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13. ABSTRACT (Maximum 200 words)

The purpose of this program was to study the growth process in melt-texturing of YBCO and reduce the overall processing time. Melt-texturing had been used to achieve high current densities in bulk YBCO as well as attain high levitation forces adn trapped fields. The melt-texturing process was however too slow to be economical for large-scale manufacturing. The objective of the program was modified in September 1996 towards development of YBCO superconducting thin films using Metal Organic Chemical Vapor Deposition (MOCVD) on biaxially-textured metal substrates. Both the buffer layer and YBCO deposition processes were developed for metal substrates.

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April 24, 1998

by

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Objectives :

The original objective of the program was to study microstructure development and growth mechanisms in melt-texturing of Y-Ba-Cu-O (YBCO) superconductor. Melt-texturing had been used to achieve high current densities in bulk YBCO as well as attain high levitation forces and trapped fields. The melt-texturing process was however too slow to be economical for large-scale manufacturing. Cooling rates of about 1°C/hour are required to obtain high performance in melt-textured YBCO and the duration of a typical melt-texturing process is typically about 3 to 4 days. The purpose of this program was to study the growth process in melt-texturing of YBCO and reduce the overall processing time. The effort at Intermagnetics during the period of March 1995 to September 1996 was consistent with this objective. Following discussions at AFOSR review meeting, March 1996 and later discussions at Wright Patterson Air Force Base with Dr. Oberly, and approval from AFOSR, the objective of the program was modified in September 1996 towards development of YBCO superconducting thin films using Metal Organic Chemical Vapor Deposition (MOCVD) on biaxially-textured metal substrates. Biaxially-textured metal substrates offer a route to fabricate high current YBCO conductors. Thin film approaches were needed to be developed in order to achieve superior performance in YBCO films on metal substrates. In this program, both the buffer layer and YBCO deposition processes were developed for metal substrates. The effort from October 1996 to March 1998 was directed towards the modified objective.

Status of Effort :

Melt-textured YBCO :

The growth kinetics of a typical slow cooling seeded-melt-texturing process was examined and the temperature regime of high growth rate was identified. This information was used to develop a modified melt-texturing process where the process time was reduced by a factor of 4. The growth kinetics of YBCO in the modified process was investigated and compared with that in a typical slow cooling melt-texturing process. Further, levitation and trapped field measurements were done in collaboration with the University of Houston on samples fabricated at Intermagnetics. Levitation and trapped field performance of the samples were related to the growth process. Finally, a thick film approach was developed to fabricate melt-textured YBCO based on the modified melt-texturing process.

YBCO Thin Film Fabrication on Biaxially-textured Metal Substrates :

One of the important outcomes of the effort in fabrication of YBCO thin films on metal substrates has been the establishment of a totally independent program at

Intermagnetics. In a relatively short time frame, Intermagnetics has established resources for

a) Biaxially-textured Metal Substrates
b) Buffer-layer deposition by thermal evaporation, and
c) YBCO deposition by MOCVD.

These resources will allow Intermagnetics to conduct an in-depth research on the numerous fundamental challenges involved in fabricating a high performance YBCO superconducting tape.

Biaxially-textured metal substrates have been fabricated by the cube-texturing technique. Epitaxial buffer films CeO_2 with a high degree of biaxial texture have been deposited on these substrates. High current YBCO films have been deposited by MOCVD on single crystal YSZ substrates. The influence of out-of-plane and in-plane texture on the current density of the YBCO films has been examined.

Accomplishments/New Findings :

Melt-textured YBCO :

The kinetics of growth of YBCO along the a-b plane and the c-axis during a typical seeded isothermal melt-texturing process was examined by quench experiments over a wide temperature range (1006°C to 955°C) during slow cooling following peritectic decomposition using samples 25 mm in diameter. Optical micrographs of the top surface of samples quenched at 1006°C, 985°C, and 968°C are shown in figures 1(a), (b), and (c) respectively. Only the impression of the Sm-Ba-Cu-O (SmBCO) seed can be seen in fig. 1(a). Detailed analysis of the top and transverse sections showed no evidence of YBCO nucleation at this temperature. A similar result was obtained in a sample quenched at 996°C indicating that an undercooling of more than 14°C (considering a peritectic temperature of 1010°C for the YBCO system) is needed for nucleation of YBCO grains.

A square growth front can be observed in the sample quenched at 985°C (fig. 1(b)). No evidence of YBCO nucleation is observed near the periphery of the sample indicating that even under isothermal conditions and at this high degree of undercooling (25°C), the nucleation is restricted at the seed interface. Analysis of the growth front showed that the solid-liquid interface is very sharp and planar, similar to that observed in samples quenched during directional solidification in a temperature gradient. The size of the YBCO domain was measured to be 11 mm.

From fig. 1(c), it can be observed that even at a temperature of 968°C (undercooling of 42°C), the growth front has not reached the periphery of the disk. The growth front is still found to be square planar with a sharp interface between the solid and liquid phases.

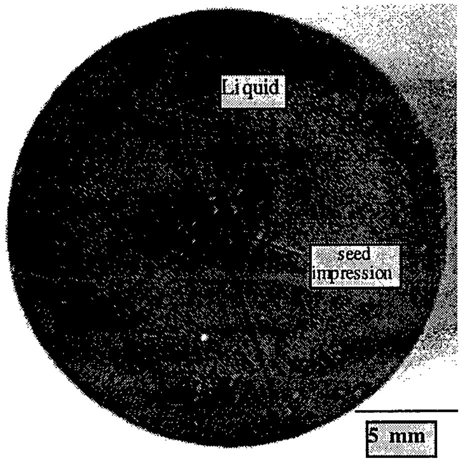


Fig. 1a Top surface of a YBCO sample quenched at 1006°C. No evidence of YBCO nucleation is seen. The impression of the SmBCO seed is visible.

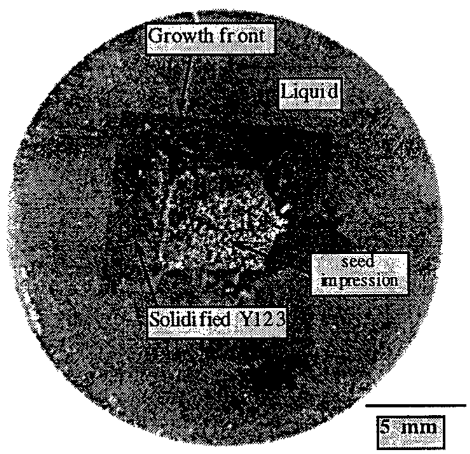


Fig. 1b Top surface of a YBCO sample quenched at 985°C. The square planar growth front has extended over a dimension of 11 mm.

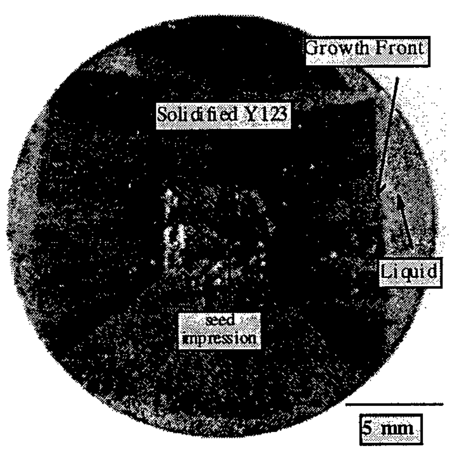


Fig. 1c Top surface of a YBCO sample quenched at 968°C. The growth front has extended over a dimension of 19 mm but has not reached the periphery of the sample.

Even at 968°C, there was no evidence of YBCO nucleation at the sample periphery. The size of the YBCO domain was measured to be 19 mm. Microstructural examination of the sample quenched at 955°C (undercooling of 55°C) showed that the growth is complete at this temperature.

The results from quench experiments are summarized in fig. 2. It can be seen that YBCO nucleates and grows rapidly along the a-b plane between 996°C and 985°C, beyond which, the growth is almost linear. In this linear regime, the actual growth rate of YBCO along the a-b plane is calculated to be about 0.4 mm/hour, under the imposed cooling rate of 1°C/h. This growth rate is comparable with the critical growth rates typically observed in directional solidification in a low temperature gradient. The figure also shows that the growth rate along the a-b plane decreases below 985°C.

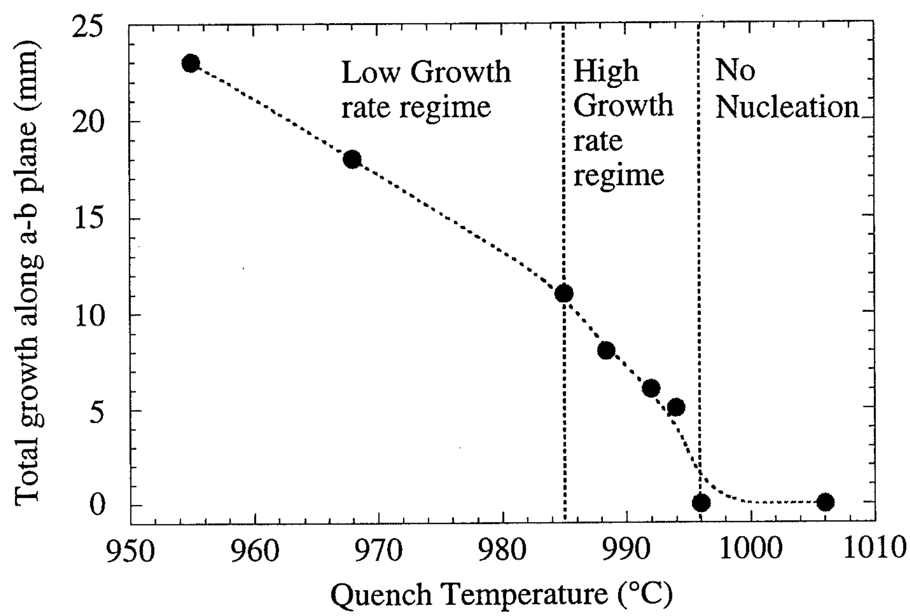


Fig. 2 Total growth along a-b plane in samples quenched at various temperatures in a typical seeded isothermal melt-texturing process involving slow cooling

Analysis of the transverse sections of samples studied in the quench experiments revealed that the growth along the c-axis is greater than that along the a-b plane in the temperature regime between 996°C and 985°C as shown in fig. 3. As displayed in fig. 3, the c-axis growth rate became less than the a-b plane growth rate with increased undercooling.

