Characteristics of an InP/InGaAs Double Heterojunction Bipolar Transistor (DHBT) with an InAlGaAs/InP Composite Collector Structure

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In recent years, heterojunction bipolar transistors (HBTs) have attracted great attention for high-speed, low-power and microwave circuits applications. Nevertheless, based on the high impact ionization rate in the narrow bandgap InGaAs base layer, these conventional HBTs with the InGaAs collector structure are strongly limited for their power applications due to the low breakdown voltage and the high output conductance. Although the improved breakdown performance can be achieved by using a wide bandgap InP layer as the collector in double HBTs (DHBTs), the conduction band discontinuity at the base-collector (B-C) interface should lead to the undesired current blocking effect. To overcome such disadvantages, several attempts have been made and reported to fabricate high-performance HBTs. These improved structures include the composite collector structure and the compositionally graded layer. Previously, an InGaAs/InAlAs chirped superlattice (CSL) of InP/InGaAs DHBTs with a continuous InAlGaAs grade layer was demonstrated to produce the InP/InGaAs DHBTs. On the other hand, a step-graded InGaAsP collector structure in an InP/InGaAs DHBT was also reported.

In this work, an interesting InP/InGaAs DHBT with an InAlGaAs/InP composite collector structure is fabricated and studied. In this structure, the composite collector consists of an InGaAs setback layer, a step-graded structure, and an InP layer. Moreover, the step-graded structure uses a quaternary InAlGaAs material between base and collector layer. The InAlGaAs material system has a wider tunable bandgap (0.75 to 1.46 eV) than the InGaAsP material system (0.75 to 1.35 eV). Due to the use an InAlGaAs/InP composite collector structure, the undesired current blocking effect can be effectively eliminated. Furthermore, the breakdown characteristics can be improved.

The collector-emitter offset voltage $\Delta V_{CE}$ as a function of the temperature is shown in the Fig. 1(a). The
offset voltage $\Delta V_{CE}$ is defined as the collector-emitter voltage at which the collector current reaches zero. Under the base current of $I_B = 20\mu A$, the offset voltage $\Delta V_{CE}$ is slightly increased from 98.4 to 100.98 mV as the temperature is elevated from 300 to 450 K. The studied device shows relatively lower offset voltage even the temperature is increased up to 450 K. The smaller offset voltage is attractive in practical circuit applications due to the lower power consumption. On the other hand, the output resistance, which can be characterized by the Early voltage $V_A$, is an important issue for transistor action. The $V_A$ as a function of temperature of the studied device is shown in Fig. 1 (b). The base current is kept at $I_B = 100\mu A$. Actually, the operating region of InGaAs-based devices is adversely determined by the onset of impact ionization. In particular, at higher temperature ambient, the increase of output conductance and decrease of breakdown voltage result in the reduction of current operating region. The $V_A$ value of the studied device is remarkably superior at least 4 times in magnitude to those observed from InP/InGaAs HBTs with InGaAs collector or InGaAs/InGaAsP composite collector. This is mainly attributed to the lower multiplication factor M-1 values resulted from the relatively higher effective energy bandgap of the studied device with the InAlGaAs/InP composite collector structure.

Fig. 1    (a) The collector-emitter offset voltage $\Delta V_{CE}$ as a function of temperature. (b) The temperature dependences of Early voltage $V_A$. 

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Figure 2 shows collector leakage current $I_{CBO}$ as a function of temperature under different reverse collector-base voltage $V_{CB}$. Generally, the $I_{CBO}$ is substantially related to the B-C layer structure. From the experiment result, a positive temperature dependence of $I_{CBO}$ is found. Under the lower reverse bias region ($V_{CB} < 6$ V), the $I_{CBO}$ values are smaller than those observed in InP/InGaAs HBTs with an InGaAs collector and an InAlGaAs collector. Under the higher reverse bias region ($V_{CB} > 6$ V), a strong bias-dependent phenomenon is found owing to the avalanche effect. Therefore, the $I_{CBO}$ is significantly increased. As the temperature is increased, the impact ionization phenomenon becomes important and leads to the rapid increase of the $I_{CBO}$. Furthermore, the raised $I_{CBO}$ causes the substantial avalanche multiplication, which certainly results in the decreases of breakdown voltage.

