The interaction of ultrathin films of Ni and Pd with W(110): an XPS study

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The interaction of ultrathin films of Ni and Pd with W(110) has been examined using X-ray photoelectron spectroscopy (XPS) and the effects of annealing temperature and adsorbate coverage (film thickness) are investigated. The XPS data show that the atoms in a monolayer of Pd or Ni supported on W(110) are electronically perturbed with respect to the surface atoms of Pd(100) and Ni(100). The magnitude of the electronic perturbations is larger for Pd than for Ni adatoms. Our results indicate that the difference in Pd(3d,5/2) XPS binding energies between a pseudomorphic monolayer of Pd on W(110) and the surface atoms of Pd(100) correlates with the variations observed for the desorption temperature of CO (i.e., the strength of the Pd–CO bond) on these surfaces. A similar correlation is seen for the Ni(2p3/2) XPS binding energies of Ni/W(110) and Ni(100) and the CO desorption temperatures from these surfaces. The shifts in XPS binding energies and CO desorption temperatures can be explained in terms of: (1) variations that occur in the Ni–Ni and Pd–Pd interactions when Ni and Pd adopt the lattice parameters of W(110) in a pseudomorphic adlayer; and (2) transfer of electron density from the metal overlayer to the W(110) substrate upon adsorption. Measurements of the Pd(3d,5/2) XPS binding energy of Pd/W(110) as a function of film thickness indicate that the Pd–W interaction affects the electronic properties of several layers of Pd atoms.

1. Introduction

The surface chemistry of bimetallic systems has been the subject of many investigations over the last several years [1–20]. In part, the motivation of these studies is the fact that mixed-metal systems are superior over their single-metal counterparts in terms of catalytic activity and/or selectivity [21]. Work on ultrathin metal films supported on well-defined metal surfaces [1–20] has shown that a metal atom in a matrix of a dissimilar metal can be significantly perturbed, and that this perturbation can dramatically alter the chemical and electronic properties of both constituents of the mixed-metal system. In this paper we study the interaction of Ni and Pd with W(110) using X-ray photoelectron spectroscopy (XPS).

The properties of ultrathin films of Pd on W(110) have been previously investigated by means of low-energy electron diffraction (LEED) [10,11], Auger electron spectroscopy (AES) [10,11], temperature programmed desorption (TPD) [10,11] and work function measurements [10]. LEED results indicate that at coverages up to 0.9 monolayer (ML), the Pd films grow with one-dimensional pseudomorphism on the W(110) substrate at room temperature [10,11]. Annealing a Pd monolayer to 850 K results in a (1 x 1) LEED pattern and a fully pseudomorphic Pd adlayer with an atomic density equal to that of W(110). AES data show layer-by-layer growth of Pd at 100 K [10]. Layers in excess of the first monolayer are metastable, forming three-dimensional (3D) islands (cluster crystallites) at temperatures above 700 K [10]. TPD of Pd from W(110) yields two discrete features [10,11] which are related to Pd desorption from the monolayer (1400–1550 K) and multilayer (1200–1350 K) states.

AES [7–9], LEED [7–9], TPD [7–9], field emission microscopy [6] and work function measurements [7] have been used to examine the interaction between ultrathin films of Ni and W(110). On
this surface the initial adsorption of Ni was found to be pseudomorphic up to a coverage near 1 ML [7-9]. This growth pattern leads to a Ni monolayer density on W(110) that is 23% and 12% less than the corresponding monolayer densities for Ni(111) and Ni(100), respectively. At 100 [9] and 300 K [7,8], Ni is adsorbed layer-by-layer on W(110). Ni films with thicknesses of up to 1.3 ML remained stable to an annealing temperature of 1200 K [7-9]. Annealing Ni films with coverages larger than 1.3 ML to 1200 K produced 3D islands (cluster crystallites), leaving a large portion of the pseudomorphic first monolayer exposed [7-9]. TPD experiments [7-9] show desorption temperatures between 1350 and 1500 K for the first monolayer of Ni on W(110), and between 1250 and 1350 K for the Ni multilayers.