Based on the above information, a modified melt-texturing process was devised where the processing time can be reduced by a factor of 4 to 5. By limiting the process to the high growth rate regime (see fig. 2), the processing time was reduced from 75 hours to 20 hours as shown in fig. 4.

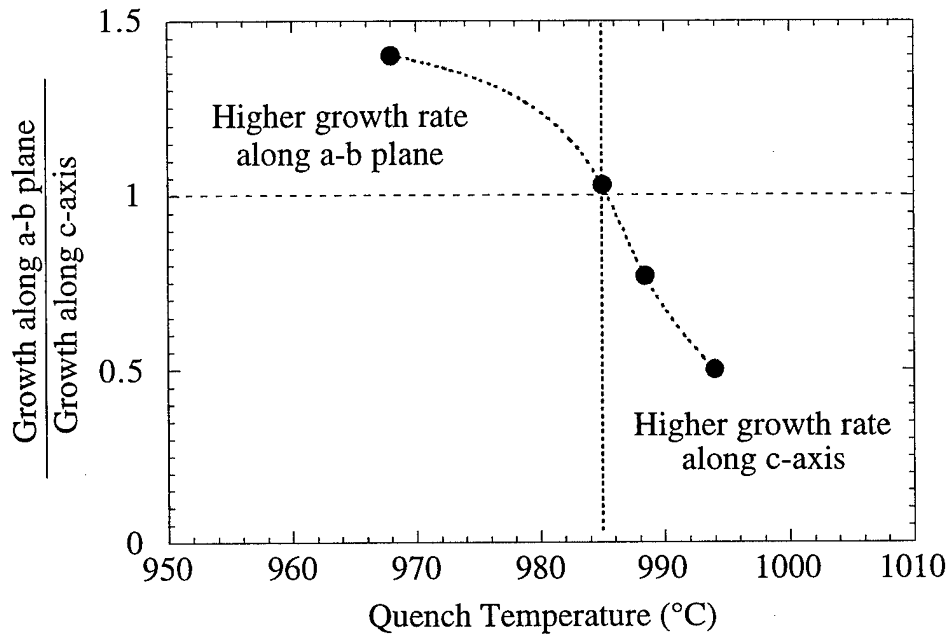


Fig. 3 Growth anisotropy at temperatures in samples fabricated by the typical slow cooling melt-texturing process

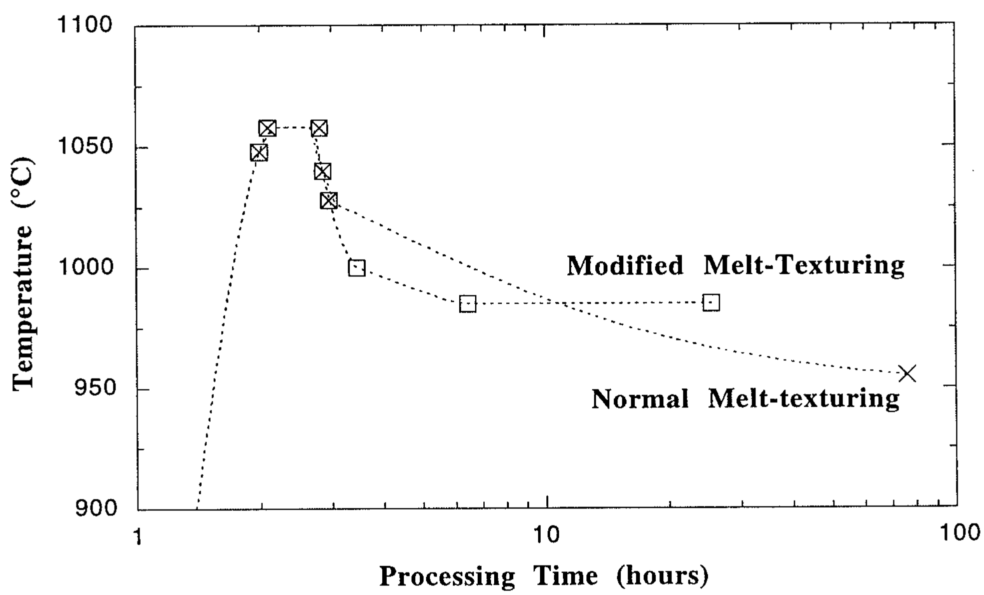


Fig. 4 Comparison of the typical and modified melt-texturing processes

Quench experiments were conducted in order to study the growth kinetics in samples fabricated by the modified melt-texturing process. Samples were quenched after 0, 3, 7, 12, 18, and 30 hour holds at 985°C as shown in fig. 5.

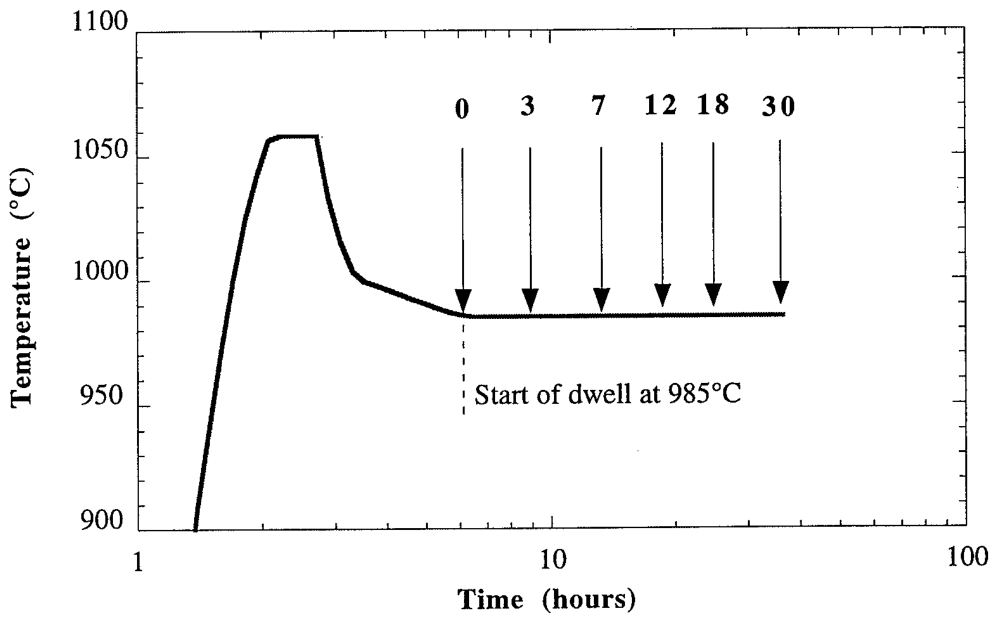


Fig. 5 Temperature Profile used in the modified Melt-texturing Process. Samples were quenched during solidification after 0, 3, 7, 12, 15, 18, and 30 hour dwells at 985°C.

Samples quenched at all time intervals showed a stable, square-shaped growth front as displayed in figures 6(a)-6(c). It can be seen from the figures that the growth front has progressed over half the disk diameter after 7 hours and almost reached the disk periphery after 12 hours. The effective growth along the a-b plane in these three samples was measured from the seed periphery and is exhibited in fig. 7. It can be seen from the figure that the growth at 985°C is linearly dependent on time at a rate of 0.54 mm/hour for the first 12 hours. It is also found that the growth along the a-b plane prior to the hold at 985°C i.e. growth between onset of nucleation and hold at 985°C is slower, at a rate of 0.26 mm/hour. Surprisingly, it was found that the growth along the a-b plane saturated after 15 hours as shown in fig. 7. The total growth along the a-b plane (including the growth below the seed) was found to approximately 19 mm in samples quenched at 15, 18 and 30 hours and did not reach the sample periphery (sample diameter after melt-texturing = 23 mm). It may be possible that the temperature has to be lowered after an isothermal hold of 12 hours to fully complete the growth.

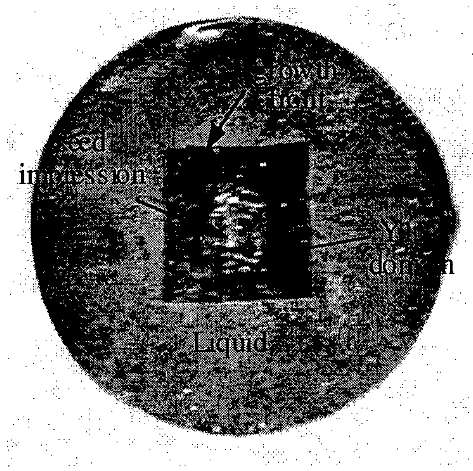


Fig. 6a Top surface of a melt-textured YBCO disk quenched after 3 hours dwell at 985°C

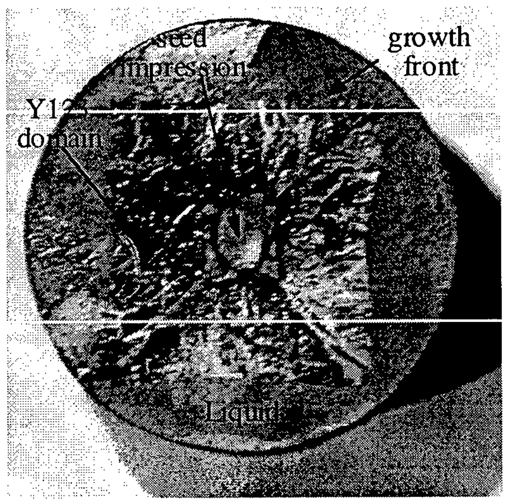


Fig. 6b Top surface of a melt-textured YBCO disk quenched after 7 hours dwell at 985°C