![Collector leakage current as a function of temperature under different collector-base voltage $V_{CB}$.](image)

Figure 3 displays the multiplication factor $M-1$ as a function of collector-base voltage $V_{CB}$ at different temperatures for the studied device. For comparison, other results of the previously reported InP/InGaAs HBT with an InGaAs collector are also demonstrated. As shown in Fig. 3, the $M-1$ values are
increased with increasing both the \( V_{CB} \) and temperature. For \( V_{CB} \) ranged from 2 to 8 V, the M-1 values for our studied device are about one to two orders of magnitude lower than those obtained in the InP/InGaAs HBT with an InGaAs collector. It reveals the substantial suppression of the avalanche effect in the B-C depletion region due to the use of an InAlGaAs/InP composite collector structure. The lower M-1 values of our device are caused by the effective higher energy bandgap of the InAlGaAs/InP composite collector structure with a thicker InP layer. Therefore, the M-1 values in our collector structure are mainly dominated by the InP layer. Based on the relatively thicker InP layer in our collector structure, as compared with the InP/InGaAs HBT with an InGaAs collector, the studied device exhibits improved breakdown performance resulting from the lower M-1 values.

![Graph showing M-1 vs. Collector-Base Voltage \( V_{CB} \) at different temperatures](image)

**Fig. 3** The multiplication factors M-1 versus collector-base voltage \( V_{CB} \) at different temperatures for the studied device and compared InP/InGaAs SHBT.

The DC current gain variation \( \Delta \beta_F \) (%), under \( I_C = 10 \) mA, versus the stress time of the studied device at the ambient temperature of 450 K is revealed in Fig. 4. The applied collector-emitter voltage is kept at \( V_{CE} = 3 \) V. After a 180 hr of stress test, the \( \beta_F \) of our studied device drops 6.89 % from its initial value. Experimentally, it is found that the bias stress could cause an increase of the base current, which certainly results in the decrease of the \( \beta_F \). Clearly, the studied device exhibits lower \( \Delta \beta_F \) during the life
test. The hot carrier-induced damage localized at E–B and B–C junction peripheries could be responsible for the increase of B–C junction leakage and decrease of current gain during bias stress. Therefore, from Fig. 4, the studied device with an InAlGaAs/InP composite collector structure exhibits the improved thermal stability and electrical reliability.

Fig. 4 The DC current gain variation $\Delta \beta_F$ (%) versus the stress time. The stress conditions are kept at $V_{CE} = 3$ V and $I_C = 10$ mA.

In conclusion, the characteristics of an interesting InP/InGaAs DHBT with an InAlGaAs/InP composite collector structure are demonstrated and studied. Experimentally, as compared with previously reported HBTs, the studied device exhibits the relatively larger Early voltage, lower offset voltage, smaller collector leakage current, and lower multiplication factor. Furthermore, the electrical reliability for studied device is also reported. Therefore, the studied DHBT device provides the promise for power and high-temperature circuit applications.

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First ZnO Rectangular Nanorod Arrays grown with Al Doping Concentration Fluctuation
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Composition fluctuation induced growth of Al:ZnO rectangular nanorod arrays, Nanotechnology 19 035605 (2008).

Low dimensional nanomaterials have attracted great interests because of their unique and fascinating optical, electrical, mechanical, and piezoelectric properties together with their wide uses in fundamental scientific researches and potential technical applications. In addition to the conventional nanowires, many interesting morphologies have been synthesized recently, such as nanocombs, \cite{1}, nanorings \cite{2}, nanowalls \cite{3}, nanopencils \cite{4}, and conic nanotubes \cite{5}. Those fantastic structures not only provide valuable models for understanding crystal growth mechanisms at nanometer scale, but also exhibit great potential for fabricating excellent optoelectronic nanodevices, such as comb gratings \cite{6}, field emission \cite{4,5}, and photocatalysts \cite{7}, etc. However, while the possible growth mechanisms of many fantastic nanostructures have been proposed, the influence of impurities and defects on formation of the nanostructures has rarely been studied.