Studies of CO chemisorption onto a monolayer of Pd adsorbed on W(110) [11] show a CO TPD maximum reduced by approximately 180 K with respect to the peak maximum on bulk palladium. This indicates that CO on Pd/W(110) is much less strongly bound to the Pd monolayer than on bulk Pd, and suggests that the electronic properties of the Pd surface atoms are quite different in each case. For CO adsorption on Ni/W(110) [9], a reduction of ~50 K in the CO TPD maximum with respect to the peak maximum on Ni(100) and Ni(111) has been observed. In the present study we examine the electronic interaction of Pd and Ni films with the W(110) substrate using XPS. The effects of adsorbate coverage and surface annealing temperature on these electronic interactions are also investigated. The CO adsorption properties of the Pd and Ni adlayers are discussed in light of our present results.

2. Experimental section

An ultrahigh vacuum system (base pressure \(\leq 4 \times 10^{-10}\) Torr) equipped with capabilities for Auger electron spectroscopy (AES), low energy electron diffraction (LEED), X-ray photoelectron spectroscopy (XPS) and temperature programmed desorption (TPD) was used in this work.

The W(110) crystal was oriented to within ±0.5° and mounted by spotwelding to 0.20 mm Ta support leads capable of resistive heating to 1600 K. The sample temperature was monitored by W–5%Re/W–26%Re thermocouples spotwelded to the edge.

The sample was cleaned by heating in 5 \(\times 10^{-8}\) Torr O\(_2\) at 1100 K for 5 min, followed by flashing to 2300 K with an electron beam heater. This was repeated until the surface was determined to have <1% impurities by AES and XPS.

Pd and Ni metals were vapor deposited (sample temperature ~350 K) by heating a 0.20 mm W filament wrapped with a 0.10 mm high purity Pd or Ni wire housed in a collimating shroud. After evaporation the sample was flashed to 475 K to desorb any accumulated CO, and no impurities were detected by AES or XPS.

In this work, absolute coverages are reported with respect to the number of W(110) surface atoms \((1.43 \times 10^{15} \text{ atoms/cm}^2)\). One adatom per W(110) surface atom corresponds to \(\theta = 1.0\). The Ni and Pd coverages were determined by TPD area analysis [9,11].

The Pd(3d), Ni(2p) and W(4f) XPS spectra of section 3 were recorded with AlK\(_\alpha\) radiation and a pass energy of 60 eV, which gave a W(4f\(_{7/2}\)) peak for clean W(110) with a 1.5 eV full width at half-maximum (FWHM). This tungsten FWHM can be taken as the overall instrumental resolution. The binding energies of the Pd(3d) and Ni(2p) XPS regions were determined by referencing against the W(4f\(_{7/2}\)) peak for W(110), which was set at a binding energy of 31.0 eV [22]. Detection was 45° off the surface normal in XPS.

3. Results

3.1. Pd on W(110)

In fig. 1 representative spectra of the XPS Pd(3d) region for various Pd coverages are shown. All spectra were taken after flashing the surface to 475 K following metal overlayer deposition (sample \(T \sim 350\) K). Coverages were determined using TPD area analysis of the desorbing metal overlayer [11]. The Pd(3d\(_{5/2}\)) peak position is observed to shift from 336.15 eV for the 0.41 and 1.05 ML coverages to the bulk (40 ML) peak.
Fig. 1. Effect of Pd coverage on the XPS Pd(3d) spectra of Pd/W(110). The relative peak intensities can be obtained by multiplying each spectrum by the corresponding scaling factor shown in the left side of the figure. The Pd was deposited at a sample temperature of ~350 K. After Pd deposition, the sample was heated briefly to 475 K to desorb any accumulated CO.

The W(4f) peaks were also monitored for various Pd coverages (not shown) and no change in line shape (1.5 eV FWHM) or in separation between the W(4f\textsubscript{7/2}) and W(4f\textsubscript{5/2}) peaks was observed. Only a decrease in intensity with an increase in Pd coverage was apparent.

In fig. 2, the XPS Pd(3d\textsubscript{5/2}) binding energy as a function of Pd coverage is plotted. Coverages of less than 1.05 ML show little shift in peak position from 336.15 eV. On the other hand, for coverages greater than 1.05 ML, there is a decrease in the peak position to a value of 335.65 eV at ~8 ML. Coverages greater than 8 ML show no further change in peak position.

Fig. 3 shows the effects of annealing temperature on the XPS Pd(3d) region of 4.5 ML of Pd on W(110). All spectra were taken after annealing the sample to the specified temperature for two min and cooling to 475 K. Annealing causes a reduction in the intensity of the Pd(3d) peaks and an increase in the Pd(3d\textsubscript{5/2}) peak position from 335.8 eV (475 K anneal) to 336.15 eV (1150 K anneal).
The FWHM decreases from 2.2 eV for the 475 K anneal to 1.7 eV for the 1150 K anneal. An important result of the annealing is that the 336.15 eV peak position and 1.7 eV FWHM following the 1150 K anneal for 4.5 ML of Pd are identical to the corresponding values for 1 ML of unannealed Pd. No apparent change in the separation between the Pd(3d) peaks was observed during the annealing process. The W(4f) region was also monitored during annealing with no observed change in line shape (1.5 eV FWHM) or W(4f) peak separation.