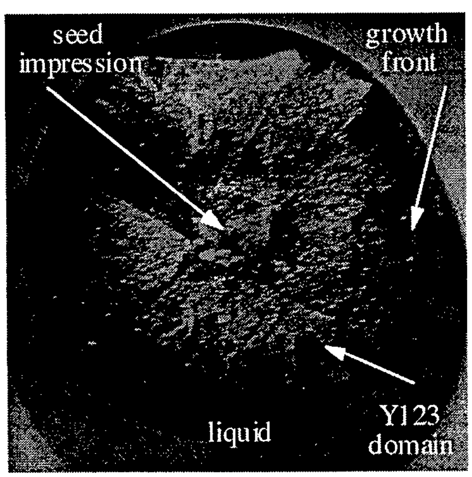


Fig. 6c Top surface of a melt-textured YBCO disk quenched after 12 hours dwell at 985°C

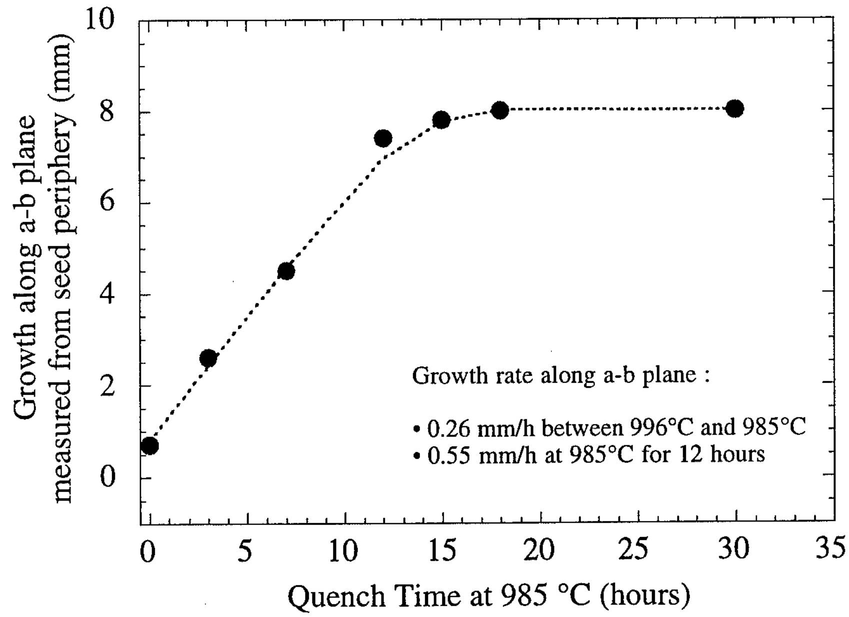


Fig. 7 Growth along a-b plane in YBCO quenched at various times at 985°C

The processing time that is saved with the modified melt-texturing process is clearly seen from fig. 8 which compares the effective growth along the a-b plane in samples quenched during a typical (slow cooling) and modified processes. It is clear that the melt-texturing time can be drastically reduced by processing the samples in the temperature regime where the growth rate is high.

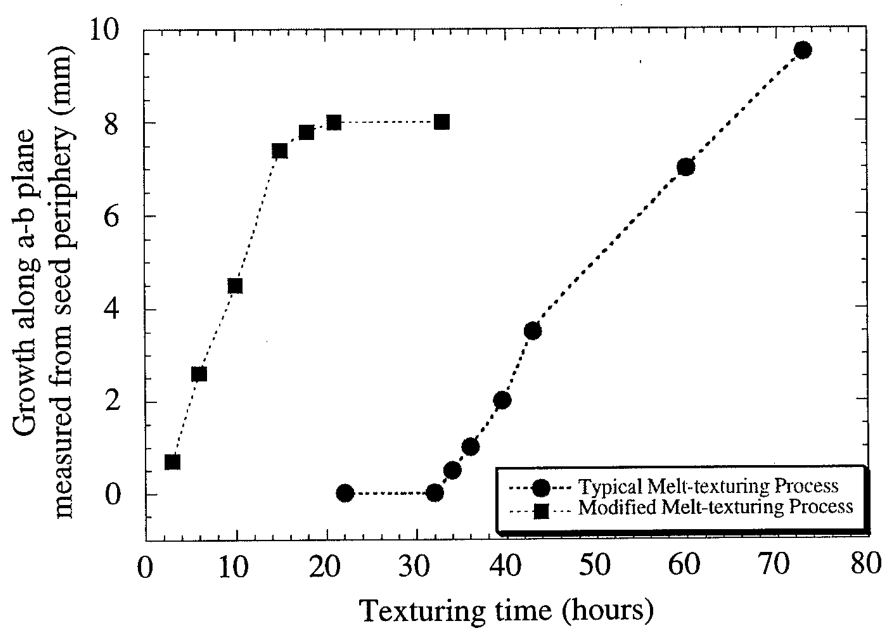


Fig. 8 Comparison of growth along a-b plane in YBCO fabricated by the typical slow cooling and modified melt-texturing processes.

Transverse sections of the samples quenched after 0, 3, 7 and 12 hours at 985°C were analyzed to determine the growth rate along the c-axis and the results are shown in fig. 9. As seen in the figure, the growth rate along the c-axis at 985°C is 0.72 mm/hour. Figure 10 compares the growth along the c-axis in samples quenched during the typical slow cooling and the modified melt-texturing processes.

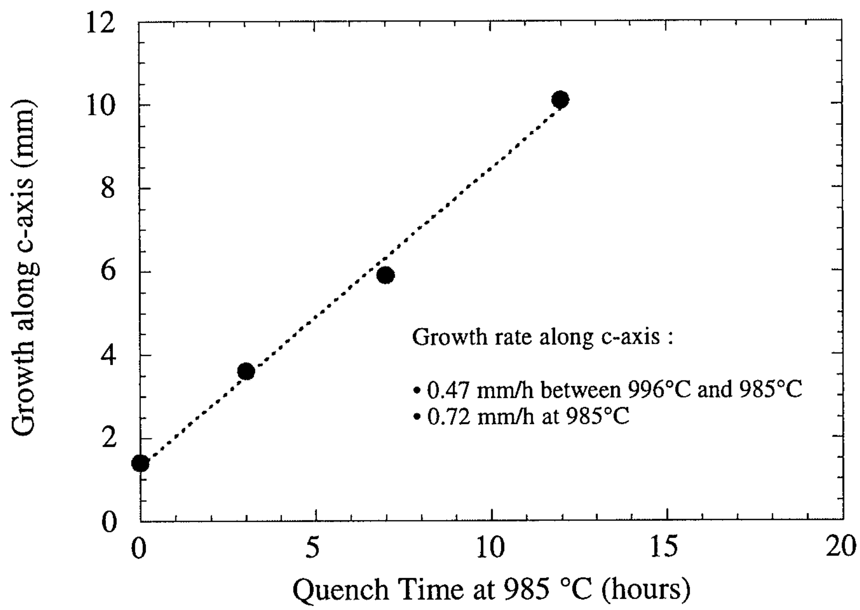


Fig. 9 Growth along c-axis plane in YBCO quenched at various times at 985°C

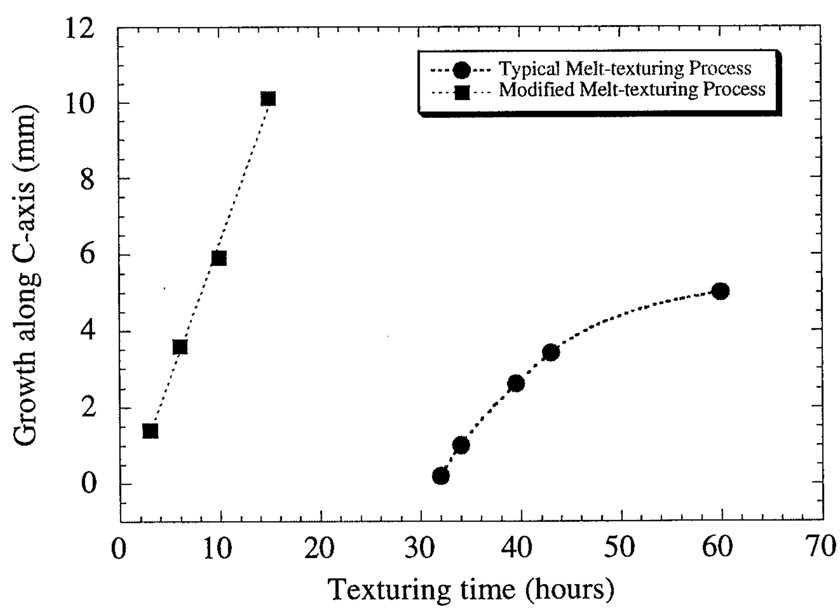


Fig. 10 Growth along the c-axis in YBCO quenched fabricated by a typical and the modified process

As seen in fig. 10, an increased growth along the c-axis can be achieved in samples fabricated by the modified melt-texturing process in a much shorter time. The growth rate along the c-axis in samples fabricated by the typical melt-texturing process decreases with increasing texturing time since the c-axis growth rate decreases with increasing undercooling. However, the growth rate along the c-axis in samples fabricated by the modified process is constant in the first 12 hours and as a result, twice as much a growth can be achieved. The growth along the c-axis in the sample quenched after 12 hours at 985°C (total texturing time of 15 hours) is about 10 mm which is almost the entire thickness of the YBCO puck.

The anisotropy in the growth at 985°C in the samples grown by the modified melt-texturing process was determined from the results shown in figures 7 and 9 and is plotted in fig. 11. It can be seen from the figure that the growth anisotropy remains relatively constant over the first 12 hours of hold at 985°C with the a-b plane growth rate being 70% of the c-axis growth rate. The anisotropy at a quench time of 0 hours at 985°C corresponds to the anisotropy in growth between the onset of nucleation (at about 996°C) and 985°C. It is seen from the figure that in this temperature regime, the c-axis growth is almost twice as that of the a-b plane growth. This result agrees well with the findings from the typical slow cooling melt-texturing process where it was found that the c-axis growth was higher at higher temperatures and the anisotropy ratio steadily increased with decreasing temperature (see fig. 3).

