confirmed to be at $z \sim 5$ with each identification number shown in Table 1. Filled pentagons show objects identified to be Galactic M stars, and open triangles show unidentified objects. A dashed (dot-dashed) line represents a color track of a model LBG spectrum with the $E(B - V) = 0.0$ mag [$E(B - V) = 0.4$ mag] from Iwata et al. (2003). The dotted line refers to a color track of an elliptical galaxy (Coleman et al. 1980). The small cross symbols are plotted with a redshift interval of 0.5 from $z = 0$ to $z = 5$. No evolution is considered in these models. Small open pentagons indicate the colors of A0–M9 stars calculated on the basis of the library by Pickles (1998).

weaker Lyα emission have stronger LIS absorption lines, redder UV continuum slopes, and larger $E(B - V)$ values. The weak Lyα emission, strong LIS absorption lines, the red UV color, and large $E(B - V)$ are considered to originate in a dusty environment. In the LBGs with no or weak Lyα emission, star formation may occur earlier and may be chemically more evolved than those with strong Lyα emission. Although Shapley et al. (2001) pointed out the possibility that the LBGs with weak Lyα emission are younger than those with strong emission from the spectral energy distribution (SED) fitting, this might be reconciled with the chemically evolved nature if the ages derived by SED fitting are affected by the most recent star formation that occurred in the LBGs.

The spectra of our seven LBGs (all except for one AGN) at $z \sim 5$ and thus the composite spectrum of them is significantly different from the composite spectrum of LBGs at $z \sim 3$ as shown in Figure 2. The Lyα emission is much weaker, and the continuum depression in the wavelength region shortward of the redshifted Lyα emission is much larger than for those at $z \sim 3$. The measured equivalent width of Lyα emission is 4.5 Å at $z \sim 5$ but 15.1 Å at $z \sim 3$. The LIS absorption lines are stronger in the spectrum for $z \sim 5$ than in that for $z \sim 3$; measured equivalent widths of Si II λ1260, O I+Si II λ1303, and C II λ1334 are -2.8, -2.3, and -2.4 Å, respectively, for $z \sim 5$, but -1.7, -2.3, and -1.5 Å, respectively, for $z \sim 3$. However, the spectra of the seven LBGs at $z \sim 5$ resemble closely the subpopulations of LBGs at $z \sim 3$; the composite spectra of LBGs at $z \sim 3$ with no or weak Lyα emission (groups 1 and 2 of Shapley et al. 2003) are quite similar to the spectra of our LBGs at $z \sim 5$. The average rest-frame equivalent widths of the three LIS absorption lines of the seven LBGs at $z \sim 5$ is -2.8 Å, very close to the -2.5 Å for group 1 (no Lyα emission). The average value of EW_{rest}(LIS) corresponds to metallicity of $12 + \log(O/H) \sim 8.0$ if we assume that the relation obtained in the local universe by Heckman et al. (1998) can be applied to the high-redshift LBGs, which is not certain at this moment. These results suggest that these LBGs at $z \sim 5$ are chemically evolved to some degree.

All our LBGs confirmed to be at $z \sim 5$ show no or weak Lyα emission with relatively strong LIS absorption lines; the fraction of LBGs with strong Lyα emission is very small, although the sample size is still small. We may be witnessing some sign of evolution of LBGs from $z \sim 5$ to $z \sim 3$. The lack of strong Lyα emission and the presence of strong LIS absorption at $z \sim 5$ are likely to be due to their dusty and chemically evolved environment (although the escape of Lyα photons may not be related in a simple way to the metallicity of the galaxy; e.g., Kunth et al. 2003) and to the presence of more neutral hydrogen in and/or around a galaxy than that at $z \sim 3$.