In fig. 4 the Pd(3d\textsubscript{5/2}) XPS binding energy and the Pd(3d)/W(4f) XPS peak intensity ratio are plotted as a function of annealing temperature for three Pd coverages (θ\textsubscript{Pd} = 1.9, 4.5 and 10 ML). Data (not shown) for annealing 1 ML of Pd to 1150 K showed no apparent changes in peak position (336.15 eV), FWHM (1.7 eV) or XPS Pd/W ratio. In fig. 4C the analogous annealing results for 1.9 ML of Pd are shown, and, in contrast to the 1 ML results, show a reduction in the XPS Pd/W ratio. There is a concomitant increase in the Pd(3d\textsubscript{5/2}) XPS binding energy from 336.00 to 336.15 eV upon annealing from 475 to 1150 K. Concurrently, the FWHM decreased from 1.9 eV for a 475 K anneal to 1.7 eV for a 1150 K anneal. In fig. 4B the results for 4.5 ML of Pd (taken from fig. 3) are shown. Similar to the data for 1.9 ML, a increase in peak position and a decrease in FWHM and in the XPS Pd/W ratio are observed following an anneal from 475 to 1150K. In fig. 4A the annealing results for 10 ML of Pd are displayed. In annealing to 1150 K there is an increase in peak position from 335.65 to 336.10 eV, but unlike the coverages in figs. 4B and 4C, a 10 ML Pd coverage shows a variation in the Pd(3d\textsubscript{5/2}) binding energy only after an anneal temperature of 675 K. The FWHM was found to decrease only slightly from 1.9 to 1.8 eV during these annealing experiments. The decrease in the Pd(3d)/W(4f) XPS intensity ratio and the shift in the Pd(3d\textsubscript{5/2}) binding energy observed in fig. 4
upon annealing can be attributed to the formation of 3D islands (cluster crystallites) which leave a large portion of the first monolayer exposed \[10,11\].

3.2. Ni on W(110)

Fig. 5 shows the effect of Ni coverage (determined by TPD area analysis \[9\]) on the Ni(2p\textsubscript{3/2}) XPS spectra of ultrathin films of Ni on W(110). All spectra were taken after flashing the surface to 475 K following dosing. The Ni(2p\textsubscript{3/2}) XPS binding energy was monitored by referencing to the W(4f\textsubscript{7/2}) peak of W(110) (at 31.0 eV \[22\]) and has an experimental error of \pm 0.03 eV. For all Ni coverages the Ni(2p\textsubscript{3/2}) peak lies between 853.05 and 853.10 eV, whereas the FWHM does not deviate significantly from 1.9 eV. The only noticeable change in the XPS spectra is an increase in peak intensity with Ni coverage.

The W(4f) peaks were also monitored (not shown) following deposition of various Ni coverages. No change in line shape (1.5 eV FWHM) or in separation between the W(4f) peaks was apparent. Only a decrease in the XPS peak intensity with increased Ni coverages was observed.

The binding energy of the Ni(2p\textsubscript{3/2}) peak position is plotted as a function of Ni coverage in fig. 6. The data suggest a small reduction in the XPS binding energy from 853.10 to 853.05 eV with increasing Ni coverage; however, the variation is very close to the experimental error. Accordingly, a straight line is drawn at 853.075 eV to fit the data for all coverages.

The effects of annealing upon the Ni(2p\textsubscript{3/2}) XPS binding energy and the Ni(2p)/W(4f) XPS intensity ratio of three different Ni films (\(\theta_{\text{Ni}} = 1.9, 3.5 \text{ and } 30 \text{ ML}\)) are shown in fig. 7. The Ni(2p\textsubscript{3/2}) and W(4f) XPS features were monitored during annealing (not shown) with no apparent change from the unannealed features. The effects on annealing 1 ML of Ni were also examined (not shown) with no changes in peak position, FWHM on XPS Ni/W ratio up to the Ni desorption temperature. Annealing also had no effect on peak position or FWHM for higher Ni coverages (A–C). The only noticeable change during annealing is the decrease in Ni/W intensity ratio that can be attributed to the formation of 3D islands (cluster crystallites).

