The partial substitution of copper with nickel oxide on the Structural and electrical properties of $HgBa_2 Ca_2 Cu_{3x}Ni_x O_{8+\delta}$ superconducting compound

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Abstract: The present study the partial substitution of copper with nickel on of $HgBa_2Ca_2Cu_{3x}Ni_xO_{8+\delta}$ superconducting compound where x=002040608 Samples were prepared by solid state reaction method with sintering temperature 850C0 for 24h. By using Xray powder diffraction structural of the samples were studied. The XRD analysis's showed the structures a polycrystalline with tetragonal diagram with majority 1223 phase and the change of the nickel concentrations produce a change in lattice parameters of the lattice a b and c axis c/a density of mass ρm and volume fraction Vphase**.** Four probe apparatus was using to test the electrical resistivity to defined the critical temperature at zero resistivity Tc offset Optimum Tc offset was found from $HgBa_2Ca_2Cu_{24}Ni_{06}O_{8+\delta}$ sample with transition temperature its equal to 137K

Keywords $HgBa_2Ca_2Cu_3O_{8+\delta}$, superconductivity, critical temperature, XRD

1. Introduction

The superconductivity of the material when cooled at very low temperatures is characterized by loss of electrical resistance to zero and expel the magnetic field outside the material [1] The Phenomenon of superconductivity was first noted in mercury in 1911 when electrical resistance of pure mercury went to zero about 4K Understanding of this behavior was not clearly known until 1957 when three physicists suggested BCS theory which governs the emergence of superconductivity[2]
$HgBa_2Ca_nCu_nO_{2n+2+\delta}$ system has a high critical temperature at n=3 The first member of the family n=1 has a critical temperature of 94K The second one n=2 has Tc =127K The third member of this family n=3 has a sharp superconducting transition at 133 K [34] It is well known that the $HgBa_2Ca_2Cu_xO_{8+\delta}$ synthesis of single phase has been found very complicated due to high volatility of Hg at elevated the temperatures when these phase formation occurs

The properties and stability of the $HgBa_2Ca_nCu_nO_{2n+2+\delta}$ family of phases can be substantially improved by partial substitution of same element in the rock salt layer 3–5 they bring in more oxygen in the oxygen deficient HgO δ layer leading to phase stability The higher oxidation state cations also

lead to hole optimization in the hole deficient as grown Hg1223 phase thus producing optimum critical transition temperature Tc [5] In this paper was focused on the study the effect the partial substitution of copper with nickel oxide on the structural and optical properties of the superconducting

2. Experimental

The $HgBa_2Ca_2Cu_{3x}Ni_xO_{8+\delta}$ with x=0020406 and 08 high critical temperature superconducting HTS was synthesized by solid state reaction process Using the required amounts of pure powders materials high purity oxides 9999% of HgONiO BaOCaO and CuO and in Commensurate with the molecular weights accordingly for these chemical formulas

$$\mathbf{HgO + 2\ BaO + 2CaO + 3xCuO + x\ NiO \rightarrow Hg}\boldsymbol{Ba_2Ca_2Cu_{3-x}Ni_xO_{8+\delta}}$$

The reactants were measured by using a sensitive balance whose sensitivity order 10^4 g The reactants were mixed jointly by a gate mortar a sufficient quantity of methanol was to homogenize the mixture dry slurry during grinding process for nearly from 40 to 60 minute Mixture was putted in alumina crucible and dehydrated for in the oven at 120°C The mixture was compressed into the discshape as pellets with diameter 15 cm and 03 cm thick by hydraulic compress under a 7 ton/cm^2 pressure Disks putted in a furnace and sintered at 850°C for 24 hours with the rate of 5 °C/min and then cooled to the room temperature by same rate Structure of crystal such as phase of crystalline the polycrystalline amorphous grain size and parameter of lattice of all samples prepared were examined by XRD technique system SHIMADZU Japan XRD 600 by records the intensity in the range of Bragg's angle θ from 2080 Cu Kα radiation source of wavelength λ=15405 Å was employed with generator setting of current 20 mA and voltage 40 kV The surface morphology of these specimens observed from the AFM technique through using SPM model AA3000 contact mode spectrometer supplied by Angstrom Advanced Inc[6]