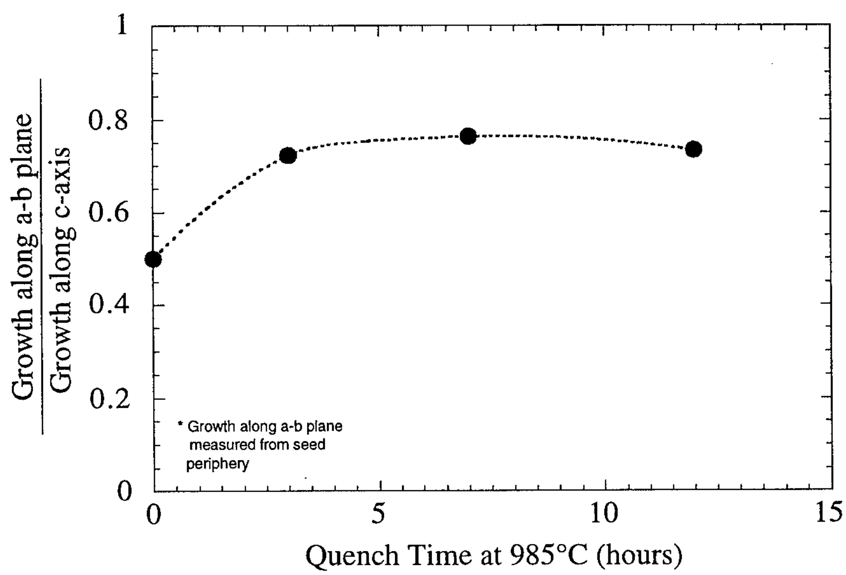


Fig. 11 Growth anisotropy at various dwell times in samples fabricated by the modified melt process

Figure 12 exhibits the levitation force of the samples fabricated by the modified melt-texturing process. The levitation force of samples fabricated by the typical melt-texturing process is also shown for comparison. It can be seen from the figure that the levitation force of the modified melt-textured samples increases proportional to the size of the YBCO domain which is similar to the behavior observed in samples fabricated by the typical melt-texturing process (see fig. 8). It can be also seen from the figure that a levitation force of 12 N is achieved in a much shorter time period in samples fabricated by the modified melt-texturing process.

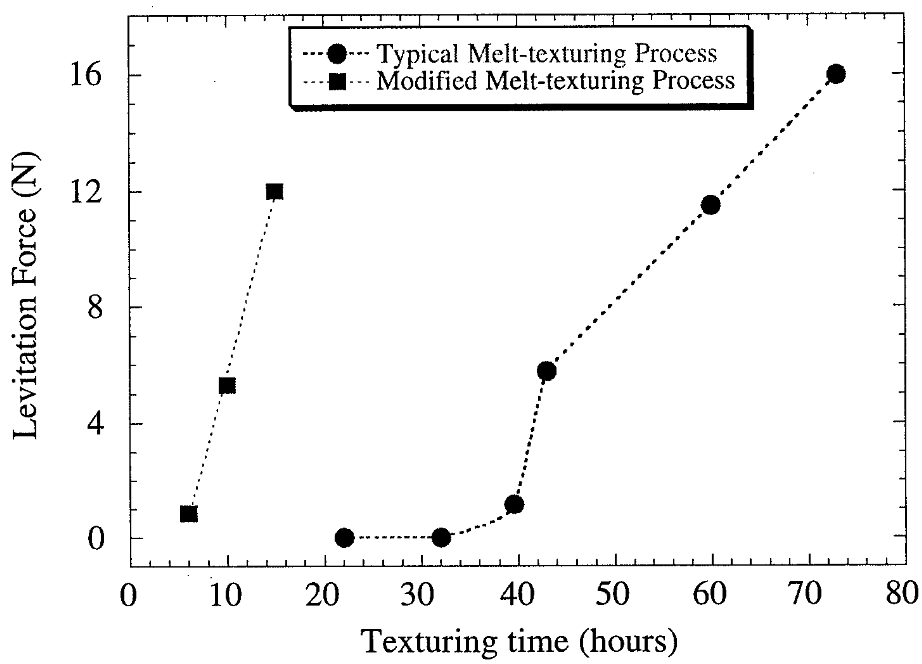


Fig. 12 Comparison of levitation force of samples fabricated by a typical and modified melt process

Thick Film YBCO Melt-texturing :

The information obtained from study of growth kinetics of melt-textured YBCO was used towards thick film YBCO melt-texturing during the transition of the program to fabrication of YBCO films on biaxially-textured metal substrates. The growth along the c-axis of YBCO in the modified melt-texturing process as shown in figure 9 corresponds to a rate of about 12 μm/min. This rate is much faster than that achievable in YBCO by any vapor deposition process. The fast rate of growth along the c-axis coupled with the instantaneous growth along the a-b plane over the entire dimension of a seed can be potentially used for the fabrication of thick film YBCO by melt-texturing. Melt-texturing would enable the fabrication of films of the order of several tens of microns in thickness which are necessary for high critical current and high overall J_c. Since the growth of YBCO is epitaxial from the seed, melt-texturing on a biaxially textured substrate would result in a biaxially textured YBCO. The lower temperatures and shorter times used in the modified melt-texturing process could enable the mitigation of reaction between the substrate and the superconductor.

In order to examine the above possibility, YBCO precursor was deposited on (100)-oriented YSZ and MgO single crystals by spin coating. Slurries with 30 to 40% solids loading of $YBa_2Cu_3O_x$ (Y123) and 15%, 25%, and 40% by weight of Y_2BaCuO_5 (Y211) were prepared and spin coated on the crystals, at a same speed (which corresponds to a same thickness). The coated samples were then processed by the modified melt-texturing process. The volume content of Y211 in the precursor was found to affect the size of the YBCO domains in samples that were melt-textured for less than 1 hour. The YBCO domains in the sample with 15% Y211 were found to be smaller with a size of about 300 μm square while the YBCO domains with 40% Y211 were of a size of about 800 μm square.

Some findings from melt-texturing on YSZ substrates :

1. Long processing times (more than 1 hour) result in severe reaction between the liquid and the substrate. Examination of transverse sections of samples revealed the presence of only a Cu-Ba-Zr-containing interfacial layer and a liquid-phase layer containing Cu and Ba. No Y123 was found.
2. Short reaction times (less than 1 hour) resulted in oriented Y123 growth. However, even in these samples, a Cu-Ba-Zr containing interfacial layer was found. A liquid-phase layer containing Cu and Ba was also observed in samples with less Y211 addition (15 wt.% as opposed to 40 wt.%). A transverse section of one such sample is shown in fig. 13.

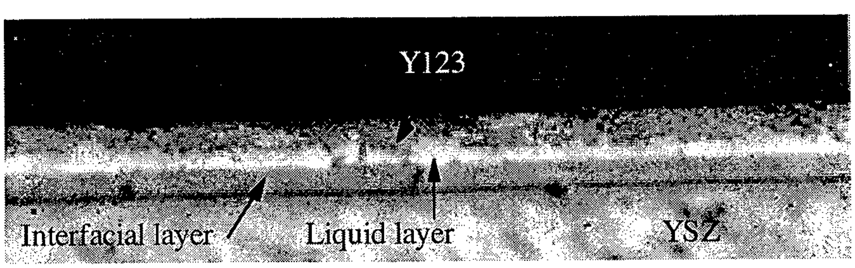


Fig. 13 Transverse section of melt-textured YBCO on single crystal YSZ

Since melt-texturing with YSZ substrates results in an interfacial layer which would prevent epitaxial growth, these substrates were replaced by MgO substrates. Since samples with higher 211 volume content resulted in less remnant liquid in samples processed on YSZ substrates, a slurry containing 40 wt.% 211 was spin coated on MgO substrates (100 orientation).

Some findings from melt-texturing on MgO substrates :

1. No interfacial layer or liquid-phase layer was observed in any of the 10 samples that were melt-processed. An example is shown in fig. 14 where an aligned YBCO domain can be seen right above the MgO substrate. The sample contained YBCO domains, about a hundred microns in size, aligned in different orientations.
2. Quench experiments revealed that no nucleation of Y123 occurs even at 998°C (undercooling of 12°C). This finding is consistent with results from seeded melt-textured YBCO pucks, where no nucleation was found above 996°C.
3. Even at 985°C, only partial nucleation (~ 10%) was observed. Partial nucleation of square Y123 domains was observed at 992°C also.

The challenge in heteroepitaxial growth of YBCO during melt-texturing is to control the nucleation such that only a-b plane aligned domains are nucleated.