However, it is worth emphasizing that the LBGs we observed are the relatively brighter ones among those at $z \sim 5$ ($I_C = 25.0$ mag corresponds to M^* of UVLF at $z \sim 5$; Iwata et al. 2003). There is a possibility that the strength of Lyα emission depends on the magnitude (i.e., UV continuum). Shapley et al. (2003) found for LBGs at $z \sim 3$ that the average UV magnitude is fainter for the LBGs with stronger Lyα emission. They also found that the average rest-frame equivalent width of the Lyα emission line of faint LBGs is larger than that of bright LBGs among the subgroup with strong Lyα emission of $EW_{rest} \geq 20$ Å. This trend could also be the case at $z \sim 5$. In fact, Lehnert & Bremer (2003), who made a similar search for LBGs at $z \sim 5$ using R-, I-, and z-band deep images, found that all of their spectroscopically confirmed six objects to be at $z \sim 5$ show very strong ($EW_{rest} > 30$ Å) Lyα emission lines. Their I magnitudes are $\sim$1 mag fainter than those of our seven LBGs at $z \sim 5$. In addition, Ouchi et al. (2003) found that the number density of Lyα emitters (LAEs) at $z = 4.86$ compared with LBGs at $z \sim 5$ rapidly decreases with increasing UV continuum light ($i' \lesssim 25$ mag). These observational results suggest that the brighter LBGs tend to show the weaker Lyα emission also at $z \sim 5$. It is also worth noting here that the LBGs with secure redshifts tend to show rather compact morphology. Thus the weakness of Lyα emission and the strong LIS absorption lines may also relate to their morphological property, which may also link to an evolutionary stage of galaxies.

If we interpret that the weakness of the Lyα emission is caused by the dusty environment in the LBGs, it might be possible that the brightest LBGs are the most chemically evolved ones at the epoch. It is known that brighter LBGs have a larger correlation length at $z \sim 3$ (Giavalisco & Dickinson 2001), suggesting that they are associated with more massive dark halos and that star formation may occur with biased manner at the earlier epoch than less clustered fainter LBGs. A similar result has been obtained for LBGs at $z \sim 4$ by Ouchi et al. (2004b). We also found the same clustering segregation with magnitude in our sample of LBGs at $z \sim 5$ (I. Iwata et al. 2004, in preparation). Thus the brighter LBGs at $z \sim 5$ may be associated with even more massive dark halos and have experienced more biased star formation, resulting in a more dusty environment than that of many of the LBGs at $z \sim 3$ with a strong Lyα emission.

Another possible reason for the difference of Lyα appearance is the effect of a strong clustering of LAEs. Ouchi et al. (2003) and Shimasaku et al. (2003) found that there is an overdensity region ($\sim 10' \times 10'$) of LAEs ($EW_{rest} > 14$ Å) at $z \sim 4.86$ from wide-field deep narrowband observations. The

observed field (44 arcmin^2) of Lehnert & Bremer (2003) may happen to fall on an overdensity region of Lyα emitters; their rest-frame equivalent widths of Lyα emission (>30–50 Å) is larger than the detection threshold of the LAE selection. But our field of view for the spectroscopy (total of $\sim$85 arcmin^2) may happen to point to a low-density region of LAEs, and we could not observe LBGs with strong Lyα emission. However, since we selected spectroscopic targets from regions where the surface density of LBG candidates is relatively high, this may be unlikely provided that the distribution of LBGs broadly coincides with that of LAEs at the same epoch.

To summarize, the results presented here may show some sign of evolution in spectroscopic features from $z \sim 5$ to $\sim$3 or the presence of luminosity dependence. However, our sample size is too small to reach any significant conclusions. Further spectroscopic observations of LBGs at $z \sim 5$ over wider field and magnitude range are necessary to reveal spectroscopic their nature and discuss its relationship with evolution of the LBG population.

We are grateful to the FOCAS team, especially support astronomer Youichi Ohyama, for their advises and supports for our observations. We thank the entire staff of the Subaru Telescope. We also appreciate the referee for comments that improved this paper. I. I. is supported by a Research Fellowship of the Japan Society for the Promotion of Science for Young Scientists and by a Grant-in-Aid for the 21st Century Center of Excellence of Japan Center for Diversity and Universality in Physics. This work is partly supported by a Grant-in-Aid for Scientific Research (15540233) from the Ministry of Education, Culture, Sports, Science, and Technology of Japan.

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