In the article, we provide another interesting route of fabricating Al: ZnO rectangular nanorods by doping induced composition fluctuations. The rectangular nanorods are nucleated from a sheet-like nanostructure with periodic thickness fluctuations resulting from doping concentration modulation. Transmission electron microscopy (TEM) characterization shows the difference in Al concentration and lattice constant between the rectangular nanorods and neighboring nanosheets.
The Al doped ZnO rectangular nanorods were synthesized via alloy evaporation deposition (AED) method on Si(100) substrate [8]. Zn and Al mixed powder (weigh ratio=93:7) was placed in an aluminum boat located inside a 1 in. diameter horizontal quartz tube reactor. The sources were heated at a rate of 20 °C/min from room temperature to an alloying treatment temperature. Argon was introduced as the carrier gas at the beginning with a flow rate of 8 sccm and the working pressure was kept at 50 Torr. The alloying treatment for the Al:ZnO nanostructures was carried out at 500 °C for 30 min. After the alloying treatment, the pressure was decreased to 1 Torr and the system was heated again at a rate of 20 °C/min to 650 °C. Once the temperature was raised to 650 °C, oxygen was introduced into the chamber with a flow rate of 1 sccm. After heating at 650 °C for one hour, the substrate was slowly cooled down to room temperature in the furnace.

A typical scanning electron microscopy (SEM) image of Al: ZnO rectangular nanorod array is shown in Figure 1(a). This structure exhibits rare four-fold or two-fold symmetry instead of the common six-fold symmetry of ZnO. An entire view of the rectangular nanorod arrays is shown in the inset of Figure 1(a).

Figure 2(a) shows a low-magnification TEM image of the Al: ZnO rectangular nanorod arrays. The uniform contrast indicates uniform thickness over individual nanorods. A corresponding diffraction pattern in Figure 2(b) reveals that the rectangular nanorods are single-crystalline wurtzite structure growing along the c-axis, while the top and side facets were (2 1 1 0) and (1 0 1 0) planes, respectively. A HRTEM image of the interface region of a rectangular nanorod and contiguous nanosheet is shown in Figure 2(c). The lattice constants of the rectangular nanorod and nanosheet are 5.10 Å and 5.12 Å, respectively, from fast Fourier transform patterns of the corresponding areas in Fig. 2(c). Besides, there are obvious lattice distortions and dislocations near the interface region as shown in the dashed circles. The atomic ratios of Al to (Al+Zn) in the rectangular nanorod and nanosheet calculated from the EELS spectrum are around 6.13 at.% and 4.07 at.%, respectively. Apparently, the lattice distortions, dislocations, and differences in lattice constant are caused by the difference in Al concentration of rectangular rods and intermediate nanosheets.
The rectangular nanorods were not grown via a conventional catalyst-assisted vapor-liquid-solid mechanism as reported previously because no catalysts were employed and found [9]. Instead, they were nucleated from single-crystalline ZnO nanobelts with periodic thickness fluctuation resulting from Al concentration modulation. In order to verify the thickness modulation, a bright-field image and the corresponding thickness map of a ZnO rectangular nanorod array derived by EELS are shown in figure 3 (a) and 3(b), respectively. Fig. 3(b) demonstrates that different contrast level is associated with different region for different thickness. Figure 3(c) shows an embryo of the rectangular nanorod array, which exhibits a nanosheet with partly developed periodic surface undulation along the length direction. Therefore, the growth mechanism of the rectangular nanorod arrays were proposed as follows. The first stage involved the growth of nanobelts along the [010] direction [10]. In the second stage, Al dopants may tend to redistribute due to the high diffusion rate at high temperature to reduce the overall lattice strain induced by Al doping, resulting in doping concentration modulation along the length direction of the sheet-like structure. The strain induced composition modulation may explain the growth mechanism here since the doped belts should endure some degree of strain due to doping. Furthermore, the regions with higher Al concentration are energetically favorable for higher deposition rate of ZnO and larger local thickness. Thus, an Al:ZnO nanosheet with periodic thickness variations was consequently formed. Finally, the thicker parts of the nanostructure grew continuously along the c-axis out of the sheet since the (0001) platform on the sides of nanosheets with periodic thickness could act as an ideal site for deposition to promote the growth of thicker rod-like part, and the array of the rectangular nanorods was developed. The schematic diagrams and the corresponding SEM images showing the different growth stages of the Al:ZnO rectangular nanorod arrays are shown in Figures 3(d) and 3(e), respectively.
In summary, arrays of single-crystalline Al: ZnO rectangular nanorods were synthesized by the AED method. The nanostructures started with the growth of single-crystalline ZnO nanobelts with periodic thickness and Al concentration modulation. The composition modulation induced by doping may serve as a driving force for creating more interesting nanostructures with tunable properties.
Observation of the $7^1\Pi_g$ State of Na$_2$ by Optical-Optical Double Resonance Spectroscopy