3. Results and Discussions

3.1. Structural Properties

The Xray diffraction pattern of $\mathbf{Hg}\boldsymbol{Ba_2Ca_2Cu_{3-x}Ni_xO_{8+\delta}}$ samples with x=0020406and 08 are shown in Fig1 We can show from this figure that all the samples have polycrystalline nature with tetragonal phase formation The peaks are observed due to diffraction from different planes shows mixed phases

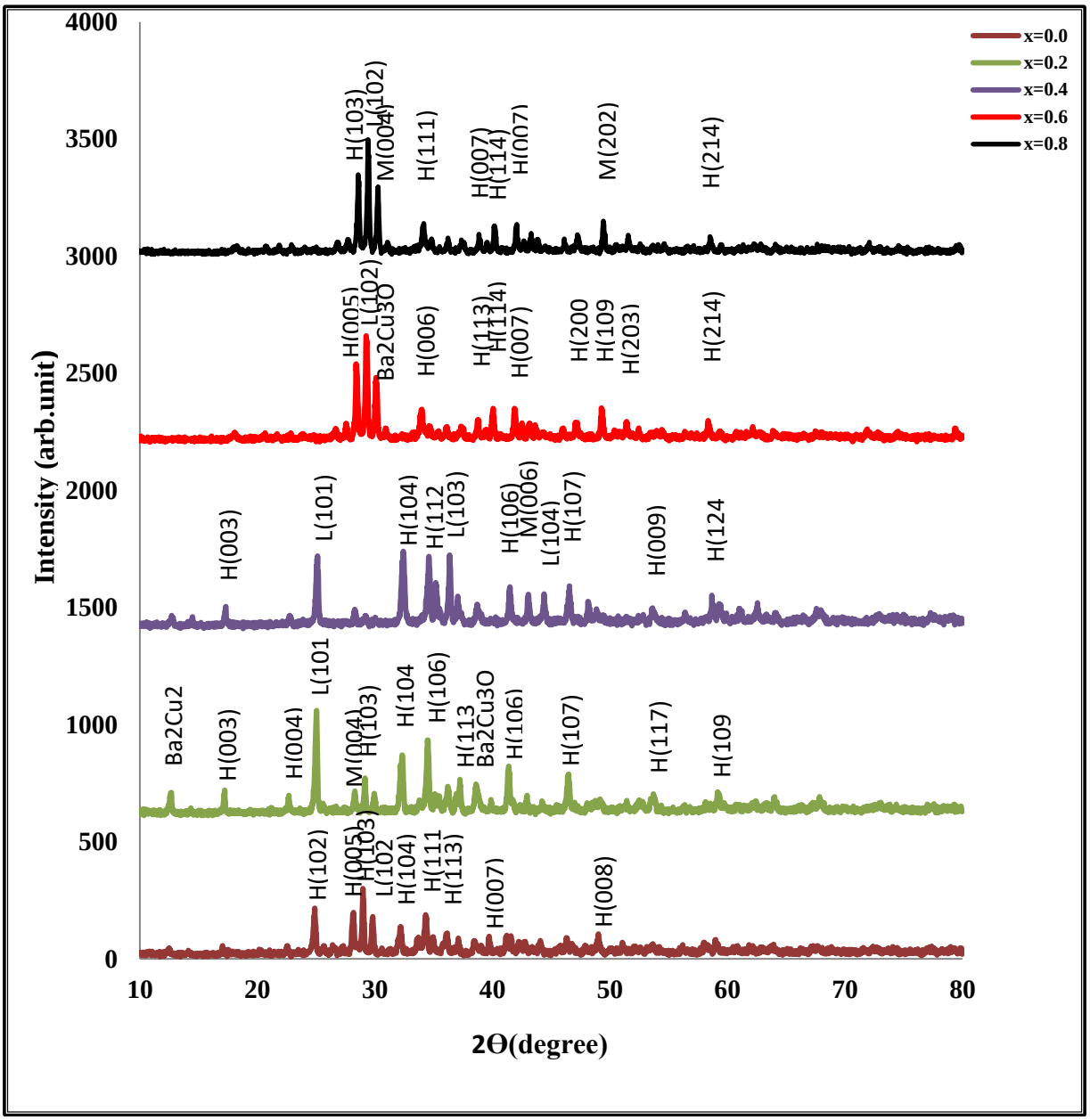


Figure 1. X-ray diffraction pattern of Hg$Ba_2Ca_2Cu_{3-x}Ni_xO_{8+\delta}$ x=0, 0.2, 0.4, 0.6 and 0.8

For the stoichiometric nominal composition of the Hg$Ba_2Ca_2Cu_{3-x}Ni_xO_{8+\delta}$ samples it was found that content a high phase Hg1223 and low phase Hg1212 and some impurity phases of Ba_2Cu_3O $Ba_2Cu_2O$and $Ba_2Cu_3O_5$ with vanishingly small concentrations of unknown phases In order to calculate the volume fraction of the phase the following formula will be used [78]

$$Vph = \frac{\sum I^o}{\sum I^o + \sum I1 + \sum I2} * 100\% \qquad (1)$$

It was found that the increase Ni concentration from 006 produce increasing from 757370% t0 829590 and decrease to 788173 when Ni=08
the mass densities d_m were calculated by using following equation

$$\rho x\text{-}ray\ d_m = Mwt/N_A V \qquad (2)$$

Where
ρ xray d_m is density calculated from XRD in units mg/cm ^{3}
N_A is Avogadro number 6022*10^{23} mol^1
Mwt is molecular weight V is volume of unit cell which equal a^2*c for tetragnal system molecular weight It was found that the increase Ni concentration from
The resistivity measurement is given as a function of temperature by using the four point probe technique at temperature range 300K The value of ρ is found by using the relation[910]

$$\rho = \frac{V}{I}\frac{wt}{L} \qquad (3)$$