4. Discussion

We have studied the interaction of Ni and Pd ultrathin films with W(110) monitoring the Ni(2p) and Pd(3d) XPS core level shifts. Previous results show a shift of 2 eV in the Ni(2p\textsubscript{3/2}) binding energy from metallic nickel to nickel oxide (NiO).
Similarly, a difference of \( \sim 1.5 \) eV is observed between the Pd(3d \(_{5/2}\)) binding energy of metallic palladium and palladium oxide (PdO) [22]. Thus, the variations in the Ni(2p \(_{3/2}\)) and Pd(3d \(_{5/2}\)) XPS binding energies can provide useful information regarding the degree of partial charge developed at a metal atom center upon bonding. XPS then should serve as a useful probe to examine the charge transfer associated with Ni–W and Pd–W bonding interactions.

XPS data for Ni(100) show that the Ni(2p \(_{3/2}\)) binding energy of the surface atoms is \( \sim 0.45 \) eV lower than that of bulk Ni [23]. A similar trend is observed for other late transition metals [12,25,29,30]. Correlations can be made between the shifts in the XPS binding energies and the surface atomic structure [12,25–30]. XPS surface core level shifts can also provide useful information regarding the surface electronic properties [12,24,26,27]. The data of figs. 5 and 6 show that the Ni(2p \(_{3/2}\)) binding energy of a monolayer of Ni on W(110) is identical to that measured for the combined bulk and surface atoms in 30 ML of Ni. If we reference the combined Ni(2p \(_{3/2}\)) peak of 30 ML of Ni on W(110) to that of Ni(100) (see fig. 8), a difference of \( \sim 0.35 \) eV is obtained between the Ni(2p \(_{3/2}\)) binding energy of a monolayer of Ni on W(110) and that of the surface atoms of Ni(100).

For the case of Pd(100), theoretical calculations [28] suggest that the Pd(3d \(_{5/2}\)) XPS binding energy of the surface atoms is shifted by \( \sim 0.4 \) eV with respect to that of bulk palladium. The predicted shift is in quantitative agreement with the shifts observed experimentally for Ni and Pt surfaces [23,30]. Applying the same type of analysis used above for the Ni(2p \(_{3/2}\)) XPS data (see fig. 8), we obtain a difference of \( \sim 0.85 \) eV between the Pd(3d \(_{5/2}\)) binding energy of a monolayer of Pd on W(110) and that of the surface atoms of Ni(100).
Pd(100). The shift toward higher binding energy observed in the Ni(2p) and Pd(3d) XPS spectra of a monolayer of Ni and a monolayer of Pd on W(110) can be attributed to a stabilization of the initial state of the Ni(2p) and Pd(3d) electronic energy levels caused by transfer of electron density from the Ni and Pd adatoms to the W(110) substrate. Experimental measurements [7,10] show a decrease in the work function of W(110) upon deposition of a monolayer of Ni or Pd atoms, suggesting that there is transfer of electrons from the occupied orbitals of the adlayer into the empty electronic states of tungsten.

Our XPS data show clearly that the atoms in a monolayer of Pd or Ni supported on W(110) are electronically perturbed with respect to the surface atoms of Pd(100) and Ni(100). This agrees very well with previous UPS results for Pd on Nb(110), Ta(110) and W(110) [47]. The electronic perturbations are the product of two phenomena: (1) variations in the Ni–Ni and Pd–Pd interactions caused by a change in the geometry of the atoms in going from the lattice parameters of Ni or Pd to the lattice parameters of W(110) in a pseudomorphic adlayer, and (2) the effects of the Ni–W and Pd–W interactions (i.e. the formation of significant chemical bonds between the metal overlayer and the substrate).

LEED results for the Ni/W(110) system [9] indicate that at coverages up to 1 ML, the Ni films grow pseudomorphically with respect to the W(110) substrate. This growth pattern leads to a Ni monolayer density on W(110) that is 23% and 12% less than the corresponding monolayer densities for Ni(111) and Ni(100), respectively. The Ni–Ni nearest-neighbor distance is ~2.49 Å in Ni(100) and Ni(111) [31], while it is ~2.74 Å in a pseudomorphic monolayer of Ni on W(110) [31]. Thus, the effective coordination of Ni adatoms on W(110) is significantly smaller than for either Ni(100) or Ni(111). This reduction in the effective coordination of the Ni atoms will lead to an overall reduction in the electronic stability of the overlayer compound compared to the bulk metal. This, in turn, leads [32] to a reduction in the Ni(2p) XPS binding energy of the Ni monolayer supported on W(110) compared to the surface atoms of Ni(100) and Ni(111). However, it appears that for the Ni/W(110) system, the effect of the variation in the spatial arrangement of the Ni atoms is compensated by transfer of electron density from Ni to W. The net effect is that the Ni(2p) binding energy of a Ni monolayer on W(110) is somewhat higher than the corresponding binding energy of the surface atoms in Ni(100).