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Understanding the fundamental building blocks of the nature is one of the scientist dreams. The chemical and physical properties of material are the interactions between atoms contained in this material. Under microscopic visualization, the fundamental behaviors of atoms and molecules can be fully understood only through the eigenfunctions and eigenvalues constructed from the quantum mechanics. Using high precision single mode tunable lasers, we can measure the separations of eigenvalues between different eigenfunctions. Information extracted from the observed data, eigenvalues and eigenfunctions for an electronic state under certain symmetry can be reconstructed, and hence the potential curve. This relies on the quantum mechanics calculations. The potential curve is the potential energy ($U$) of the electrons as a function of internuclear separation. Therefore, the force between atoms is just the derivative of this potential with respect to the internuclear distance ($\vec{F} = -\nabla U$). This potential curve contains the parameters for calculating the collisions between atoms and provides the information of the system dynamics. Figure 1 shows a single mode auto-scan tunable Ti:sapphire laser pumped by a 10 Watts solid-state laser in our laboratory$^1$. 
Fig. 1. The single mode auto-scan Ti:sapphire laser in our laboratory.

Fig. 2. Experimental block diagram of the OODR spectroscopy.
In this study, cw lasers with high precision and resolution are used to probe the rovibrational levels in different electronic states of Na$_2$. Analyzing the observed spectra, vibrational quantum number $\nu$ and rotational quantum number $J$ can be identified for a certain electronic state. Using RKR method (developed by Rydberg, Klein and Rees)$^2$, we can construct the potential curve for this electronic state. The linewidth of the lasers have to be less than 1MHz ($\Delta\nu/\nu \sim 10^{-9}$) to resolve the rovibrational levels for sodium dimmer. Figure 2 shows the experimental block diagram of the optical-optical double resonance (OODR) spectroscopy. A single line Ar$^+$ laser (Coherent, I-90, 9 Lines) is used to pump the thermal populated ground state sodium dimers to the intermediate B$^1\Pi_u$ state. Another cw Autoscan Ti/dye ring laser (Coherent 899-29) pumped by a solid state laser serves as a probe laser and counter-propagates into the center of heat pipe to overlap with the Ar$^+$ laser. This probe laser excites the molecules from the intermediate B$^1\Pi_u$ state to a higher Rydberg states, for example 7$^1\Pi_g$ state in this study. Investigating all the observed spectra, we can sort out intensity patterns and vibrational progressions of the electronic transitions. The interaction force between atoms at their equilibrium can be approximated by a spring. The quantized vibrational energy is $E_{\text{vib}} = (\nu + 1)\hbar \omega$, where $\nu$ is the vibrational quantum number, $\hbar$ is Planck constant divided by $2\pi$ and $\omega^2$ is the spring constant divided by reduced mass of the molecule. Therefore, the energy difference for adjacent vibrational quantum number is approximately equal (about 100cm$^{-1}$, 1cm$^{-1}$=1.988x10$^{-23}$ Joule for Na$_2$). If we consider the rotation, the sodium dimer is similar to a dumbbell. Therefore, the quantized rotational energy is $E_{\text{rot}} = B_J (J(J+1))$, where $J$ is the rotational
quantum number and $B_v$ is the rotational constant. Whenever the Rydberg state is excited (for example $7^3\Pi_g$), violet fluorescence from triplet excited states (populated via collisions) to triplet ground state can be detected by a filtered-PMT (the filter is to block the scattered light form visible lasers) and recorded on a computer. Fig. 3 shows the RKR potentials (dotted points) constructed from experimental observations and the \textit{ab initio} calculations (solid lines). The accuracy of our data is less than 0.02 cm$^{-1}$ which provides a stingy test for the theoretical calculations. All the assigned vibrational quantum numbers are confirmed by comparing the calculated Franck-Condon Factor with the excitation intensity on the spectra.