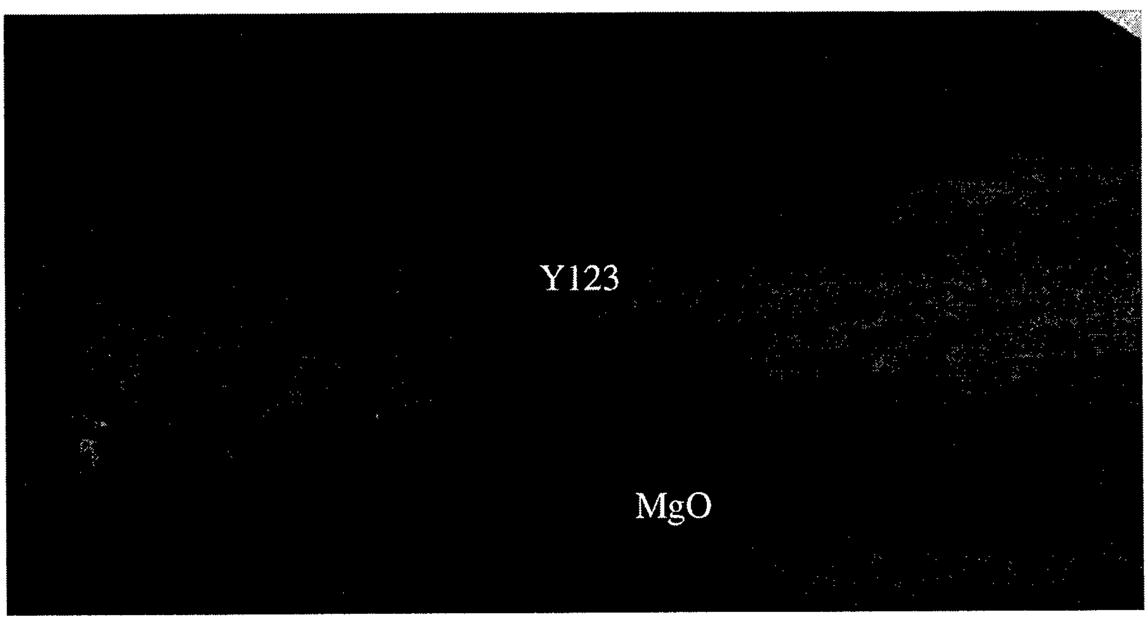


Fig. 14 Transverse section of melt-textured YBCO on single crystal MgO

YBCO Thin Film Fabrication on Biaxially-textured Metal Substrates :

Substrate Fabrication :

Biaxially-textured metal substrates were fabricated by a metal working process based on techniques well-established for achieving cube texture in Ni alloys. In this technique, polycrystalline metals are subjected to heavy deformation by rolling followed by a suitable recrystallization process which results in texturing along the (100) orientation in the rolling plane and along the [100] orientation in the rolling direction. Nickel and copper substrates were fabricated in this study by the conventional cube texturing technique.

The metal working and heat treatment process parameters were optimized to achieve a high degree of cube texture in both Ni and Cu substrates. Results from a theta-2-theta X-ray Diffraction (XRD) measurement performed on a Ni substrate is shown in fig. 15. A high degree of texturing along the (200) plane can be observed. Figure 16 displays the (111) polefigure from a Ni substrate. A clear evidence of strong in-plane texturing is seen. Typical values for out-of-plane and in-plane textures are 7° and 10° respectively which compare well with the values reported by other researchers.

Buffer Layer Deposition by Thermal Evaporation :

The approach that was used at Intermagnetics for buffer layer deposition on biaxially-textured Ni substrates was thermal evaporation. A thermal evaporator with a ramp-controllable substrate heater, *in situ* film thickness monitor, and gas flow-through facility was set up at Intermagnetics. The deposition parameters that influence the film properties are the substrate temperature, deposition rate, base pressure, partial pressure of reducing gas, film thickness, and cooling rate. These parameters affect the achievement

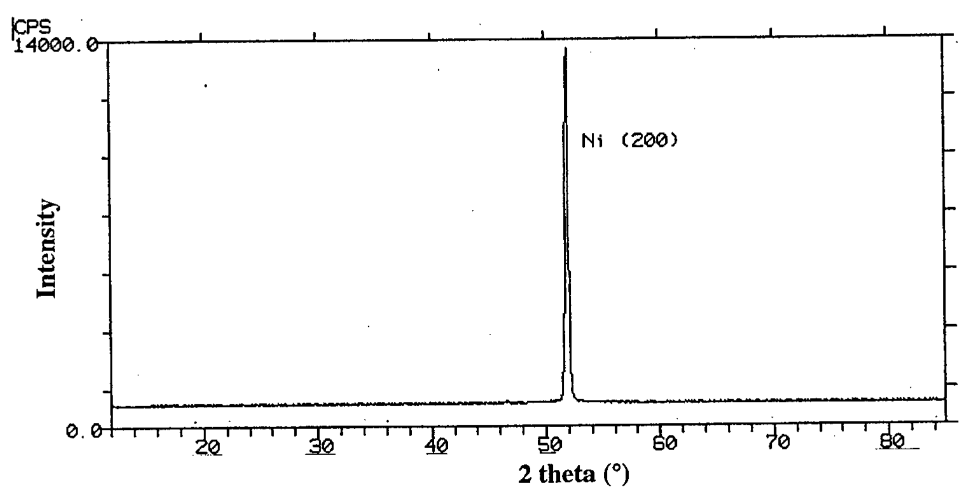


Fig. 15 Theta-2-theta XRD pattern of a cube-textured Ni substrate showing an intense (200) texture.

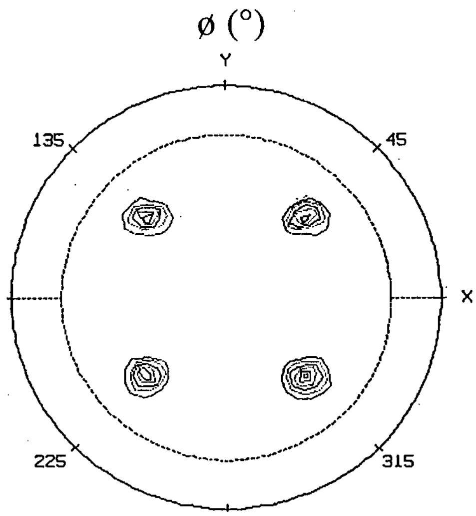
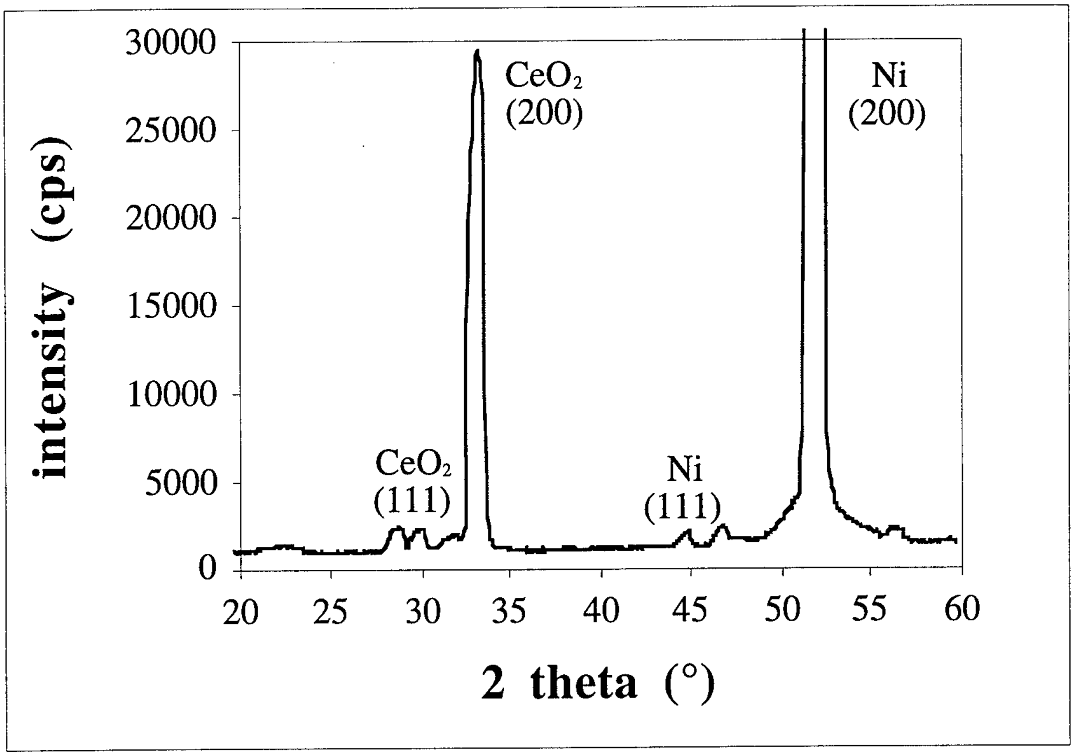


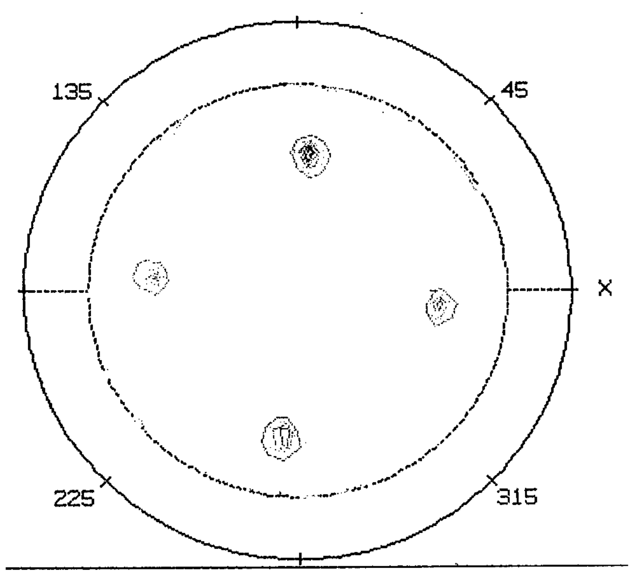
Fig. 16 Polefigure of the (111) peak of a cube-textured Ni substrate showing a high degree of in-plane texture.

uniform and complete coverage of the buffer layer over the metallic substrate which is necessary to avoid oxidation of the metal during subsequent deposition of YBCO. Also, optimum processing conditions had to be determined to achieve smooth, crack-free films without impurities. Most importantly, it was crucial to determine the deposition conditions which would also result in a biaxial texture in the buffer layer similar to or better than that of the metallic substrate.

CeO_2 buffer films were deposited on textured Ni substrates by thermal evaporation. The deposition was conducted at 750°C in an atmosphere of Ar-4%H_2 gas. Ar-4%H_2 gas was used as the deposition atmosphere in order to avoid oxidation of Ni which would otherwise prevent epitaxial growth of CeO_2 on Ni. The base pressure was 0.1 to 0.4 mTorr. The deposition rate was maintained at 1 A°/s and the film thickness was varied from 500 A° to 2500 A°. Results from the experiments show a reproducible biaxial texture in the CeO_2 films. Figures 17 (a) and (b) show the XRD theta-2-theta pattern and (111) polefigure of CeO_2 from one of the samples. A strong degree of CeO_2 (200) texturing can be seen in fig. 17(a). Figure 17 (b) shows an excellent in-plane texture in the sample (8° FWHM) and compares well with results reported by other researchers (ORNL reports an in-plane texture of about 8° in their buffer layers, LANL reports an in-plane texture of 12 to 14° in their IBAD buffer layers).