Where V is the voltage I is the current w is the width *t* is the thickness and L is the length

$$G_s = \frac{0.9\,\lambda}{\beta\cos(\theta)} \qquad (4)$$

Where the wavelength λ of Xray θ is angle of the diffraction and β is FWHM[11]
These data of transition temperatures a b c/a and volume fraction of high phase V1223ph phase V1212ph phase V1201ph as shown in Table 1 it observed increases high phase by increasing the concentration of Ni oxide
It was found that substituting with NiO show that a tetragonal structure with lattice parameter value c creased006 with increasing of the critical temperature T_C this corresponds to the results [12]

Table1 the value of parameters a,b,c with different substitution and the critical transition temperature Tc

X	a=b (A˚)	c(A˚)	c/a ratio	v(A˚)³	dm(gm/cm³)	V ph(1223)%	V p*h*(1212)%	V ph(1201)%	Vp impurities%	T_c(K)
0	3.8038	15.7117	4.0982	230.9309	6.2848	74.7270	16.100	1.2180	7.9540	119
0.2	3.8813	15.8075	4.2478	218.9034	6.6227	75.7370	4.5570	13.9410	5.7640	123
0.4	3.9732	15.8753	3.9955	250.6125	5.7783	78.4210	7.6310	8.4210	5.5260	130
0.6	4.0798	16.2484	3.9826	270.4508	5.3485	82.9590	8.2470	7.7010	1.0910	137
0.8	3.9064	16.0123	4.0989	244.3471	5.9133	78.8173	6.5868	14.5958	3.5179	129

Fig2 shows the electrical resistivity versus temperature for $HgBa_2Ca_2Cu_{3-x}Ni_xO_{8+\delta}$ compound where the critical temperature is determined from this figure[13] we observed that substitution of NiO leads to increase T_C to T_C=137K because of increasing of c axis leads to increase in the CuO layer These results were almost identical to those reported in reference [14] The optimum $T_{c0ffset}$ was found from $HgBa_2Ca_2Cu_{24}Ni_{06}O_{8+\delta}$ sample with transition temperature 137K x=0.6