For Pd/W(110), a pseudomorphic monolayer of Pd atoms has a Pd–Pd nearest neighbor distance of ~2.74 Å [31], very close to the value of 2.75 Å observed for bulk palladium [31]. Thus, for this bimetallic system, any perturbation in the electronic properties of the Pd adatoms is primarily a consequence of Pd–W interactions. The data in fig. 8 indicate that the difference in Pd(3d,3/2) binding energy between a monolayer of Pd on W(110) and the surface atoms of Pd(100) is larger than the difference in Ni(2p3/2) binding energy between a monolayer of Ni on W(110) and the surface atoms of Ni(100). This indicates that the overlayer electronic modifications induced by adsorption on W(110) are more significant for palladium. Two possible explanations for this observation are: (1) for the Pd/W(110) system, the effects of the transfer of charge from the adsorbate to the substrate are not compensated by the effects of altering the adsorbate–adsorbate separation (as happens for the Ni/W(110) system); and (2) similar metallic radii of Pd and W [31] enhance the overlap between the occupied electronic levels of the Pd monolayer and the empty electronic levels of the tungsten substrate. This overlap leads to a transfer of electron density from the Pd adsorbate to the W substrate which, in turn, leads to a higher shift in XPS binding energies for Pd.

Thermal desorption of Ni [9] and Pd [11] from W(110) shows that the separation between the desorption temperature of the multilayer and monolayer features is larger for the Pd/W(110) system (~230 K) than for the Ni/W(110) system (~130 K). These data suggest that the Pd–W interaction is relatively stronger than the Ni–W interaction, consistent with the relative shifts in the XPS binding energies of fig. 8.

In fig. 9A we compare the desorption temperature of CO from a monolayer of Ni on W(110) with the corresponding values for pure Ni. A
similar comparison is shown in fig. 9B for Pd/W(110) and Pd. These data show a marked reduction in the desorption temperature of CO in going from Pd to Pd/W(110). The decrease in the CO desorption temperature is ~50 K for Ni/W(110) and ~180 K for Pd/W(110). There is a qualitative correlation between the relative reduction in CO desorption temperature shown in fig. 9 and the relative shifts in the XPS binding energies displayed in fig. 8.

According to the Blyholder mechanism [39,40] CO adsorption on transition metal surfaces involves donation of electron density from the CO 5σ level into the unoccupied metal electronic levels, and a corresponding back-donation from the occupied metal electronic levels into the lowest unoccupied molecular orbitals (2π*) of the CO molecule. In addition, there is a repulsive interaction between the metal σ charge and the electrons in the 5σ orbital of CO [40,42]. This bonding mechanism is similar to that observed for CO bonding in transition metal carbonyl complexes [41]. Recent theoretical calculations using the constrained space orbital variation (CSOV) method indicate that in a synergistic bond of this type, the π component of the bond is more important in determining the overall bond strength than is the σ component [42–43]. Results of inverse photoemission spectroscopy support the relative importance of π back-donation in CO chemisorption on Pd and Ru [44]. The assumption that the antibonding 2π* orbitals of CO are populated upon adsorption is consistent with results of HREELS [45] and infrared reflection absorption spectroscopy [38] which show that the C–O stretching frequency and the C–O force constant of CO adsorbed on Pd(100) and Ni(100) are lower compared to the corresponding values for molecular CO.

Our XPS results in fig. 8 indicate that the Pd(3d) levels of a monolayer of Pd supported on W(110) are ~0.85 eV more stable than those of the surface atoms of Pd(100). A similar shift toward higher binding energy can be expected [47] for the Pd valence levels of the Pd/W(110) system. This shift increases the separation between the occupied valence bands of Pd (below the vacuum level) and the empty 2π* orbitals of CO (at ~1.8 eV above the vacuum level [52,53]), leading to a reduction in π back-donation and a subsequent weakening of the Pd–CO bond. The results of XPS and work function measurements are consistent with transfer of charge from the Pd monolayer to the W(110) substrate (see above). A partial positive charge on the Pd adatoms is consistent with a reduction in the availability of electron density to coordinate to CO via backbonding, and thus an overall weaker Pd–CO bond on Pd/W(110) compared to Pd(100).