This high precision laser spectroscopy has several significant contributions for understanding the properties of molecules. First of all, we are the first group to observe the doubly-excited $2^1\Delta_g$ state of Na$_2$. There are only two doubly-excited states of Na$_2$ have been observed and it is a treasure to the theoretical modeling. Secondly is the observation of “$L$-uncoupling” in the highly Rydberg states. According to the interaction energy, Hund’s coupling cases play a key role to understand the transition patterns. These coupling cases depend on the internuclear separations, principal quantum number $n$ and the symmetry of the outer electrons. We are able to study the transformation of coupling cases as a function of $n$. The third is an interesting phenomenon of “twin states”. If two electronic states with same symmetry are parallel and adjacent to each other, the wavefunctions will be mixed due to the quantum tunneling effect. This effect causes the irregularities of transition intensities and patterns. Therefore, the spectra are difficult to observe and analyze. To unravel this puzzle, we proposed the ideas of “entangled wavefunctions” and “twin states” to successfully solve this problem.

In our laboratory, we use high precision and high resolution laser spectroscopy to probe the physical properties of atoms and molecules. This simple and fine observation of the basic structure of atoms, the building blocks of nature, brings the microscopic quantum mechanics results to the real life, not only the calculated eigenfunctions.

\footnote{This figure is adapted from \url{http://www.ncku.edu.tw/hischool/summary/intro/leap.pdf}.}


Amelioration of collagen-induced arthritis in rats by nanogold

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Angiogenesis plays a part in the pathogenesis of rheumatoid arthritis (RA). As nanogold inhibits vascular endothelial growth factor (VEGF) activities, we investigated whether intraarticular delivery of nanogold ameliorated collagen-induced arthritis (CIA). To evaluate the prophylactic effect of nanogold on CIA, groups of 6 rats were immunized with collagen on days 0 and 7, followed by an intraarticular injection of nanogold, PEG-nanogold or phosphate buffer (PB) into the ankle joints on day 7. The articular index (Figure 1A) and ankle circumference (Figure 1B) in nanogold-treated group were significantly smaller than those in PB-treated or PEG-nanogold-treated group. These results indicate that nanogold administration resulted in a significant reduction of joint inflammation. We next assessed the effect of nanogold administration on radiographical and histological changes in CIA rats after sacrifice of the animals on day 17. Joint space narrowing and bone erosion were noted in PB-treated (Figure 1C) and PEG-nanogold-treated (Figure 1D) ankles, but were prevented in the nanogold-treated counterpart (Figure 1E), as examined by plain radiograph. The radiological score based on joint space, degree of bony destruction, and soft tissue swelling was also significantly lower in nanogold-treated group than in the two control groups (Figure 1F). Histopathologic analysis of PB-treated (Figure 2A) and PEG-nanogold-treated (Figure 2B) joint tissues revealed synovial hyperplasia, inflammatory cell infiltration, cartilage erosion, and bone destruction. However, in nanogold-treated rats, relatively intact cartilage on the joint surface was found and no damage to the synovial membrane was observed in the joint tissues (Figures 2C).

Furthermore, the histological score based on synovial hyperplasia, cartilage erosion, and leukocyte infiltration was significantly lower in nanogold-treated group than in PB-treated or PEG-nanogold-treated group (Figure 2D). Taken together, nanogold reduced the severity of CIA, as revealed by examination of the clinical, radiographic, and histological features. Gold salts, such as sodium gold thiomalate, have long been used in the treatment of patients with RA and are still considered as important disease-modifying anti-rheumatic drugs. However, their adverse side effects in 30 to 45% of treated patients resulted in discontinuation of the treatment. Gold salts have been shown to inhibit VEGF production by cultured synovial cells stimulated with lipopolysaccharide. The precise modes of action of gold compounds in RA have not been clarified, but an interaction with thiol groups on proteins and cell membranes is thought to be important. Long-term accumulation of gold salts in the body may result in adverse or toxic effects. Studies of gold nanoparticles in the interaction with phagocytes in vitro
have demonstrated their biocompatible properties, such as non-toxic, non-immunogenic, and high tissue permeable features without hampering cell functionality. Therefore, as an anti-arthritic agent, nanogold, especially when given intraarticularly, is expected to be much less toxic than conventional gold salts given systemically.