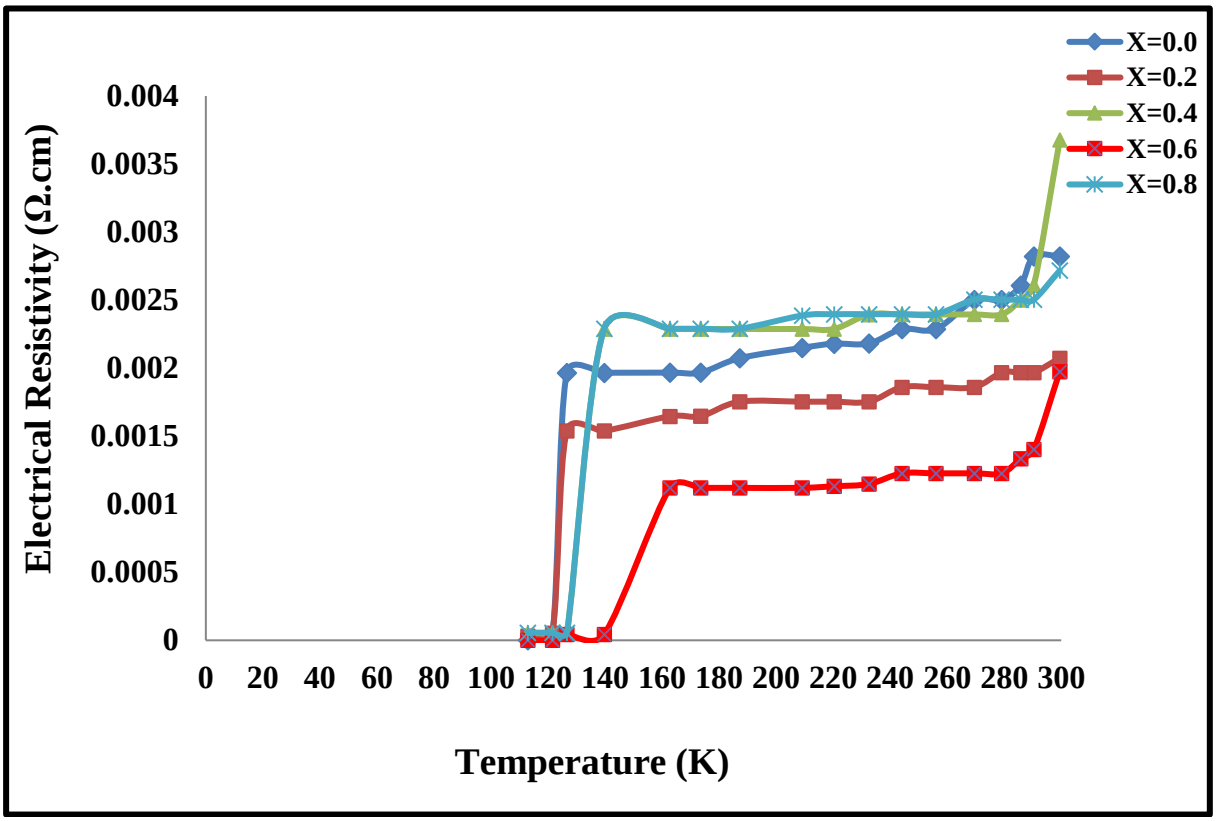


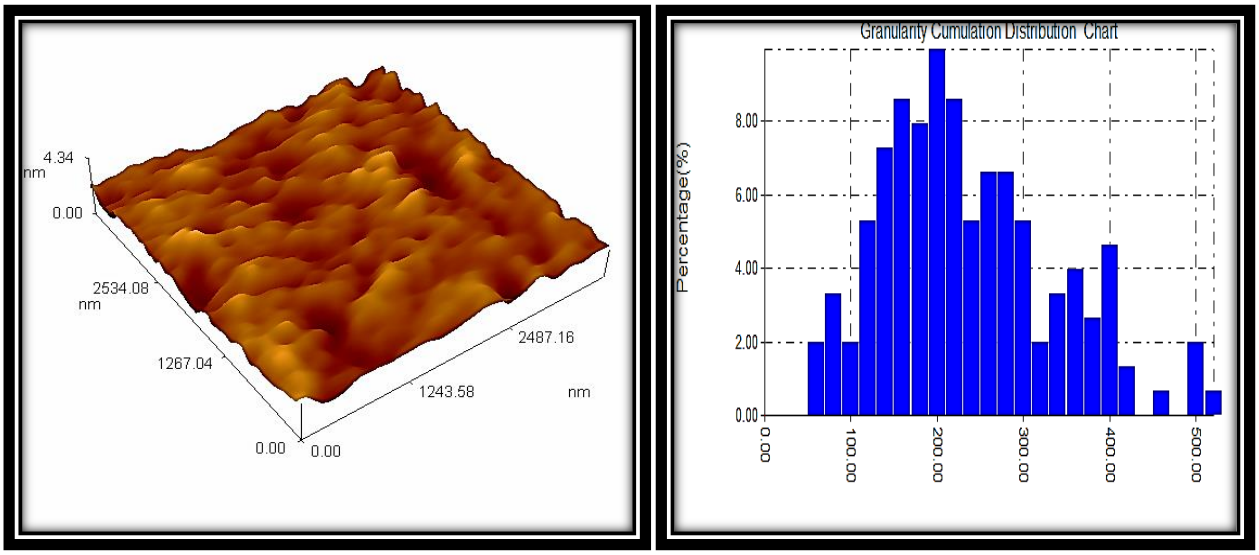
Figure 2. Shows the electrical resistivity versus temperature

The surface morphology of Hg$Ba_2Ca_2Cu_{3-x}Ni_xO_{8+\delta}$ where x=0, 0.2, 0.4, 0.6 and 0.8 was observed using AFM Figure 3 shows the AFM images of these plats with