(a)



(b)

Fig. 17 Texture measurements on a CeO_2 buffer layer deposited by thermal evaporation at Intermagnetics on textured Ni substrate. A high degree of both (200) texturing and in-plane texturing can be seen. The spread in the in-plane texture is 8° FWHM and is comparable with the best results reported by other researchers.

Scanning Electron Microscopy was conducted to analyze the microstructure of the buffer layers. Figure 18 shows a Back Scattered Electron image of the surface of a CeO_2 film deposited on Ni. The film is seen to be very dense with no porosity. Also, no evidence of microcracking was observed. The grains are several tens of microns in size. However, the grain size of the film is expected to be of the order of a few microns. The grain structure seen in the figure is tentatively attributed to grain structure of the underlying nickel substrate (perhaps visible because of thermal etching at the high deposition temperature).

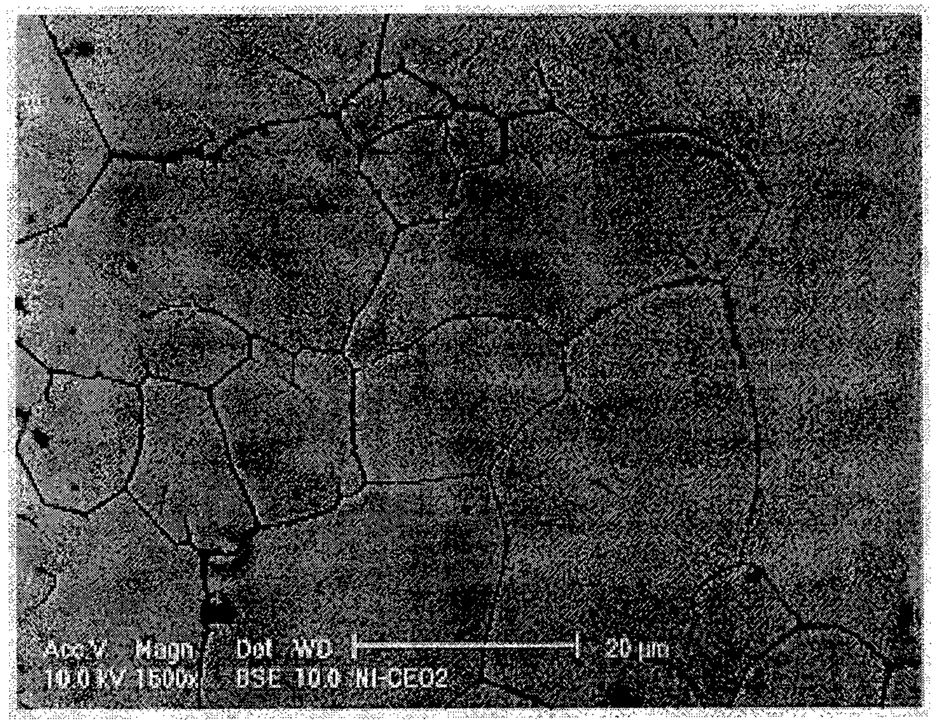


Fig. 18 Back-scattered Electron image of the top surface of a CeO_2 film on Ni. The film is very dense without porosity and microcracking.

The thermal evaporation process has been successfully 'scaled up' for reproducible deposition of 15 to 25 highly biaxially-textured buffer films per week. Following the success of this process, a new vacuum chamber has been designed for long-length deposition of CeO_2 buffer films on Ni substrates. The new chamber is expected to be installed in June 1998.

YBCO Deposition by MOCVD :

A MOCVD facility has been set up for YBCO film deposition on buffered metal substrates. The MOCVD system was designed and completely built at Intermagnetics. The system is designed for deposition on both short samples as well as long tapes. A schematic of the MOCVD facility that has been set up at Intermagnetics is shown in fig. 19. A photograph of the facility is displayed in fig. 20.

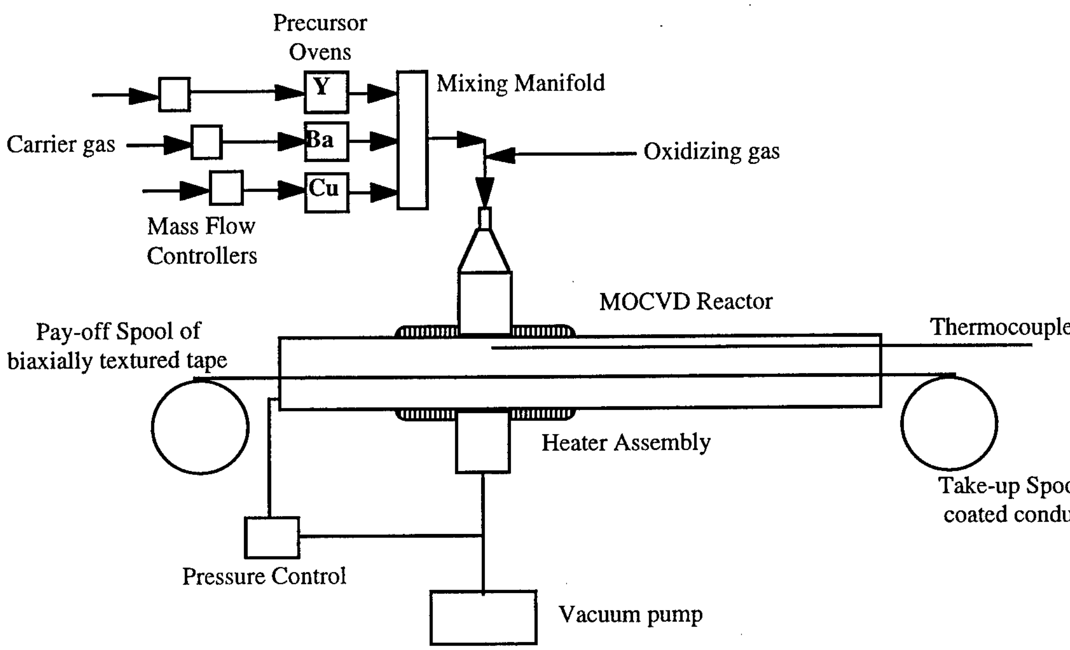


Fig. 19 Schematic of MOCVD facility set up for YBCO deposition on buffered, textured metal substrates.

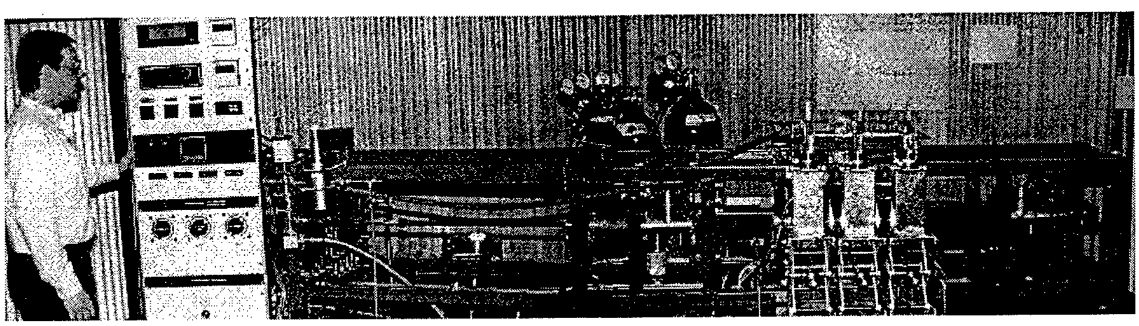


Fig. 20 An overall view of the MOCVD system at Intermagnetics

While the effort on preparation of biaxially-textured Ni substrates and deposition of buffer layers was continuing in this program, a parallel effort was undertaken to optimize the MOCVD process of deposition of YBCO films. Since YBCO would be deposited on a YSZ film on Ni substrates, initial MOCVD experiments were using single crystal YSZ substrates. This parallel effort is expected to speed up the optimization process for MOCVD of YBCO on Ni/CeO_2/YSZ substrates when they become available.

The MOCVD processing conditions that were optimized are the deposition temperature, precursor sublimation temperatures of Y, Ba, and Cu precursors, flow rates of precursor carrier gas, partial pressure of oxidants (oxygen & N_2O), and deposition time. The composition of the YBCO films was analyzed by Energy Dispersive X-ray Spectroscopy (EDS). The texture was examined by X-ray Diffraction. The transport critical current density of the films was determined by four-probe resistive technique at 77 K.

The best result achieved so far is a critical current (Ic) of 18 A measured in a YBCO film at 77 K. This is a high value of critical current for a thin film even on single crystal substrate. A Current-Voltage (I-V) curve obtained from this sample is shown in fig. 21. The thickness of the YBCO film was measured by surface profilometry. The thickness of the 18 A sample was measured to be 0.46 μm which corresponds to a critical current density (Jc) of 0.4 MA/cm^2. This is a high Jc value considering that the lattice mismatch between YBCO and YSZ is about 5 %. Typically current densities of 1 MA/cm^2 are achieved only in YBCO deposited on single crystal substrates of $SrTiO_3$ or $LaAlO_3$ where the lattice mismatch is about 0.2%. The achievement of high current as well as a high Jc in YBCO deposited on single crystal YSZ is very encouraging for our efforts for YBCO deposition on YSZ-buffered Ni substrates.