Figure 1. Prophylactic effects of nanogold on rat CIA. Nanogold-treated rats showed a reduction in arthritis on both hind limbs with regard to the articular index (A) and ankle circumference (B) compared with PB-treated rats. The arrow denotes time of the treatment. Joint space narrowing, soft tissue swelling, and bony erosion were noted in PB-treated (C) and PEG-nanogold-treated (D) ankle joints, but were prevented in the nanogold-treated ankle joint (E). (F) Nanogold-treated rats exhibited lower radiological scores compared with PB-treated or PEG-nanogold-treated rats.
Nanogold reduced angiogenesis, macrophage infiltration, and proinflammatory cytokines in the synovium of CIA in rats. There were fewer microvessels in the synovium of nanogold-treated group (Figures 3C) than in the PB-treated (Figure 3A) or PEG-nanogold-treated counterpart (Figure 3B), as assessed with the anti-von Willebrand factor antibody. Nanogold-treated rats showed a 40% reduction in microvessel density compared with the control rats (Figure 3D). As macrophage infiltration is associated with angiogenesis, we investigated whether nanogold suppressed macrophage infiltration into the synovium of CIA rats.

Figure 2. Histopathological analysis in nanogold-treated CIA rats. PB-treated (A) and PEG-nanogold-treated (B) joint tissues showed synovial hyperplasia and infiltration of inflammatory cells (original magnification ×40). (C) Nanogold-treated joint tissue showed relatively intact cartilage on the joint surface and relatively minor damage to the synovial membrane (original magnification ×40). (D) Nanogold-treated (n=6) rats exhibited lower histological joint scores compared with PB-treated (n=5) or PEG-nanogold-treated (n=6) rats. Each value represents the mean ± SEM. **, P < 0.01.
Figure 3. Decreased angiogenesis in nanogold-treated CIA rats. Rats were immunized with collagen on days 0 and 7 followed by intraarticular injection of nanogold, PEG-nanogold (6.7 μg in 20 μl PB) or PB into the ankle joints on day 7. Paw joints were harvested on day 16 and the joint tissues processed for immunohistochemical stain with anti-von Willebrand factor antibody for microvessels and counter stain with hematoxylin. Representative joint sections from rats treated with PB (A), PEG-nanogold (B), and nanogold (C) are shown (original magnification ×40). The number of von Willebrand factor-positive microvessels was counted in three randomly selected high-power fields (×400) in each section (D). Each value represents mean ± SEM (PB, n=5; nanogold and PEG-nanogold, n=6). *, P < 0.05.

Immunohistochemical staining revealed a significant decrease in macrophage infiltration in nanogold-treated group (Figure 4C) compared with PB-treated (Figure 4A) or PEG-nanogold-treated (Figure 4B) group. These results indicate that decrease in infiltrating macrophages in the synovium was highly correlated with reduced joint erosion, bone destruction, and angiogenesis in nanogold-treated rats, which further supported a beneficial effect of nanogold on the treatment of arthritis. Because TNF-α and IL-1β are two important proinflammatory cytokines involved in the pathogenesis of RA, we compared their levels in the ankle joints between the three treatment groups. The levels of TNF-α and IL-1β were reduced by approximately 50% and 30%, respectively, in the synovial tissue from nanogold-treated ankle compared with the two control counterparts (Figure 4D).
In conclusion, nanogold was administered intraarticularly into CIA rats before the onset of arthritis. Nanogold bound to VEGF in RA synovial fluid (SF), thereby resulting in inhibiting RA SF-induced endothelial cell proliferation and migration. Significant reductions in ankle circumference, articular index, and radiographic score were observed in the nanogold-treated group compared with its control counterpart. The histological score based on synovial hyperplasia, cartilage erosion, and leukocyte infiltration, as well as microvessel density and macrophage infiltration in the ankle joints were also significantly reduced in nanogold-treated rats. Furthermore, levels of tumor necrosis factor α and interleukin-1β were decreased in the ankle joints from nanogold-treated CIA rats. Our results demonstrate for the first time that intraarticular administration of nanogold ameliorated the clinical course of CIA in rats. Nanogold exerted antiangiogenic activities and subsequently reduced macrophage infiltration and inflammation, which resulted in anti-arthritic effect. Therefore, this work provides a novel approach on the potential biomedical applications of nano-scale gold particles for the treatment of experimental arthritis. Our data suggest that nanogold may have therapeutic potential for ameliorating...
RA and may be applicable to the modulation of various chronic VEGF-dependent inflammatory diseases.

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