sintering 858^{0}C for 24 h substrate the values of average size range were found to be dependent on the Ni content shown in Table 2 and Grain size nm

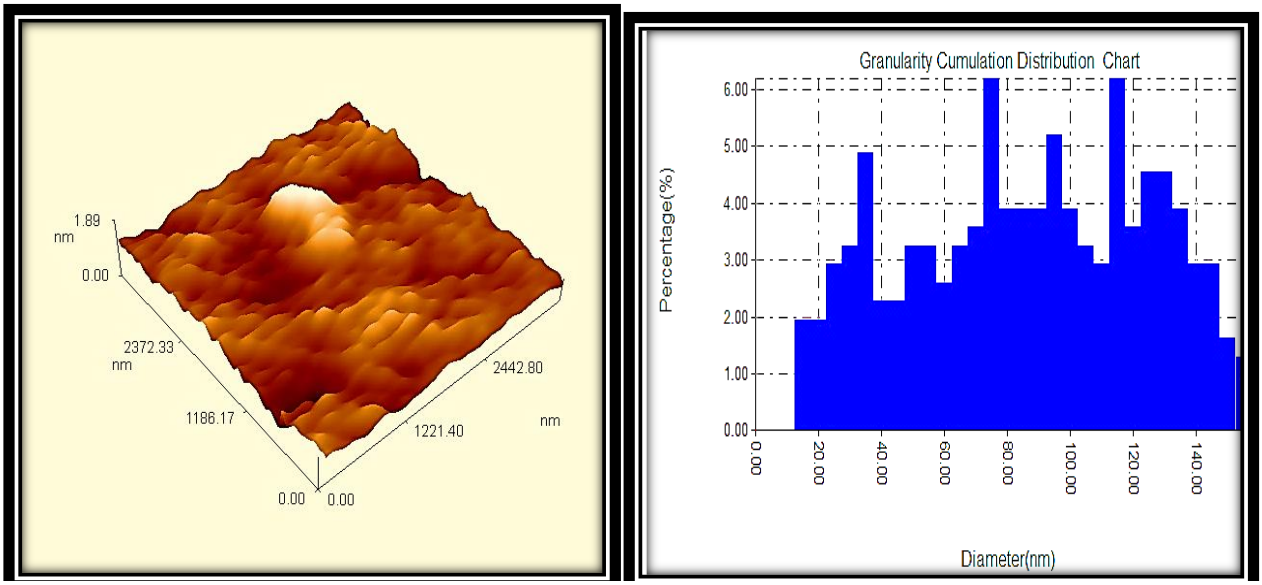
We denote decreasing in value Grain size and Avg Diameter by increasing the concentration of Ni oxide from 004 and then increasing