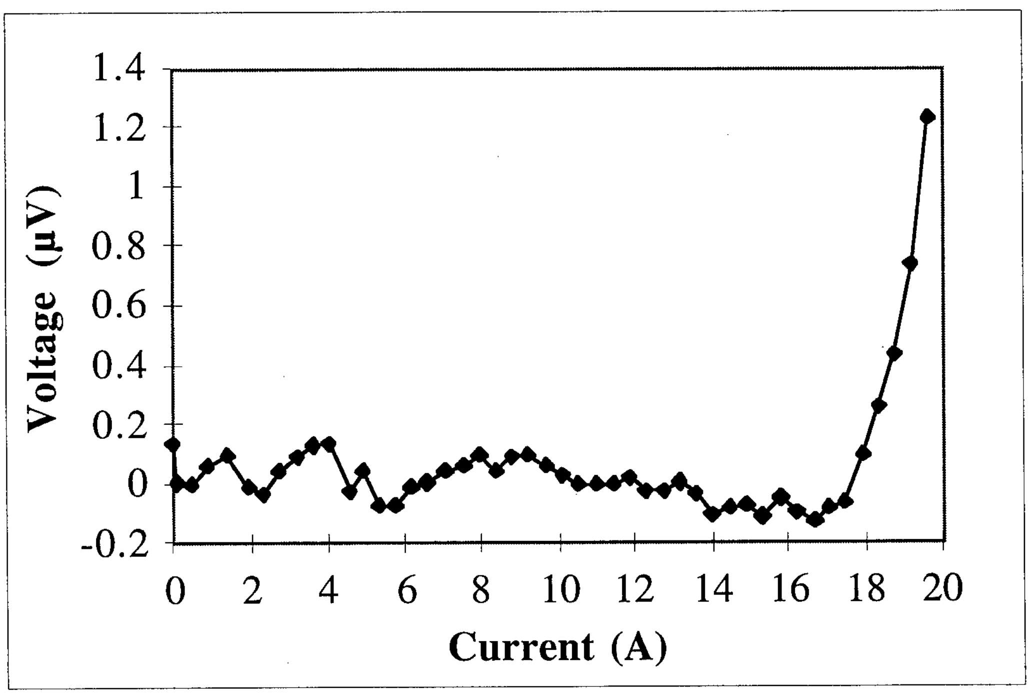


Fig. 21 I-V curve of a YBCO film deposited by MOCVD on a single crystal YSZ substrate showing a critical current of 18 A (Jc ~ 0.4 MA/cm^2)

Microstructural examination of the high current film revealed a very smooth and uniform film surface accentuated by Cu- and Y-rich precipitates as shown in fig. 22.

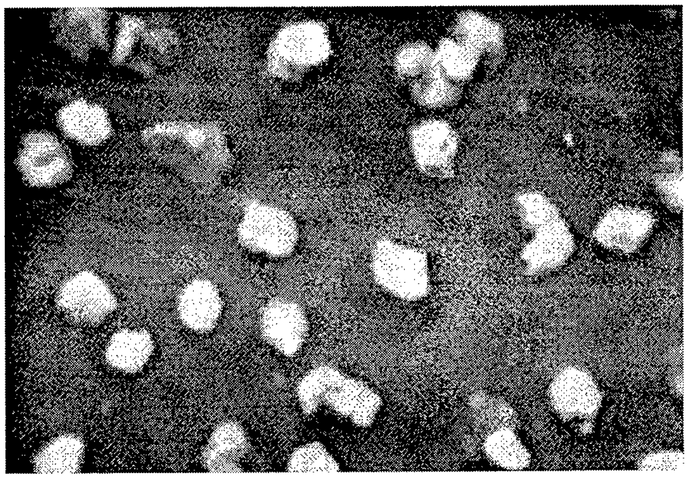
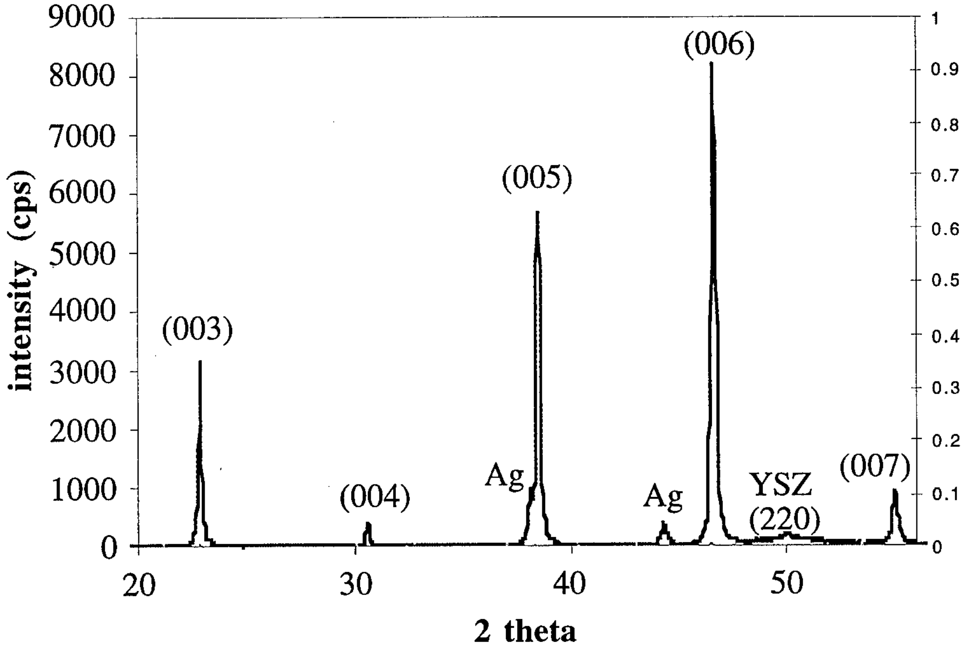


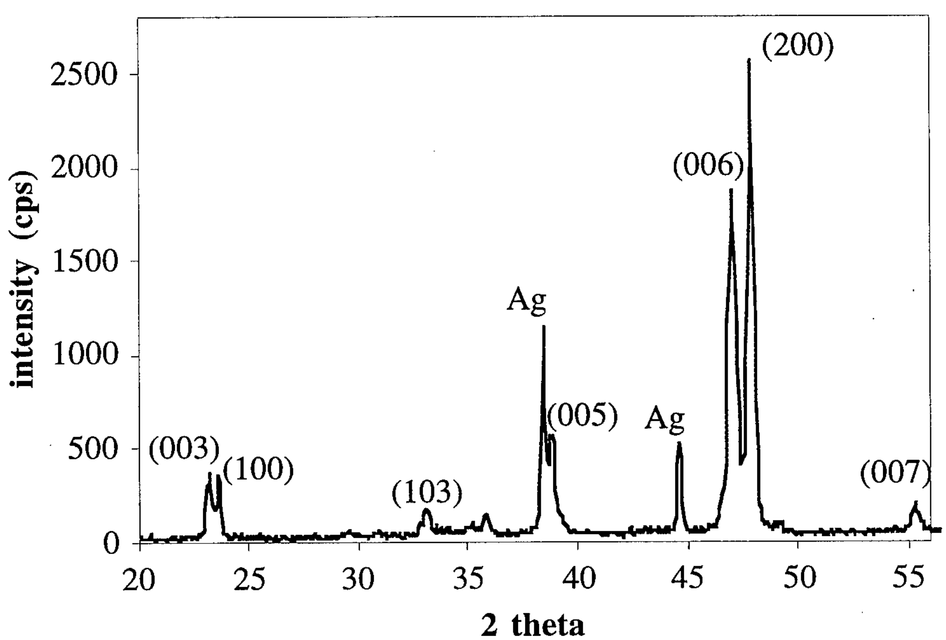
Fig. 22 SEM micrograph of a high current YBCO film deposited by MOCVD on single crystal YSZ

Texture measurements were conducted on a high current (Ic = 18 A, Jc = 0.4 MA/cm^2) and a low current (Ic = 4.3 A, Jc = 50 kA/cm^2) YBCO films and the results are shown in figs. 23 and 24. The high Jc sample shows a strong c-axis texture (fig. 23a). Polefigure measurements on this sample indicate a strong biaxial texture with the spread in the in-plane texture of about 4° FWHM (fig. 24a). It can be seen from fig. 23b that the low Jc sample exhibits a substantial amount of a-axis grains and some misoriented grains. The low Jc film also showed 2 sets of in-plane orientation (fig. 24b). Two sets of in-plane orientation (rotated 45° apart) is usually seen in YBCO films deposited on single crystal YSZ substrates (without buffer layer) due to the large lattice mismatch (5%). These results show a good correlation between texture and Jc.

Optimization of YBCO deposition by MOCVD is continuing at Intermagnetics. YBCO deposition on buffered Ni substrates will be started soon. In a relatively short time frame, a totally independent program has thus been established at Intermagnetics to conduct an in-depth research on the numerous fundamental challenges involved in fabricating a high performance YBCO superconducting tape.