For the Ni/W(110) system the reduction in CO desorption temperature is smaller than that observed for the Pd/W(110) system (see fig. 9). For a pseudomorphic monolayer of Ni on W(110), the effects of the Ni–W interaction (transfer of electrons to the tungsten and a corresponding reduction in the backbonding to CO) are in part compensated by an increase in the Ni–Ni nearest-neighbor distance. This increase in the Ni–Ni distance reduces the effective coordination of the Ni adatoms. This latter effect should enhance the coordination between the Ni and CO by facilitating backbonding.
The results of figs. 1 and 2 show a monotonic variation of the XPS Pd(3d$_{5/2}$) binding energy until a film of 8 ML of Pd is deposited on the W(110) surface. The spectra of fig. 1 represent a combination of the binding energies of surface and subsurface Pd atoms. These data indicate that the Pd–W interaction can affect the electronic properties of several Pd atomic layers, perhaps up to as many as 5 or 6 layers. A similar result has been seen for the Pd/Nb(110) system [13], where films thicker than 5 monolayers of Pd are necessary to obtain CO desorption behavior near that of Pd(111).

Our results show that a monolayer of Pd on W(110) is stable up to 1150 K, with no changes in XPS Pd(3d$_{5/2}$) peak position, FWHM or XPS Pd/W ratio upon annealing. This fact is consistent with the AES results [10,11] and work function measurements [10] for the Pd/W(110) system. The data in fig. 4 indicate that layers in excess of the first monolayer are metastable, with substantial alteration of the morphology of these layers occurring at temperatures above 850 K. Previous studies using AES [10] show that these changes initiate at temperatures near 700 K. The discrepancy between the previous AES results and the XPS results presented here may arise due to diffraction of the exiting electrons produced in each measurement [51] and to the fact that the analyzer takeoff angle for the present results was necessarily significantly different from that used for the AES measurements.

The decrease in the Pd/W XPS intensity ratio observed in fig. 4 may be a consequence of: (1) diffusion of the Pd into the bulk (alloy formation); and/or (2) the formation of 3D islands of Pd (cluster crystallites) that leave a large fraction of the first Pd monolayer exposed. The very small miscibility of Pd in W [46] suggests that the latter is more likely responsible.

The results in section 3.2 show that the properties of one monolayer of Ni on W(110) do not change upon annealing to 1100 K. A similar result has been obtained previously using AES [7,9] and work function measurements [7]. These previous studies [7,9] showed that annealing Ni films with coverages larger than 1.3 ML to 1200 K produces 3D islands (cluster crystallites). The data in fig. 5 indicate that 3D island formation occurs even at temperatures as low as 600 K.

5. Conclusions

(1) The XPS data show that the atoms in a monolayer of Pd or Ni supported on W(110) are electronically perturbed with respect to the surface atoms of Pd(100) and Ni(100). The magnitude of the electronic perturbation is larger for Pd than for Ni.

(2) A correlation exists between the shifts in the Ni and Pd XPS binding energies and the variations in the desorption temperature of CO from the adlayers.

(3) The shifts in XPS binding energies and CO desorption temperatures can be explained in terms of:
(a) variations that occur in the Ni–Ni and Pd–Pd interactions when Ni and Pd adopt the lattice parameters of W(110) in a pseudomorphic adlayer;
(b) transfer of electrons toward the W(110) substrate, caused by the Ni–W and Pd–W interactions.

(4) The XPS results for Pd/W(110) indicate that the Pd–W interaction affects several (5 or 6) Pd layers.

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References

[26] For late transition metals, as a general trend (see refs. [12,25,29,30,33]), “open” surface planes exhibit lower XPS binding energies than closer-packed surface planes. In general, lower surface XPS binding energies are observed when the coordination number of the surface atoms decreases (see refs. [12,25–30,33]).
[41] Results of ultraviolet photoelectron spectroscopy for a monolayer of Pd on Nb(110) [48], Ta(110) [49] and W(110) [50] show a large lowering of the Pd(4d) density of states at the Fermi level. In these bimetallic systems the valence d-levels of Pd are at higher binding energy than those of pure Pd substrates.
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