Table 2 The value of Grain size Roughness Root mean square

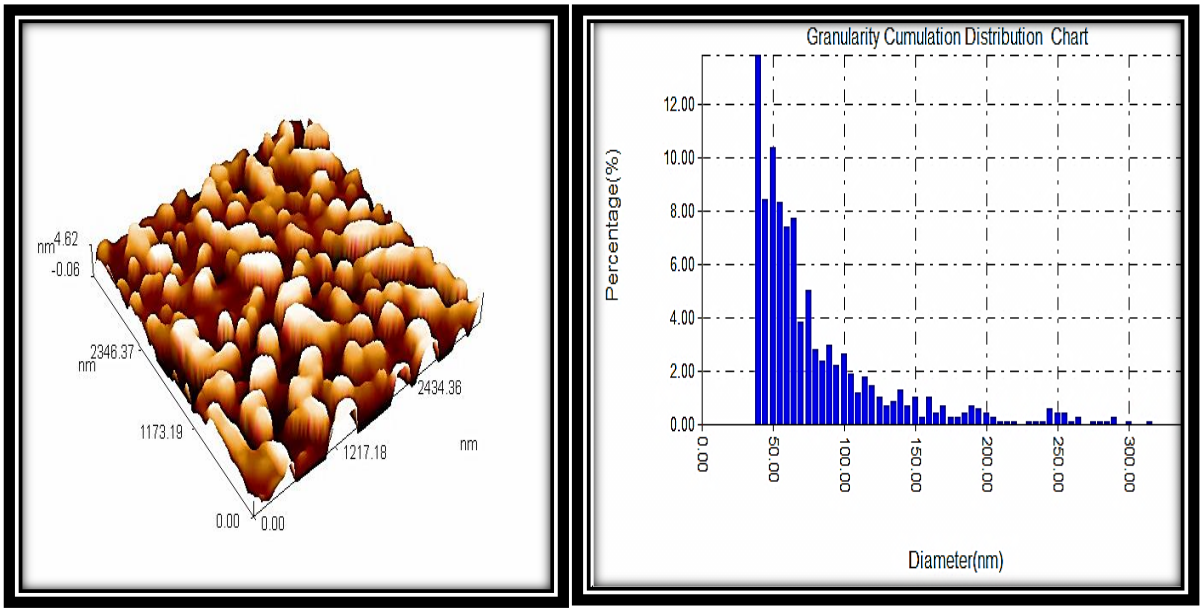
x	Grain size(nm)	Roughness (nm)	Root mean square(nm)	Avg. Diameter (nm)	D_m (gm/cm³)	$T_{c(oFF)}$ K	$T_{c(oN)}$K
0	545.2484	0.278	0.365	225.99	6.2848	116	121
0.2	380.2717	0.159	0.219	84.26	6.6227	121	124
0.4	254.2405	1.18	1.36	79.99	5.7783	128.9	131.9
0.6	401.7333	1.76	2.03	105.44	5.3485	131	143
0.8	448.865	0.372	0.54	124.10	5.9133	129	130


4.34
nm
0.00
2534.08
nm
1267.04
0.00
0.00
1243.58
2487.16
nm
Granularity Cumulation Distribution Chart
Percentage(%)
8.00
6.00
4.00
2.00
0.00
0.00
100.00
200.00
300.00
400.00
500.00