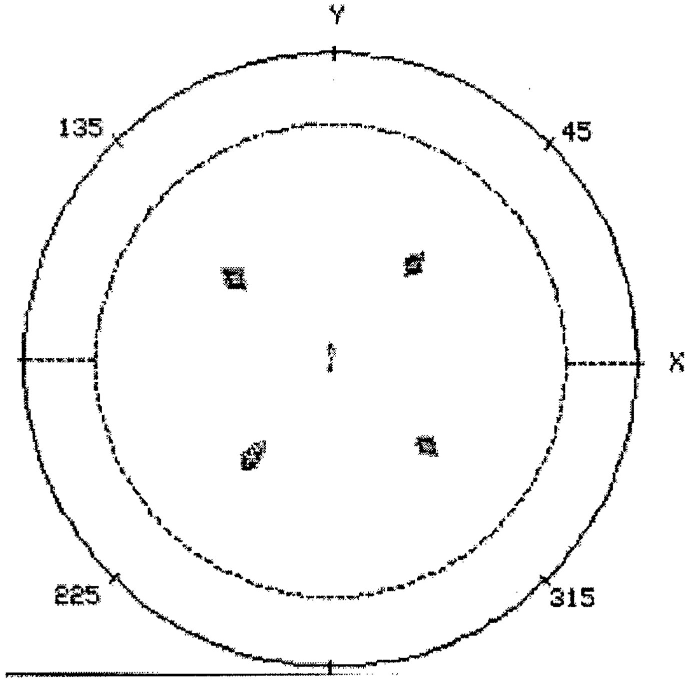


(a)

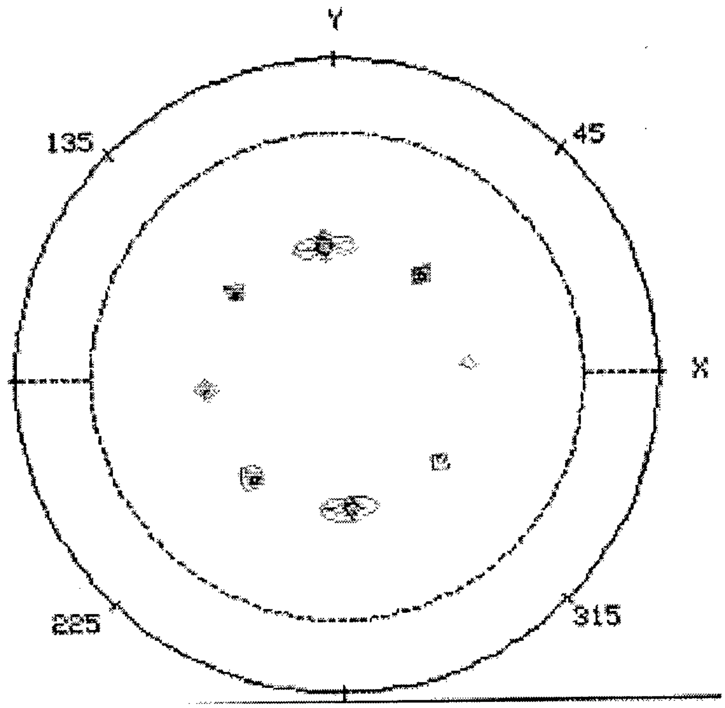


(b)

Fig. 23 XRD theta-2 theta patterns of YBCO films deposited by MOCVD on single crystal YSZ. Pattern (a) is from a film with a Ic of 18 A (Jc = 0.4 MA/cm^2). Pattern (b) is from a film with a Ic of 4.3 A (Jc = 50 kA/cm^2). A high degree of c-axis texture is seen in the high Jc film whereas substantial a-axis orientation (in addition to c-axis texture) is seen in low Jc film.



(a)



(b)

Fig. 24 (111) polefigures of YBCO films deposited by MOCVD on single crystal YSZ. Pattern (a) is from a film with a Ic of 18 A (Jc = 0.4 MA/cm^2). Pattern (b) is from a film with a Ic of 4.3 A (Jc = 50 kA/cm^2). The high current film exhibits a single set of peaks spaced 90° apart indicating a single in-plane texture. The low current film exhibits sets of peaks spaced 45° apart indicating at least 2 in-plane orientations.

Personnel Supported :

Dr. Venkat Selvamanickam, Principal Investigator, Intermagnetics

Mr. Karl Pfaffenbach, Intern from Alfred University

Mr. David Kirchoff, Intern from Rochester Institute of Technology

Mr. Steven Alles, Intern from Rensselaer Polytechnic Institute

Mr. Jerry D'Frank, Intermagnetics

Ms. Chandra Trautwein, Intermagnetics

Mr. George Galinski, Intermagnetics

Publications :

1. V. Selvamanickam and R. S. Sokolowski, 'Microstructure Development in Isothermally Melt-textured Y-Ba-Cu-O Superconductors' in *High Temperature Superconductors : Synthesis, Processing, and Large-Scale Applications*, ed. U. Balachandran, P. J. McGinn, and J. S. Abell, p.261, TMS Publication, PA, 1996.
2. V. Selvamanickam, K. Pffafenbach, R. S. Sokolowski, Y. H. Zhang, and K. Salama 'Development of Melt-textured Y-Ba-Cu-O Superconductors for Magnetic Bearings' *Proc. Third International Symposium on Magnetic Suspension Technology,* NASA Conference Publication 3336, p. 231, 1996.
3. V. Selvamanickam, A. Ivanova, D. B. Fenner, T. Thurston, M. S. Walker, A. E. Kaloyeros, and P. Haldar, "Fabrication of Biaxially-textured thick film Y-Ba-Cu-O Superconductor by MOCVD on cube-textured metal substrates", *High Temperature Superconductors : Synthesis, Processing, and Large-Scale Applications II*, ed. U. Balachandran and P. J. McGinn, p.165, TMS Publication, Warrendale, PA, 1997.
4. V. Selvamanickam, D. Kirchoff, C. E. Oberly, K. Salama, Y. Zhang, and S. Salib, "Growth Kinetics and Processing Time Reduction in Melt-texturing of Y-Ba-Cu-O Superconductor", *High Temperature Superconductors : Synthesis, Processing, and Large-Scale Applications II*, ed. U. Balachandran and P. J. McGinn, p.117, TMS Publication, Warrendale, PA, 1997.

Interactions/Transitions :

a. Conference Presentation :

1. V. Selvamanickam, K. Pfaffenbach, and R. S. Sokolowski, 'Microstructure development in isothermally melt-textured Y-Ba-Cu-O Superconductors', *TMS Annual Mtg.,* Anaheim, Feb. 1996 (invited)
2. V. Selvamanickam, 'Development of Y-Ba-Cu-O Superconductors for Magnetic Bearings', *Third International Workshop on Magnetic Suspension Applications,* Tallahassee, Dec. 1995.

3. V. Selvamanickam, A. Ivanova, D. E. Fenner, P. J. Kung, M. Chudzik, T. Thurston, G. Kozlowski, M. Lanagan, A. E. Kaloyeros, C. E. Oberly, U. Balachandran, M. S. Walker, and P. Haldar, "A MOCVD Approach to Biaxially-textured Thick Film $YBa_2Cu_3O_x$ superconductor Fabrication on Metallic Substrates", *MRS Spring Mtg.,* Boston, March 1997.
4. V. Selvamanickam, A. Ivanova, D. E. Fenner, T. Thurston, A. E. Kaloyeros, M. S. Walker, and P. Haldar, " Fabrication of Biaxially-textured YBCO Superconductor by MOCVD using Cube-textured Metal Substrates" *TMS Ann. Mtg.,* Orlando, February 1997 (invited).
5. V. Selvamanickam, D. Kirchoff, C. E. Oberly, Y. Zhang, S. Salib, and K. Salama, "Growth Kinetics and Processing Time Reduction in YBCO Melt-texturing", *TMS Ann. Mtg.,* Orlando, February 1997 (invited).
6. V. Selvamanickam, A. Ivanova, D. E. Fenner, A. E. Kaloyeros, M. S. Walker, and P. Haldar, 'Thick Film YBCO Conductor Development' *MRS Fall Mtg.,* Boston, Dec. 1996.
7. V. Selvamanickam, 'Processing Issues in Surface-Coated YBCO Conductor Manufacturing', *Phase Diagram Workshop,* Santa Fe, Nov. 1996 (invited)

b. Interaction :

During the course of the program, Intermagnetics collaborated extensively with the Materials Engineering group of Texas Center for Superconductivity at University of Houston. Over 30 samples that were fabricated by Intermagnetics were characterized by levitation force and trapped field measurements by Prof. Kamel Salama' group on a no-funds exchanged basis. V. Selvamanickam also assisted graduate student work in Prof. Salama's group on melt-texturing of YBCO and served on the thesis committee of a graduate student.

Intermagnetics has been extensively collaborating with WPAFB in the development of YBCO coated conductors. Two visits were made by Intermagnetics personnel to WPAFB for technical discussions, sample exchange, study of WPAFB's MOCVD facility and other materials processing facilities. Samples have been exchanged for characterization as well as film deposition. The texture of biaxially-textured nickel substrates fabricated at Intermagnetics have been analyzed at WPAFB. Buffer layers of CeO_2 and YSZ have been grown by r.f. sputtering and Pulsed Laser Deposition (PLD) on Intermagnetics' substrates at WPAFB. The buffered films have been characterized at Intermagnetics. Intermagnetics worked with the State University of New York (SUNY), Albany for YBCO film deposition by MOCVD, texture characterization by XRD, and composition analysis by Rutherford Back-Scattering Spectroscopy (RBS). Intermagnetics' personnel have used the

MOCVD facilities at SUNY, Albany for YBCO film deposition on Intermagnetics' substrates as well as on Intermagnetics' substrates with buffer layers deposited at WPAFB. Intermagnetics has also collaborated with Argonne National Lab for characterization of its samples by X-ray diffraction and Electron-backscattered diffraction. Buffer layer film deposition has been conducted in collaboration with Advanced Fuel Research. University of Pittsburgh and Rensselaer Polytechnic Institute have assisted Intermagnetics in microstructure and texture characterization.

c. Transition :

Intermagnetics has been interested in the development of trapped flux devices using melt-textured YBCO. The results obtained from the AFOSR contract on study the microstructure development of melt-textured YBCO can be directly used for developing better trapped flux materials. The results can also be used to develop YBCO rods with high current carrying capacity which could be used for high current leads. The results from thick film YBCO melt-texturing could be potentially used for surface-coated YBCO conductors.

The AFOSR program was also one of the main materials development programs at Intermagnetics to develop Surface Coated YBCO Conductor by thin film fabrication and textured metal substrates. The success of the Coated conductor programs at Intermagnetics could lead to the replacement of Bi-2223 conductor and perhaps even Nb-Ti conductor. Bi-2223 conductor is currently the main HTS conductor available in long lengths for all device programs at Intermagnetics such as transformers, cables, fault-current limiters, and generators. Based on its superior performance and potential lower cost, YBCO is the clear choice for HTS conductor for all these devices. The information obtained from the AFOSR program would eventually enable the fabrication of a high performance superconducting tape that can find wide use in electric power, magnetic, medical and military applications.

8. Inventions :

None

9. Honors & Awards :

V. Selvamanickam was awarded the Presidential Early Career Achievement Award which is accompanied by a $500,000 grant over a five-year period through AFOSR. This grant is being used at Intermagnetics to continue the effort of this AFOSR program.