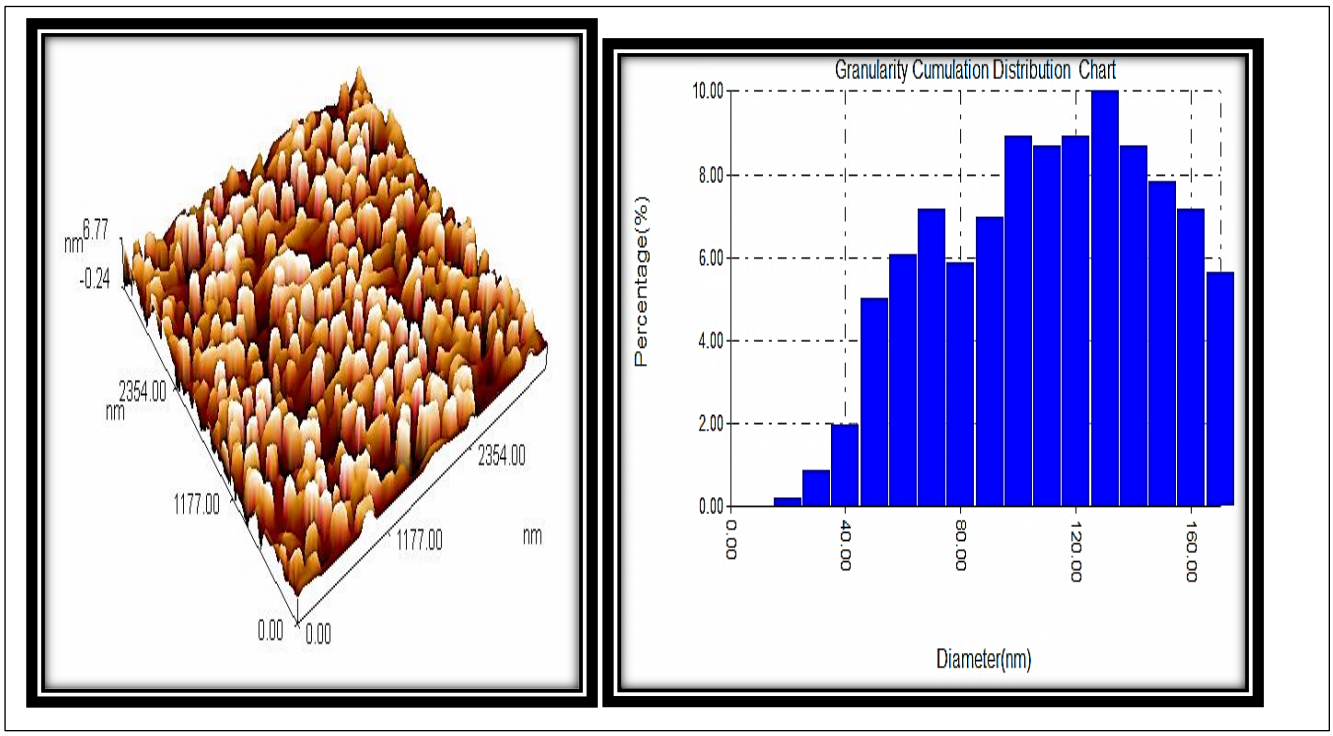
1


1.89
nm
0.00
2372.33
nm
1186.17
0.00
0.00
1221.40
2442.80
nm
Granularity Cumulation Distribution Chart
Percentage(%)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
Diameter(nm)

2


4.82
nm
-0.06
2346.37
nm
1173.19
1217.18
2434.36
nm
0.00
0.00
Granularity Cumulation Distribution Chart
Percentage(%)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
Diameter(nm)

3


6.77
nm
-0.24
2354.00
nm
1177.00
2354.00
1177.00
nm
0.00
0.00
Granularity Cumulation Distribution Chart
Percentage(%)
10.00
8.00
6.00
4.00
2.00
0.00
0.00
40.00
80.00
120.00
160.00
Diameter(nm)

4

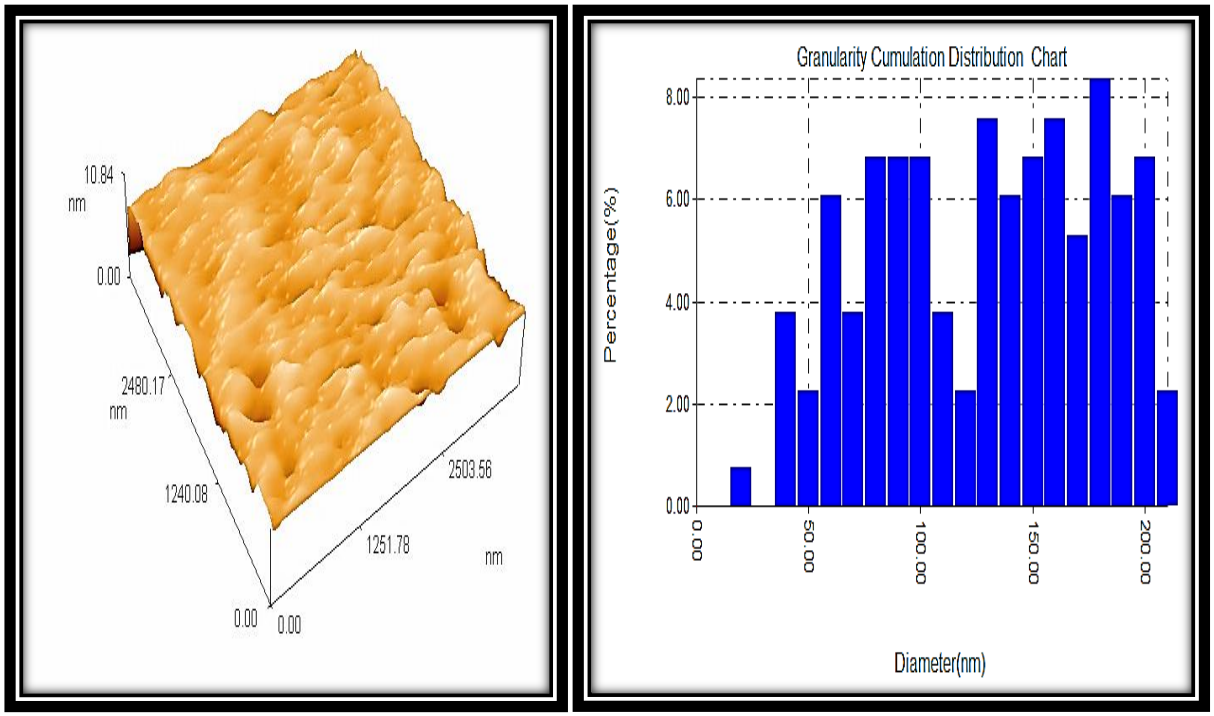


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Figure 3. Reveals the 3D AFM images and the chart distribution of Hg$Ba_2Ca_2Cu_{3-x}Ni_xO_{8+\delta}$

4. Conclusions

In the present work we have successfully synthesized Hg$Ba_2Ca_2Cu_{3-x}Ni_xO_{8+\delta}$ high Tc superconducting compounds x= 0, 0.2, 0.4, 0.6and 0.8 specimen have been synthesized through the three step SSR doing

The XRD data collected from various samples show that all the samples are polycrystalline and correspond to Hg1223 phase The critical transition temperature Tc of the partial substitution of copper by nickel oxide on the of Hg$Ba_2Ca_2Cu_{3-x}Ni_xO_{8+\delta}$ with x = 0, 0.2, 0.4, 0.6and 0.8 range between119-137K The partial substitution of copper by nickel oxide on the of Hg$Ba_2Ca_2Cu_{3-x}Ni_xO_{8+\delta}$ with x = 0, 0.2, 0.4, 0.6and 0.8 has found a the best Tc value obtained for the compound is x = 0.6

Xray analyses have shown a tetragonal phase and there is an increasing in c axis lattice constant with the increasing of concentration of NiO then a decreasing

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